ABOUT CTA

The Technical Centre for Agricultural and Rural Cooperation (CTA) is a joint international institution of the African, Caribbean and Pacific (ACP) Group of States and the European Union (EU).

Its mission is to advance food and nutritional security, increase prosperity and encourage sound natural resource management in ACP countries. It provides access to information and knowledge, facilitates policy dialogue and strengthens the capacity of agricultural and rural development institutions and communities. CTA operates under the framework of the Cotonou Agreement and is funded by the EU.

www.cta.int

ABOUT FARA

The Forum for Agricultural Research in Africa (FARA) is the apex organisation charged with the strategic role of coordinating and advocating for agricultural research and development in Africa.

FARA weaves together key networks and stakeholders on the continent and globally to reinforce the capacity of Africa to improve its agricultural science and innovation for food and nutrition security and poverty reduction. FARA serves as the technical arm of the African Union Commission (AUC) on matters concerning agricultural science, technology and innovation. FARA provides a continental forum for stakeholders in AR4D to shape the vision and agenda for the sub-sector and to mobilise themselves to respond to key continent-wide development frameworks, notably the Comprehensive Africa Agriculture Development Programme (CAADP) in which it helps to implement and sustain the momentum of CAADP especially in harnessing knowledge, information and skills (KIS) for Africa’s agriculture development. FARA delivers on its mandate through three mutually-inclusive options of envisioning its strategic direction, integrating its capacities for change and creating enabling policy environment for implementation. And some key initiatives are implemented to bring about specific results in these broad areas.

www.fara-africa.org
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THE OTHER CONSORTIUM PARTNERS

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- International Foundation for Science (IFS)
- New Partnership for Africa’s Development Planning and Coordinating Agency (NEPAD Agency)
- Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

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- Chimwemwe Chamdimba, Policy and Programme Officer, NEPAD Agency, South Africa
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- Ameenah Gurib-Fakim, Managing Director, CEPHYR, Mauritius
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- Maurice Ochieng Bolo, Director, The Scinovent Centre, Kenya
- Ifion Ohiomoba, Ag Director-AKT & Manager, PSTAD Project, FARA, Ghana
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- Ekaya Wellington, Training & Quality Assurance Manager, RUFORUM, Uganda
- Myra Wopereis-Pura, Former Director Access to Knowledge and Technology, FARA, Ghana
- Zaina Yusuph Maima, Gender Expert and Independent Consultant, The Netherlands
- Ellen Mulder, Project Assistant, CTA, The Netherlands (Secretarial and Administrative Support)

THE COMPETITION JUDGES

- Ameenah Gurib-Fakim (Chief judge and Member Expert Panel)
- Demba Farba Mbaye, USAID/ERA Project, Virginia Tech University, Senegal
- Abdoulaye Gouro, Executive Secretary, Conseil National de la recherche Agronomique of Niger, Niger
- Marjorie Kyomuhendo, Public Relations & Strategic Communication Specialist, Makerere University, Uganda
- Robert Obura, Deputy Principal (A&R), Laikipia University College, Kenya.
This is yet another demonstration of partnership in action. Our combined investment in the execution of the 3rd Africa-wide Science competitions has contributed to the empowerment of African women and young professionals in science, technology and innovation; we believe this would go a long way in supporting agricultural and rural transformation in sub-Saharan Africa so that the goal of “Feeding 1 Billion in Africa in a Changing Climate” can be fully realized.

The Consortium partners wish to especially thank all the African women and young professionals who responded to the call for abstracts and in particular those whose winning abstracts were developed into full papers that eventually led to this publication. We especially acknowledge the contribution of the authors and co-authors, the lead trainers in scientific writing, communication and policy advocacy and the editorial teams that led to successful outcomes. The collective efforts of partners, experts and the women and young professionals have served to ensure that this unique publication is of a very high standard.
FOREWORD
This publication has come out of the 3rd Africa-wide Women and Young Professionals in Science Competitions, and it profiles the achievements of the semi-finalists and all who participated.

The two competitions were both timely and strategic as science, technology and innovation is increasingly regarded as an important ingredient for agricultural transformation and sustained socio-economic development in Africa. Policymakers at national, continental and international levels are more committed than ever to advancing agriculture. CTA, FARA and partners believe that knowledge especially that which is generated through research should be communicated to a wide range of stakeholders to catalyse agricultural innovation.

Through the competitions, the consortium partners supported African women and young professionals to showcase their work in agricultural research to stakeholders and the public on the continent and the larger international community. Through their outstanding research and the ‘winning’ papers they wrote, enterprising and promising women and young professionals contributed to the success of the 2012/13 competitions. This publication provides insights into their research which is aimed at resolving Africa’s challenges in food and nutrition security and highlights the priority areas for further investigation.

Most of the winners work in their national systems and their research is already making a difference on the ground. The diversity of topics and approaches demonstrates the great potential of African women and young professionals in using science and innovation to address Africa’s challenges.

Furthermore, the strategies, methods and tools that they are using to disseminate – scientific findings, technologies, or approaches – show their creativity in reaching the intended audiences and beneficiaries. The competitions have shown that African women and young professionals are making a difference and can make an even greater impact if the resources are made available to them and they are given due recognition.

CTA and FARA consider this publication as an important communication tool for encouraging African women and young professionals to make greater strides in the pursuit of science and innovation. It also underlines the importance of investing in women and future generations.

We believe that with the support and cooperation of policy makers, academic community, private sector, and development partners, African scientists can contribute to agricultural transformation on the continent. In addition, scientific excellence that responds to the needs and aspirations of African farmers and the wider society must be supported, promoted and rewarded.

Dr Yemi Akinbamijo
Executive Director, FARA

Michael Hailu
Director, CTA
SYNTHESIS REPORT: LESSONS LEARNED

Judith Ann Francis, CTA & Chair Expert Panel
‘Being at the first place gives me a legitimate sense of fulfilment with respect to the relevance of my research. It has also instilled in me the confidence that I can make a difference in the field of bio-resource management.’

Dr Nafiisa Sobratee, Mauritius.
1st prize winner, 3rd Africa-wide Women in Science Competition (2013).

‘It opened doors to international collaboration, helped me to build a research network in my field and to get a promotion as a lecturer in my university.’

Dr Julius Kofi Hagan, Ghana.
3rd prize winner, 3rd Africa-wide Young Professionals in Science Competition (2013).

‘Having won the first prize is an immense honour for me. I feel strongly motivated to continue working hard and contribute to more research on wheat production for the benefit of African farmers.’

Dr Jemanesh Kifetew Haile, Ethiopia.
1st prize winner, 3rd Africa-wide Young Professionals in Science Competition (2013).
INTRODUCTION

The above statements confirm the decision by CTA, FARA, IFS and other consortium partners to organize the 3rd Africa-wide Women and Young Professionals in science competitions ‘Feeding 1 billion in Africa in a changing World’ which extended over the period 2012 – 2013. In sub-Saharan Africa (SSA), agriculture remains the dominant economic activity for the majority of the population. It accounts for between 15-45% of the gross domestic product (GDP) and 48-70% of employment. Intensifying agricultural production in a sustainable manner, adding value to locally produced foods, competing in local, regional and international markets and improving health, well being and prosperity, are national imperatives for African countries. Increasing investments in science, technology and innovation (STI), building the human resource base and strengthening the policy and institutional framework is considered a viable option for modernizing the agricultural and food sectors, improving economic performance and achieving the sustainable development goals, post MDGs.

Between 2003 and 2013, the African community has mobilized around a shared agenda for agricultural development through the implementation of the Comprehensive African Agricultural Development Programme (CAADP), which is coordinated by the New Partnership for Africa’s Development Planning and Coordinating Agency (NPCA). In 2006, African Heads of State and Government endorsed Africa’s Science and Technology Consolidated Plan of Action (CPA) for harnessing and applying STI for Africa’s development. The CPA has since been updated and eradicating hunger and achieving food and nutrition security (FNS) is one of the six priority areas identified in the revised document entitled STI Strategy for Africa or STISA-2024. However, despite the commitments, dating back to the 1980 Lagos Plan of Action to allocate 1% GDP to STI, domestic funding is still inadequate.

Most countries’ STI investments fall between 0.2% and 0.48% GDP and only three; Malawi, Uganda and South Africa approximate the 1% GDP target. In Ethiopia investment is estimated to be 0.17% GDP while in South Africa, it is 0.92% GDP. In 2006, African Union member states also committed to allocating 1% of agricultural GDP for agricultural research and development.

Presently, Africa only accounts for about 2% of the global knowledge produced. The majority of African scientists have limited access to national research funding and many work in facilities that can be generally described as “sub-optimal”. The average age of laboratory equipment for basic science is estimated to be 12 years and for engineering, it is 16 years. Within the last decade, Africa has also witnessed a rapid expansion in the number of universities and student enrolment, which have caused great strain on existing staff and physical infrastructure. In Kenya, for example, the number of public universities shot from 7 to 22 between 2010 and 2013. Staffing is further constrained as several faculty members are nearing retirement age or need additional training including postgraduate training and new skill sets. After 10 years of rolling out CAADP, only nine countries; Burundi, Burkina Faso, Republic of Congo, Ethiopia, Mali, Malawi, Niger, Senegal, Zambia have achieved the 2003 Maputo commitment of 10% GDP for agriculture. Ghana and Togo are close to achieving the target. Several countries have developed CAADP investment plans through a national consultative process but little or no provisions have been made for financing research, tertiary education and extension. To date, only Botswana, Burundi, Kenya, Mauritania, Mauritius, Namibia, South Africa and Uganda have surpassed the 1% agricultural GDP commitment made for investing in agricultural research and development.

Africa’s 1.0 billion population is expected to reach 1.3 billion by 2030 and 2 billion by 2050.
The majority of the population are youth (50%) under the age of 25. Smallholder farmers and small-scale processors and traders are mainly women. Significant rapid gains in capacity and infrastructural development; human and physical, must be made if Africa’s agricultural sector is to make the quantum leap into the 21st century. The role that increased investments in science and innovation and in women and youth can play should therefore not be underestimated. African women and young professionals engaged in science, technology and innovation (STI) need to have access to financial and physical resources and their contributions to transforming African agriculture, acknowledged and encouraged.

THE COMPETITIONS

Competitions serve to raise standards, bring out the best among peers, individuals and organizations, inspire others and identify new opportunities for innovation and investment. They showcase excellence and transcend all fields of human endeavour; sport, education, science and business. They also facilitate and support networking and are generally used to: (i) identify new talent and motivate individuals and groups to venture into new domains; (ii) promote new or improved concepts, technologies, products, services and brands and bring them to the attention of a wider public or target group e.g. policymakers; (iii) develop knowledge and skills; and (iv) reward excellence.

The 3rd Africa-wide Science Competitions sought to recognize and reward the contributions of African women scientists and young professionals who are involved in:

- Pioneering and innovative research, technology development and engineering;
- Communicating their research results and technological developments to improve agricultural performance, enhance livelihoods and build resilience of African communities; and
- Advocating for policy change and influencing policy processes through their research, education and outreach programmes to transform the agricultural and rural sectors, reduce hunger, improve prosperity and sustain the natural resource base.

The goal was to raise awareness of the need to support and sustain the engagement of women and young professionals in STI and value and exploit their scientific contributions for addressing current and future development challenges and for igniting Africa’s agricultural and socio-economic transformation.

The competitions were launched in March 2012 through an Africa-wide call for extended abstracts (1,000 – 2,000 words) on “Excellence in Science, Technology and Innovation for Agricultural and Rural Development”. The call targeted: (i) young professionals (25-40 years) in sub-Saharan Africa (SSA), North Africa and the Diaspora\(^1\) and (ii) Women scientists, researchers, educators, extension workers, agro-entrepreneurs and farmers in sub-Saharan Africa (SSA), North Africa and the Diaspora.

This attracted 316 submissions from nationals of 28 countries (Tables 1 & 2), across a range of themes (Table 3). About 41% of the submissions were eliminated during the pre-screening stage due to non-conformance with the basic requirements. For example, full papers as opposed to abstracts were submitted, the word limit was exceeded, or entrants failed to respect the deadline. Shortlisted abstracts (187; 59%) were critically evaluated by a multi-disciplinary expert panel using established criteria; logic (10), content (20), communication

FOOTNOTE

\(^1\) African nationals working or studying abroad and doing research on African issues linked to/and contributing to Africa’s development. Proof of citizenship is mandatory.
(20), impact – actual or potential (20), innovation (15) and originality (15). The expert panel acknowledged the marked improvement in the quality of abstracts received in response to the 3rd Africa-wide science competitions.

Forty-five (45) semi-finalists were shortlisted to develop their abstracts into full papers and for various reasons, forty-two (42) participated in the tailor-made training workshop on “Scientific-writing, Policy Advocacy and Communication” which was held in conjunction with the 3rd RUFORUM Biennial Conference, 24-28 September 2012, Entebbe, Uganda. Their full draft papers were used as working documents for the scientific writing component. On completion of the training, semi-finalists identified scientific writing, publishing, referencing, ethics in science, policy advocacy and effective communication among the important topics discussed. They also reported that they had gained knowledge on the importance of knowing existing agriculture and STI policies, and developed skills in public speaking and delivering presentations. They anticipated that they would need institutional support to apply the knowledge and skills gained on return to their organizations. Participation in the RUFORUM Biennial also allowed the women scientists and young professionals to network with a wider cross section of African and

<table>
<thead>
<tr>
<th>TABLE 1: DEMOGRAPHIC OVERVIEW OF PARTICIPANTS IN WOMEN IN SCIENCE COMPETITION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abstracts</strong></td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>131</td>
</tr>
</tbody>
</table>

| **Semi-Finalists**              |
| Total                           | Southern Africa | West Africa | Central Africa | North Africa | East Africa | En | Fr | Nationalities |
| 19                              | 4               | 4           | 1              | 0            | 10          | 18 | 12 |

<table>
<thead>
<tr>
<th>TABLE 2: DEMOGRAPHIC OVERVIEW OF PARTICIPANTS IN YOUNG PROFESSIONALS IN SCIENCE COMPETITION</th>
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<tbody>
<tr>
<td><strong>Abstracts</strong></td>
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<tr>
<td>Total</td>
</tr>
<tr>
<td>185</td>
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</tbody>
</table>

| **Semi-Finalists**              |
| Total                           | Southern Africa | West Africa | Central Africa | North Africa | East Africa | En | Fr | M | F | Nat. |
| 26                              | 1               | 12          | 4              | 0            | 9           | 16  | 10 | 20  | 6  | 10 |
international scientists, academicians, development partners and other stakeholders. All papers were finalized after the training workshop and subsequently evaluated by the multi-disciplinary expert panel, using agreed criteria for selecting the top 20 finalists; 10 in each category. All 45 scientific papers, were peer reviewed and edited for publication in this volume of *Agricultural Innovations for Sustainable Development, Volume 4: Issue 3*.

The twenty finalists vied for the top awards and prizes on 15 – 16 July 2013, during a Side Event of the Forum for Agricultural Research in Africa (FARA) 6th Africa Science Week and General

### Table 3: Abstract Submission by Themes

<table>
<thead>
<tr>
<th>Themes</th>
<th>Sub-themes</th>
<th>Women</th>
<th>YPs</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Agricultural production and food security</td>
<td>Biotechnology and Bio-safety</td>
<td>59</td>
<td>84</td>
<td>143</td>
<td>45</td>
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<tr>
<td></td>
<td>Nutritional quality, Agricultural Health and Food Safety</td>
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<td></td>
<td>Horticulture, Livestock, Fisheries and Aquaculture</td>
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<td></td>
<td>Seeds and Seed systems</td>
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<tr>
<td>2 Environment and ecological sustainability</td>
<td>Biodiversity, Forestry, Water and Soils</td>
<td>21</td>
<td>35</td>
<td>56</td>
<td>18</td>
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<td></td>
<td>Renewable Energy</td>
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<td></td>
<td>Climate Change</td>
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<tr>
<td>3 Marketing, economics, trade and policy</td>
<td>Land and Water Governance</td>
<td>23</td>
<td>48</td>
<td>71</td>
<td>22.5</td>
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<td>Food Price Volatility</td>
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<td>Market Access</td>
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<td>Value chain development and Innovation systems</td>
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<td></td>
<td>Gender</td>
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<tr>
<td>4 Post harvest and value addition</td>
<td>Postharvest losses</td>
<td>19</td>
<td>07</td>
<td>26</td>
<td>8</td>
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<tr>
<td></td>
<td>Processing and Packaging</td>
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<td></td>
<td>Agricultural Machinery / Engineering</td>
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<tr>
<td>5 Tertiary education, knowledge management and ICT</td>
<td>Curriculum development</td>
<td>09</td>
<td>11</td>
<td>20</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>Teaching and Learning Innovations</td>
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</tbody>
</table>

|                  |                 | 131   | 185   | 316   | 100 |

SYNTHESIS REPORT:
LESSONS LEARNED
Assembly (GA), which was held in Accra, Ghana. Each finalist delivered a 15-minute oral presentation to an inter-disciplinary panel of distinguished African judges and in the presence of a wider audience of their peers. The judges focused on: (i) the soundness and relevance of the research and its demonstrated and potential impact; (iii) the communication tools and approaches used to disseminate the results to peers, policymakers and end-users; and (iv) the oral delivery and ability to convincingly and confidently communicate the highly technical subject matter within a short timeframe. This final stage of the competitions served to further reinforce the importance of investing in women and young professionals for achieving the desired agricultural transformation in Africa.

The Award and Prize Distribution Ceremony was held during the main FARA GA plenary which was attended by over 1500 delegates comprising government ministers, senior officials of the African Union, NEPAD Agency, sub-regional research organizations and other major African lead agencies, development partners and various African and international stakeholders committed to the development of Africa’s agricultural and rural sectors. All winners (Box 1) received their awards and prizes from Professor Monty Jones, co-winner of the 2004 World Food Prize and outgoing Executive Director of FARA. In addition to the top 10 awards and prizes, all 45 semi-finalists received certificates of recognition as they are all considered winners.

 Hosting the Finals and Award Ceremony during the FARA GA, a major event on the African research calendar, provided added visibility for African women scientists and young professionals. Receiving their awards from the first African scientist to receive the World Food Prize also served as motivation to continue to pursue their careers in STI that benefit Africa and the wider world. This high-profile event also demonstrated to the wider public that the scientific contributions of Africa’s women and young professionals corresponded to Africa’s priorities as well as the priority themes which the FARA GA endorsed for their ensuing three-year work programme. It also confirmed that African governments must increase funding to support African women scientists and young professionals in their STI endeavours.

Some key observations have been made with respect to the level of participation, the research themes, scientific excellence and relevance, communication for impact and funding.

Level of participation – It was noted that West Africa (129; 41%) dominated the 1st stage of both competitions, followed by East Africa (105; 33%) and that Central Africa (45, 14%) made a strong showing especially among entrants for the Young Professionals’ competition. The highest number of entrants for the Women’s competition came from Nigeria (20), Kenya (16) and Ethiopia (9) followed by Burkina Faso and Cameroon (8 each), the Ivory Coast, Sudan, Uganda, and Zimbabwe (7 each) and Benin and Senegal (6 each). The highest number of entrants for the Young Professionals’ competition were from Nigeria (29), Cameroon (23), Ethiopia and Kenya (16 each) followed by Benin and Burkina Faso (11 each). At the semi-final stage, East Africa dominated the Women’s competition (53%) while West Africa (46%) continued its domination of the Young Professionals’ competition. Ugandan scientists placed among the top 5 in both competitions; obtaining three places out of the top 10 awards. The ratio of young men to young women was 3:1, at the initial stage of the Young Professionals in Science competition and this increased slightly to 3.3:1 for the semi-finals. However, whereas the women were outnumbered in the early stages, they dominated the awards, securing the 1st, 2nd and 3rd places in the finals. More work is needed to build the scientific capacity of young African male and female scientists and to encourage them to continue to strive for excellence. Funding
BOX 1: WINNERS AND PRIZES 3RD AFRICA WIDE SCIENCE COMPETITIONS

Winners of the Young Professionals in Science

1st – Dr Jemanesh Kifetew Haile, Ethiopia
QTL mapping of resistance to Ethiopian stem rust races of Puccinia graminis f. sp. *Tritici* including UG99 and stem rust resistance genes in durum wheat (*Triticum durum* Desf.)

2nd – Stella Kabiri (PhD candidate) Uganda
Landscape-scale management of Invasive *Cymbopogon afronardus* (Stapf) in the rangelands of Uganda

3rd – Dr Julius Kofi Hagan, Ghana
Introducing heat-tolerant genes into exotic chicken for improved egg production under hot and humid environments

4th – Komi Edem Koledzi, Togo
Valorisation des déchets solides urbains à Lomé : approche méthodologique pour une production durable du compost (Recovery of urban solid waste in Lomé: methodological approach towards sustainable compost production)

5th – Donald Rugira Kugonza, Uganda
Enhancing pig productivity in Lake Victoria crescent zone: the effect of genotype and post-weaning diet

Winners of the Women in Science

1st – Dr Nafiisa Sobratee, Mauritius
Valorisation of poultry litter to compost: an assessment of the pathogen reduction potential

2nd – Dr Florence Beatrice Lubwama Kiyimba, Uganda
Labour saving tools for women: The forage chopper for smallholder dairy farmers in Uganda

3rd – Dr Ijeoma Chinyere Akaogu, Nigeria
Agronomic performance of extra-early maize hybrids under stress and non-stress environments in Nigeria

4th – Dr Loule Clementine, Dabire Binso, Burkina Faso
Sécurité alimentaire en Afrique: une technique innovante efficace de conservation du niébé (Food security in Africa: an innovative technique for cowpea storage)

5th – Dr Fredah Karambu Rimberia, Kenya
Improvement of papaya productivity for commercial application

The prizes for the Young Professionals were as follows:

1st Prize
Trophies, laptop and $3,000 cash, books

2nd Prize
Video camera and $2,000 cash, books

3rd Prize
Digital camera and $1,500 cash, books

4th & 5th places
$1,000 each, books

The prizes for the Women in Science were as follows:

1st Prize
Trophies, laptop and $5,000 cash, books

2nd prize
Laptop and $3,000 cash, books

3rd prize
Laptop and $2,500 cash, books

4th & 5th places
$1,500 cash each, books
their research and using science competitions to encourage and reward excellence can further contribute to building strong research teams, enhancing academic excellence, and mobilizing engineers and entrepreneurs that Africa needs for the future.

The high numbers of participants from across Africa was rewarding and in some way can be attributed to the collective strength of the consortium partners. RUFORUM and its member universities have been working to improve postgraduate training and build research capacity in East and Southern Africa and particularly in post-conflict countries such as Sudan. ANAFE, the other university network partner, has a strong presence in West and Central Africa, and their mobilization efforts, may have accounted for the increased participation of French-speaking researchers. IFS has been encouraging and supporting young researchers through their grants and capability enhancing support and has also strengthened its Alumni association in West Africa. An increase in the number of quality abstracts from all African countries in future competitions is an ambitious goal for the partners.

**Thematic focus** – Agricultural production and food security (45%) was the dominant theme for the first and second stages for both competitions (Table 3). Submissions in other areas such as marketing, economics and trade (22.5%), environment and ecological sustainability (18%), postharvest and value addition (8%) and tertiary education, knowledge management and ICTs (6%) were lower, which suggests the need for broadening and deepening the research in these non-traditional areas. The expert panel was also of the view that the research results that were submitted especially in the area of climate change modelling, though interesting, was still work in progress or at the proof of concept stage.

**Scientific excellence and relevance** – The papers published in this volume show that the women and young professionals are committed to scientific excellence. They span a range of domains including biotechnology (e.g. see papers for Olasanmi et al. and Kwapata), soil science (e.g. see papers for Azeez et al. and Ekebafe et al.), microbiology (e.g. see paper by Sobratee et al.), technology development (e.g. papers by Compaore et al. and Ahmed et al.) and economics (e.g. see paper by Ambagna and Kane). They also address issues of strategic importance such as: climate change (e.g. see paper by Ogouwale et al.); emerging threats to major food crops (e.g. see paper by Haile et al.); improved breeds that can adapt to abiotic stressors (e.g. see paper by Hagan and Olympio), nutritional content of local foods (e.g. see paper by Atero et al.), reducing post harvest losses (e.g. see paper by Zossou) and value addition (e.g. see paper by Okafor et al.). The research and published papers confirm that the research efforts of the scientists who participated in the competitions respond to Africa’s priorities.

**Communication for Impact** – The scientists did not only communicate their research outputs among peers through publications in international journals and by participating in conferences but used various methods including field visits, farmer field schools, fairs and trade shows and engaged with print and electronic media including radio and television to reach farmers, policymakers and other stakeholders. Their communication efforts are to be commended and augur well for the communication of science and recognition of the need to demystify science and strengthen the relationship between science and society. However, despite the improvements in the quality of papers, the expert panel was of the view that, there is need to further intensify efforts to develop capacity in research methods and scientific writing. The university networks and other consortium partners have taken careful note.

**Funding** – A review of the acknowledgments of the papers published in this volume confirm the long-held view that the major source of funding for
African researchers is external. The majority of the research undertaken was funded either through the European Commission framework programme, EU member states e.g. France (IRD), Norway (NORAD) and The Netherlands (NUFFIC) and development partners e.g. BMZ - Germany, CIDA - Canada, DFID - UK, USAID - USA. Several scientists had gained their PhDs and developed capacity through overseas attachments at state of the art facilities in Europe (e.g. Denmark, The Netherlands, Sweden) and the USA. However, it was also noted that researchers from Cameroon, Ghana, Nigeria and Uganda acknowledged national sources of funding, suggesting that positive developments are occurring in Africa. The opportunities and benefits that African scientists derive from overseas attachments and external funding for their research are extremely valuable as they allow them to widen their network and broaden their vision and perspectives. However, African governments must live up to their responsibility and are encouraged to honour or exceed their commitments to investing at least 1% agricultural GDP in agricultural research and development.

CONCLUSION

Africa’s agriculture must ‘leapfrog’ into the 21st century. Investing in science, technology and innovation, building the human capital and putting the necessary policies and institutional mechanisms in place, including financing, would help to achieve the much needed transformation. Africa needs a skills revolution and investing in women and youth provides a win-win entry point. Governments must invest and live up to their commitments of at least 1% GDP in STI and 1% agricultural GDP in research and development. At the same time, the African scientific community, including women scientists and young professionals must pursue STI endeavours that: (i) address Africa’s priorities and challenges; (ii) increase production efficiencies while doing no more damage to the environment and expand opportunities for farmers and other agri-chain actors to move up the value chain; (iii) create wealth for African people and communities; and (iv) increase Africa’s contribution to the global knowledge pool. These science competitions have taught CTA, FARA, IFS and partners that:

1. African women scientists and young professionals are taking up the challenges and are ready to do more. They need to be capacitated - provided with adequate training, mentored by scientists from within Africa and beyond, motivated and well resourced - funding and facilities).
2. Science competitions help to showcase Africa’s scientists and engineers and bring their contribution to the forefront as well as identify areas for further intervention.
3. Future science competitions should continue to focus on young professionals and encourage wider participation from all the African countries.
4. The Consortium partners are open to new ideas and additional co-funding and expertise of national, continental and international development partners to expand the scope and reach of the competitions.
WOMEN IN SCIENCE
IMPROVEMENT OF TRADITIONAL CHURNER FOR BUTTER EXTRACTION IN ELKIRYAB, SUDAN

M.E. Ahmed¹, J.M. Diop² and E.M. Mahjoob¹
ABSTRACT

A traditional churning technology was developed and modified for butter production through participatory innovation development (PID). The objectives were to: (i) analyse churning practice as a traditional and indigenous innovation technology; (ii) evaluate the physical effort deployed by women in relation to the income generated; and (iii) develop an improved design of a local traditional churner technology with a superior performance rating. Two areas of Sudan using churning technology were selected and surveyed. Two different churning devices were used: AlBukhsa gourd and ElSein, a goat-leather agitator. The milk processing method was virtually identical in the two study areas. Matrix ranking was used to prioritise and select one of the local innovations: the milk-churning technology ElSein was more popular with the women in the village. There were two reasons for this. First, the technology was inherited from grandmothers and it is practised as a custom; second, it is an income-generating activity. The design was developed successfully and appropriated by the women’s group. Joint preliminary experimentation showed that the design was simple, user-friendly (less effort exerted by women compared with using the leather gourd), portable and easy to clean. It gave a high extraction rate of 90–95% butter in 15 min, compared with the unimproved traditional churner, which took over 2 h to produce the same amount.

KEY WORDS: BUTTER CHURNER, DESIGN DEVELOPMENT, INNOVATION, MILK PROCESSING, PARTICIPATORY

AFFILIATIONS

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2 ETC Netherlands
INTRODUCTION

Participatory approaches facilitate the process of linking communities with the scientific community (researchers and academics). Use of participatory rapid appraisal (PRA), participatory technology development (PTD) and participatory action research (PAR) has increased interest in and respect for indigenous knowledge, and pose a challenge to top-down approaches for extension and development projects (Chambers, 1994).

Participatory innovation development (PID) is one of the participatory approaches used by the PROLINNOVA programme (Promoting Local Innovations in Ecologically-oriented Agriculture and Natural Resource Management), which identifies and analyses local innovations and provides a focus for community groups to examine opportunities and set the agenda for research and development, and to consider new approaches to be tried out by the community (Scheuermeier et al., 2004). PID is also defined as a process and the ability to create something new, as agreed by Reed (2007), and by Rai and Shrestha (2006).

The technology for butter making is almost universal. Generally, rural women in Sudan spend considerable amounts of time milking animals and processing the milk to produce products such as sour milk, yoghurt, cream, cheese, butter and clarified heated butter or ghee (known locally as saman) (Mariod et al., 2010). The cooked and clarified butter is spooned off the container and collected, then the butter is heated to produce saman, which can be stored for long periods in an airtight container (dark glass bottle) (FAO, 1990). Traditionally, the sour milk is poured and agitated in a churn (e.g. AlBukhsha/ElSein) to produce butter and butter milk. Rural women in West Sudan use AlBukhsha made of gourd/calabash, while in northern and central regions of Sudan, women use an agitator made from goat skin called ElSein. Traditional methods of milk processing generally give low yields and require high labour inputs.

In addition, the end products are hygienically inferior and are of low stability (El-Hag et al., 2003). However, there is a market demand for these products.

The broad objective of the research was to develop a technology adapted from the traditional churning devices (ElSein or AlBukhsha) using participatory approaches mainly through PID, PRA and PTD in collaboration with one female innovator, with other women’s groups involved in all the development stages. The intention was to set up a process of joint experimentation in PID that takes into account gender aspects in improving the design of the traditional churner. The new and improved churner was expected to deliver a better performance in terms of ease of use, time saving, improved productivity rate (quantity) and enhanced product quality.

The specific objectives were to:
- analyse and determine the churning practice as traditional and indigenous innovation technology;
- evaluate the physical labour used by women in relation to the income generated; and
- develop an improved design of the local technology delivering a superior production rate and hygienically high-quality products.

MATERIALS AND METHODS

The research methodology was mainly a PID cycle based on participatory approaches at all stages: survey, design development and experimentation, including monitoring and evaluation. This can be defined as a process cycle encompassing three stages, e.g. diagnosis, implementation or action, and sustainability (Wettasinha et al., 2008).

The diagnosis stage was undertaken in two survey areas. The first was situated in central Sudan near Khartoum state (semi-urban area), where the ElSein is used. The second area was located in western Sudan near Al-Obied (Faris village in rural area), where the AlBukhsha device is used. Participatory
tools such as matrix ranking, semi-structured interviews, focus group discussions and observations were used to gather information about the traditional churning technology.

After collecting and analysing the data, the design development process commenced with the full participation of the female innovator (Fatima Mohammed, aged around 70) and other women’s groups in ElKiryab village, and continued by using the PID triangle approach (female innovator–extensionist–researcher). The female innovator explained her innovative approach to milk preparation and churning techniques, outlined the constraints she faced, and suggested desired areas of improvement. Based on these constraints and desires, a new design for a milk-churning process was proposed and discussed and then agreed with the women’s group.

Preliminary testing of the new design was undertaken chiefly by the innovator and the researcher. The design development concept considered the economic, social and environmental aspects alongside the female innovator’s experience of traditional technology. The key principle for the designer was agitating the milk until the butter separated (churning), and the ease with which parts could be moved for operation and cleaning. The designer also considered low-cost local manufacturing materials. Another important consideration was how to achieve improved butter yield in a relatively short time. The innovator contributed by suggesting using a plastic container, based on its availability and affordability. She also advised the designer not to use perforated blades because they affect the churning process.

Joint experiments were carried out to test the new modified churner. The researcher and the innovator with her family worked together mainly on milk preparation and churning, and churning experiments were conducted in the morning and evening. The churning experiments were first performed using the traditional churner. Based on her own experience, the innovator adjusted the optimum amount of starter added for milk, taking into account the temperature diversity over the course of the day. Further experiments were performed using the same methodology, but with the new modified churner. Comparison experiments were carried out to compare the traditional churner (ElSein) and the new modified churner. Experiments were conducted under normal conditions. The butter produced from the new modified churner and from the traditional churner was weighed. During the research process, some other researchers and academic institutions were consulted for their ideas on how to improve local milk-churning practices.

The survey findings

The two regions of Sudan utilised the same traditional technology, but with devices made from different materials. The milk preparation was the same in both areas: the milk was heated, then cooled, and the starter (yoghurt) was added; for 8 litres of sour milk about 15 ml of starter was added. The two regions differ in their environments and natural resources. Western Sudan is richer in animal resources compared with the area near Khartoum. The women of eastern Khartoum used ElSein, and the churning process began by pouring the milk into the ElSein, which is then hung up. The woman then blow into the ElSein, tie it shut and start the churning process. The blowing is unhygienic.

Women living in the rural area near ElObeid (Faris village) used AlBukhsa, which is an emptied gourd, the fruit of a vegetal species which normally grows in the area. The gourd used as a container was suspended from a wooden tripod. The AlBukhsa gourd is not found in the region of Khartoum, which is why women use ElSein instead for churning. Women from both regions emphasised the need for improved technology allowing them to produce butter using a less physically demanding churning process. They also stressed the importance of being able to easily clean the device after processing, besides the need to increase the
output, which is impossible using traditional methods. Women who participated in the research also reported that both AlBukhsa and ElSein practices are not sustainable and are prone to damage during milk processing.

Selection of local innovation
In one of the selected sites (ElKiryab) near Khartoum, the local innovation that was most commonly used by women in the village was the milk churner ElSein. This local practice was inherited from their grandmothers and was regarded by women as an income-generating practice. The parameters considered in terms of the churning technology design were based mainly on ‘important’ and ‘desirable’ characteristics that were a plus for the innovation. The important characteristics considered for the selected innovation were the potential benefits of milk churning to produce more than two products (butter and sour milk) by adding more processing activities such as heating to produce ghee, or collecting sour milk to produce a kind of milk drink. Another important characteristic was its ability to increase daily income, especially for elderly women. The main desirable characteristics were the technology’s cost-effectiveness and the ease with which it could be adapted and improved for new churner technology. The new technology can deliver a better performance environmentally, economically, technically and socially. Moreover, it can be widely replicated throughout parts of Sudan.

Butter churner design development
The churner consisted of an agitator shaft with blades attached by bearings fixed to a bar which could be adjusted by women to the desired height. The shaft is dipped in the plastic container. The new churner is easy to use. The arm and arc control the motion of the agitating shaft via a chain attached to the ends of the arc. The action generates high turbulence in the milk molecules, causing the butter to form and float on the surface of the milk in the plastic container.

![Figure 1: Left, agitator; Centre, agitator dipped in plastic container; Right, agitator fixed to a bar](image_url)
RESULTS

Joint experimentation

In 15 min, 90–95% butter extraction was achieved, while the traditional churner took over 2 h to produce the same percentage. Table 1 shows the acceptability factors for the new modified churner compared to the traditional churner according to the innovator and the other women.

DISCUSSION AND CONCLUSION

The butter churner was selected as it represents traditional and heritage technology utilised by women in the selected area. In this research, the new modified design was based on indigenous knowledge and a scientific technical background. According to Berry (1989), it is more useful to investigate the outcome of the interaction of new ideas and indigenous knowledge. Women from the two selected areas using two churners (AlBukhsa or ElSein) highlighted similar problems, which were the significant effort expended in churning, the difficulty of cleaning, and the length of time taken to produce a low yield of butter.

The new modified design of the churner was developed successfully by analysing traditional technology according to women’s needs and capabilities using the PID triangle – researcher, extensionist and innovator – with community support. This is in agreement with Reed (2007), who found that there should be collaboration between extensionists, scientists and local innovators to facilitate PTD. The participation of the female innovator in the design development was based on her local knowledge and experience.

The modified churner gave good results in terms of the cleaning process and in other hygienic practices (women didn’t blow into the new churner). Also, less effort was exerted, as churning can be done single-handed. The innovator and the community

<table>
<thead>
<tr>
<th>Factor</th>
<th>New modified churner</th>
<th>Traditional churner ElSein</th>
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<tr>
<td>Perceived ease of use</td>
<td>Operated single-handed</td>
<td>Operated double-handed</td>
</tr>
<tr>
<td>Easy to clean</td>
<td>Container and agitator can be moved easily for cleaning</td>
<td>Cleaning takes time; there is a certain type of tree used for cleaning</td>
</tr>
<tr>
<td>Hygiene aspects</td>
<td>Manufacturing materials used are hygienic</td>
<td>Unhygienic – women blow into the device before starting</td>
</tr>
<tr>
<td>Churning effort</td>
<td>Reduced churning effort</td>
<td>Considerable churning effort</td>
</tr>
<tr>
<td>Portability</td>
<td>Can be easily moved from place to place within the house</td>
<td>Not easy to change locations as ElSein is hung in a particular place (shelter)</td>
</tr>
<tr>
<td>Ease of assembly for women</td>
<td>Can be easily assembled with some assistance from the family</td>
<td>No assembly required as it is one piece</td>
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</table>
found that the design gave a good yield of 90–95% of butter in 15 min, which was agreed to be better than the traditional churner, which gave a similar yield after 2 h. Also, the modified churner is portable and can easily be assembled by women. The adaptability, durability and affordability were considered in the modified churner design, which was made by local artisans using readily available and low-cost materials. The success of this research was that the female innovator and her family, and the whole community, were involved in the PID process. Further research is needed to investigate the extraction rate by studying the modern churning conditions for the new modified churner compared with the traditional method in collaboration with the Food Research Center.

ACKNOWLEDGEMENTS

This study was conducted by Mrs Mawahib Eltayeb Ahmed (Researcher) and Emad Mahjoub (designer) as research in the Appropriate Technology Department of the National Center for Research in Sudan. Remote support was received from Dr Jean-Marie Diop, who was Back-stopper of the PROLINNOVA program in Sudan. The research was funded by Practical Action through the PROLINNOVA programme. I would like to thank the Practical Action staff in Sudan, namely Dr Noureldin Ahmad Abdelaila. I would like to thank the female innovator, Fatima, and the farmer community in ElKiryab village.

COMMUNICATION STRATEGY AND IMPACT

The results were shared and discussed with the community and researchers from a related field both during and at the end of the experiment. This served as a basis from which to decide whether the results were useful locally, or if technical guidelines could be developed for their wider application. It emerged from the discussions that the technology had a significant impact on the income derived from the churning process by increasing the amount of churned milk to about 12 litres.

The results were also shared with the community, who agreed on increasing productivity. A PID network was also established in the community to develop other innovations, where innovators acted as resource persons in events, exchange visits and field days. Communication strategies were proposed, which entailed preparing materials such as booklets and audiovisual materials aimed at government, financing bodies and research centres for support and finance.

REFERENCES


AGRONOMIC PERFORMANCE OF EXTRA-EARLY MAIZE HYBRIDS UNDER STRESS AND NON-STRESS ENVIRONMENTS IN NIGERIA

I.C. Akaogu¹, B. Badu-Apraku², V.O. Adetimirin³ and M. Oyekunle²
ABSTRACT

The availability of extra-early maturing varieties has facilitated the expansion of maize production into the savannas of West and Central Africa (WCA). However, maize production and productivity in the sub-region is greatly constrained by low soil nitrogen, drought, and infestation by *Striga hermonthica* (Del) Benth. Research was therefore initiated to determine the yield performance and stability of selected extra-early hybrids under drought conditions, artificial *Striga* infestation, and optimal growing environments. The performance of 120 extra-early hybrids and an open-pollinated check were assessed in Nigeria under managed drought at Ikenne during the 2010 and 2011 dry seasons; artificial *Striga* infestation at Mokwa and Abuja; and optimal conditions at Mokwa and Ikenne during the 2010 and 2011 growing seasons.

Under *Striga* infestation, the grain yield of the hybrids ranged from 735 kg ha\(^{-1}\) for TZEEI 99 × TZEEI 95 to 3200 kg ha\(^{-1}\) for TZEEI 83 × TZEEI 79. Under drought conditions, grain yield ranged from 128 kg ha\(^{-1}\) for TZEEI 62 × TZEEI 63 to 1982 kg ha\(^{-1}\) for TZEEI 71 × TZEEI 79. Under optimal conditions, grain yield ranged from 653 kg ha\(^{-1}\) for TZEEI 102 × TZEEI 63 to 3781 kg ha\(^{-1}\) for TZEEI 70 × TZEEI 79. The hybrids TZEEI 67 × TZEEI 63, TZEEI 71 × TZEEI 79, and TZEEI 81 × TZEEI 95 were identified as the highest-yielding and most stable across the research environments. Based on these results, the hybrids identified may be grown in *Striga* endemic and/or drought-prone areas for enhanced productivity in the sub-region. In conclusion, stable, high-yielding, extra-early hybrids with drought tolerance at the flowering and grain-filling periods and *Striga*-tolerant varieties are available for the first time in the sub-region. Work is under way to promote the release and commercialisation of these hybrids in WCA.

KEY WORDS: Drought, Hybrids, Performance, Stability, *Striga hermonthica*, Yield

AFFILIATIONS

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INTRODUCTION

Maize (Zea mays L.), a major staple food crop in West and Central Africa (WCA), is adapted to all agro-ecological zones in the sub-region. The availability of early maturing varieties (90–95 days to maturity) and extra-early varieties (80–85 days to maturity) has allowed maize to expand into the dry savannas of WCA, replacing traditional cereal crops such as sorghum (Sorghum bicolor (L.) Moench) and millet (Pennisetum glaucum (L.) R. Br.), thus tackling food scarcity in July, when food reserves are depleted after the long dry season. The production of maize in the savannas of WCA, which have the best potential for high yields due to high solar radiation, low night temperatures, and low disease pressure, are greatly constrained by low soil nitrogen (low N), recurrent drought, and parasitism by Striga hermonthica. The levels of Striga infestation are often so high that maize can suffer total yield loss and farmers are forced to abandon their farmlands.

Several measures have been developed to combat the Striga menace, but the parasitic weed seems to have defied all available cultural control options. The use of host plant resistance, exemplified by a reduced level of Striga attachment to the host, or tolerance, the ability of the host plant to produce a yield despite infestation, is considered the most economically feasible and sustainable approach for reducing its effects (Badu-Apraku et al., 2011).

On average, drought occurs two to three times in each decade in sub-Saharan West Africa (DNRP-GAPCC, 2000). The onset of drought from a few days before anthesis to the start of grain filling can reduce grain yield by as much as 90% (Badu-Apraku et al., 2011). Unfortunately, drought is unpredictable and affects grain yield most severely during the flowering and grain-filling periods of maize development. Striga parasitism and drought occur simultaneously under field conditions, with severe consequences. Thus breeding for early and extra-early maturing maize cultivars with improved tolerance to drought stress and tolerance to Striga that fit into areas with a short growing season is essential to improve productivity and ensure stable production of the crop.

Development of hybrid varieties, their promotion and adoption are promising strategies for an appreciable increase in maize production and to revolutionise agriculture in WCA. A number of seed companies have sprung up in the sub-region in the past decade, setting the stage for commercial hybrid seed production. However, there are no commercial extra-early and early maturing hybrids available to these companies to produce for farmers in the savanna, where there is a short growth period. Fortunately, the International Institute of Tropical Agriculture (IITA) maize programme has developed a large number of extra-early inbred lines with improved tolerance to Striga and drought at the flowering and grain filling stages (Badu-Apraku and Oyekunle, 2012). The major challenge facing IITA’s maize breeders presently is to test these inbred lines in hybrid combinations and to identify and promote commercialisation of productive hybrids with tolerance to Striga and drought in WCA. The objective of the research was to determine the yield performance and stability of selected extra-early maize hybrids under drought, artificial Striga infestation, and optimal growing environments.

MATERIALS AND METHODS

120 extra-early hybrids and an open-pollinated variety (OPV) check, 2008 Syn EE-Y DT STR, were assessed under managed drought stress at Ikenne during the 2010 and 2011 dry seasons. The cultivars were also evaluated under artificial Striga infestation at Mokwa and Abuja, and under optimal conditions (rainfed) during the 2010 and 2011 growing seasons at Mokwa and Ikenne, in Nigeria. The trials were laid out as an 11 × 11 randomised incomplete block design with two replications. Row and hill spacing were 0.75 m and 0.40 m, with two plants per hill. The cultivars were evaluated under artificial Striga infestation at Mokwa and Abuja using the IITA Striga
infestation method (Kim, 1991) that ensures uniform infestation. The managed drought stress at Ikenne was achieved by withdrawing irrigation water 21 days after planting until harvesting, so that the maize plants relied on stored water in the soil for growth and development. The hybrids were evaluated at a population density of 66,000 plants/ha at all sites, following standard agronomic practices.

Data were recorded for all experiments for days to silking (DS), anthesis (DA), anthesis to silking interval (ASI), plant height, number of ears per plot (EPP), ear aspect and plant aspect. Leaf senescence data (stay-green characteristic) were recorded only for the moisture-stressed plots at 65 days after planting on a scale of 1 to 9, where 1 = almost all leaves green and 9 = all leaves dead. The observations made on the Striga-infested experiments were the same as those of the managed drought and optimal conditions, except that no data were recorded on the stay-green characteristic. Additional data were collected on the Striga-infested plots on the number of emerged Striga plants and host-plant damage at 8 and 10 weeks after planting.

The productive single-cross hybrids for commercial production under Striga infestation and managed drought stress were identified separately for each stress factor using a selection index (Badu-Apraku et al., 2011) which integrated standardised data for selected variables. The best 10 and the worst 10 single-cross hybrids under Striga infestation and drought were selected using the respective base indices (Tables 1 and 2). The genotype main effect plus genotype × environment interaction (GGE) biplot analyses revealed TZEEI 67 × TZEEI 63, TZEEI 71 × TZEEI 79, and TZEEI 97 × TZEEI 63 as the highest-yielding as well as the most stable hybrids across the research environments (data not shown).

RESULTS

The analysis of variance showed significant genotype, location, and genotype × location interactions for grain yield and most measured traits under the three research conditions (Tables 1 and 2). Under Striga infestation, the grain yield of the hybrids ranged from 735 kg ha⁻¹ for TZEEI 99 × TZEEI 95 to 3200 kg ha⁻¹ for TZEEI 83 × TZEEI 79. Under managed drought stress, the mean grain yield ranged from 128 kg ha⁻¹ for TZEEI 62 × TZEEI 63 to 1982 kg ha⁻¹ for TZEEI 71 × TZEEI 79. Under optimal conditions, yields ranged from 653 kg ha⁻¹ for TZEEI 102 × TZEEI 63 to 3781 kg ha⁻¹ for TZEEI 70 × TZEEI 79. Under Striga infestation, the highest-yielding hybrid, TZEEI 83 × TZEEI 79, out-yielded the OPV control by 157%, while the highest-yielding drought-tolerant hybrid, TZEEI 71 × TZEEI 79, out-yielded the OPV check, 2008 Syn EE-Y DT STR, by 129% under managed drought stress. The hybrids TZEEI 80 × TZEEI 79, TZEEI 86 × TZEEI 79, and TZEEI 97 × TZEEI 63 delivered an outstanding performance across the two stress conditions using the base indices (Tables 1 and 2). The genotype main effect plus genotype × environment interaction (GGE) biplot analyses revealed TZEEI 67 × TZEEI 63, TZEEI 71 × TZEEI 79, and TZEEI 81 × TZEEI 95 as the highest-yielding as well as the most stable hybrids across the research environments (data not shown).

DISCUSSION AND CONCLUSIONS

The significant mean squares observed for genotypes for all measured traits under Striga infestation, managed drought stress and optimal conditions indicated that there was a large genetic variation among the genotypes, allowing good progress from selection for improvements for Striga resistance, tolerance to drought that occurs at flowering (including grain-filling) stages, and improved grain yield across the test environments.
<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Grain yield (kg ha⁻¹)</th>
<th>Days to silk</th>
<th>ASI‡ (days)</th>
<th>PLHT (cm)</th>
<th>Ear aspect</th>
<th>EPP</th>
<th>SDR (WAP)</th>
<th>NESP (WAP)</th>
<th>Base Index</th>
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| Genotype × location|                      |              |            |           |           |     |          |            |            |            |            |            |            |            |            |            |            |

‡ ASI: anthesis–silking interval; PLHT: plant height; EPP: ears per plant; SDR: Striga damage rating; WAP: weeks after planting; NESP: number of emerged Striga plants.
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‡ ASI: anthesis–silking interval; PLHT: plant height; PASP: plant aspect; EASP: ear aspect; EPP: ears per plant; SGS: stay green characteristics.
The results of this study are encouraging as the drought-tolerant hybrids identified are not only drought-escaping (a characteristic), but also carry genes that are tolerant to drought at the flowering and grain-filling stages (Badu-Apraku and Oyekunle, 2012), as well as genes for *Striga* resistance. The superior hybrids identified across the research environments, TZEEI 67 × TZEEI 63, TZEEI 71 × TZEEI 79, and TZEEI 81 × TZEEI 95, are presently undergoing extensive multi-location testing on-station and on-farm in WCA in preparation for their release to farmers in the sub-region. Similarly, promising hybrids identified in this study, such as TZEEI 83 × TZEEI 79, TZEEI 71 × TZEEI 79, TZEEI 80 × TZEEI 79, TZEEI 86 × TZEEI 79, TZEEI 97 × TZEEI 63, and TZEEI 70 × TZEEI 79, are being vigorously promoted by the Drought Tolerant Maize for Africa (DTMA) project for commercialisation and production by farmers to enhance food security. It is noted here that farmers are already asking for hybrids with combined resistance/tolerance to *Striga* and drought to reduce the instability of maize yields, especially in the savannas, as well as during the second season in the forest agro-ecological zone. It is also important to note that this is the first report on extra-early hybrids with combined resistance/tolerance to *Striga* and drought that can withstand drought stress during the flowering and grain-filling stages. The adoption and commercialisation of the *Striga*-resistant/tolerant and drought-tolerant extra-early hybrids should contribute significantly to food security and improve the incomes and lives of farmers in WCA.

In conclusion, drought- and *Striga*-resistant/tolerant extra-early maize inbred lines and hybrids are available. These should be commercialised and made available to farmers to contribute to sustainable food security in WCA.

COMMUNICATION STRATEGY AND IMPACT

The potential vehicles for the dissemination of output from this research work are the agents of national agricultural extension services and NGOs. Strategies being adopted for promotion of the extra-early hybrids include on-farm trials, farmers’ field days, farmers’ open days, and demonstration plots. Furthermore, the private seed companies and community-based seed producers of WCA are being supported by the Alliance for a Green Revolution in Africa (AGRA) and the DTMA project to produce large quantities of seeds of the new drought- and *Striga*-resistant extra-early hybrids for commercialisation and adoption by farmers of the sub-region.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support of the Alliance for a Green Revolution in Africa (AGRA), the Drought Tolerant Maize for Africa (DTMA) project, the IITA technical staff, and Mrs Rose Umelo for editorial assistance.

REFERENCES


AFRICAN INDIGENOUS LEAFY VEGETABLES AS A SOURCE OF $\beta$-CAROTENE FOR UNDER-FIVE-YEAR-OLD CHILDREN

A.A. Atero¹, A. Namutebi² and M. Kabahenda²
ABSTRACT

Iganga and Luuka districts have been identified as having the highest vitamin A deficiency levels in Uganda, despite being rich in plant biodiversity. A study was conducted to establish the levels of β-carotene in commonly consumed indigenous leafy vegetables in the area, and their adequacy to supply the vitamin A needs of children under the age of five. The findings of this study contributed to the achievement in Uganda of the Millennium Development Goal of reducing child mortality by cutting the number of deaths due to vitamin A deficiency. Four commonly consumed indigenous vegetables were selected from Makuutu and Ikumbya sub-counties in Iganga and Luuka Districts, respectively, to determine the levels of β-carotene using high-performance liquid chromatography (HPLC). They included Colocasia esculenta, Cleome gynandra, Cucurbita maxima and Amaranthus lividus. The β-carotene content of Colocasia esculenta and Cleome gynandra was on average 13.48 ± 3.30 and 14.25 ± 3.83 mg/100 g dry weight, respectively. These two vegetables exhibited higher amounts of β-carotene compared with the other vegetables analysed in this study. For the rest of the vegetables, β-carotene content levels ranged from 10.00 ± 1.40 to 12.07 ± 1.42 mg/100 g dry weight. Generally, leafy vegetables from Makuutu sub-county had a higher β-carotene concentration than those from Ikumbya sub-county. Makuutu sub-county, located closer to the lake, has richer soil than Ikumbya. In conclusion, the β-carotene content of the most consumed indigenous leafy vegetables in Iganga and Luuka districts is moderately high and can contribute to meeting the pro-vitamin A needs of a child under the age of five.

KEY WORDS: Cleome gynandra, Colocasia esculenta, Uganda, vitamin A deficiency

AFFILIATIONS

1 Uganda National Council for Science and Technology.
2 Makerere University, Uganda.
INTRODUCTION

The pro-vitamin A carotenoid content of many underutilised vegetable species used in Sub-Saharan Africa is comparatively higher than that of other well established vegetable crops such as spinach (Bioversity International, 2007). Nutrition plays a key role in alleviating food insecurity and ill health in developing countries (e.g. Mittal et al., 2007; Webner and Grune, 2012). For example, boosting the vitamin A intake of children would decrease overall child mortality rates by 25%, measles death rates by 50%, and death caused by diarrhea by 40% (FAO, 2004).

Malnutrition is one of Uganda’s biggest ‘silent emergencies’, killing thousands every year and sapping the long-term vitality of the nation. The most common malnutrition problems in Uganda are micronutrient deficiencies, especially of vitamin A and iron (FANTA, 2010). In 2005, UNICEF estimated that 29,000 children die every year in Uganda due to vitamin A deficiency (VAD), while it also estimated the percentage of children aged under six in Uganda with sub-clinical vitamin A deficiency to be 66,000 (UNICEF et al., 2005). If the deficiency remains unchecked, it will be responsible for 160,000 child deaths between 2006 and 2015 (FANTA, 2010). According to the Uganda Demographic and Health Survey (UDHS) report of 2006, 20% of children (6–59 months) in Uganda are categorised as having vitamin A deficiency (<0.835 µmol/litre of retinol-binding protein, RPB), levels that are always considered to have functional consequences in terms of morbidity and mortality. Children (6–59 months) in East Central Uganda have the highest VAD levels (32%) in the country, compared with a national figure of 20% (UBOS and Macro International Inc., 2006). Iganga and Luuka districts are located in East Central Uganda in the Lake Victoria Basin, which is characterised by rich plant biodiversity that includes indigenous leafy vegetables.

Given the above trend, and should it persist unchecked as seen in the two sampled districts of Luuka and Iganga, the country will have undermined its battle to achieve the Millennium Development Goal of reducing child mortality and promoting a healthy, strong and vibrant population. Vegetables are the most common and rich source of pro-vitamin A for the poor populations of the developing world (Rodriguez-Amaya, 1997), being easy to produce, fast-maturing, and available all year round. The objective of this study, therefore, was to establish the levels of β-carotene in commonly consumed indigenous leafy vegetables in the area and their adequacy to supply the vitamin A needs of children under the age of five.

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Local name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthus lividus</td>
<td>Operated single-handed</td>
</tr>
<tr>
<td>Cucurbita maxima</td>
<td>Amalibwa variety</td>
</tr>
<tr>
<td>Colocasia esculenta</td>
<td>Timpa (red and white variety)</td>
</tr>
<tr>
<td>Cleome gynandra</td>
<td>Eiyobyo</td>
</tr>
</tbody>
</table>
METHODOLOGY

The vegetables listed in Table 1 were selected and analysed for \( \beta \)-carotene.

The above indigenous leafy vegetables were collected from Ikumbya and Makuutu sub-counties in Luuka and Iganga districts, respectively. Stratified sampling was carried out by selecting homesteads where the vegetable samples were collected. Two strata were identified based on their distance from Lake Victoria: Makuutu sub-county is nearer Lake Victoria, while Ikumbya sub-county is further away. From each stratum, six homesteads were selected in a systematic sampling manner, that is, every third homestead in the Easterly road from the town. About 500 g of each leafy vegetable was collected from each homestead, bagged and labelled, and stored in a cool box.

In the laboratory at the department of Food Science and Technology, Makerere University, part of each sample was used immediately to determine the moisture content using the AOAC Methods (Cunniff, 1999). The remaining leafy vegetable samples were blanched for 2–3 min in steam. After blanching, the samples were immediately dipped in refrigerated chilled water (10°C) to prevent further thermal stress. The blanched samples were flushed with nitrogen then placed in opaque plastic containers with tight-fitting lids before being refrigerated. Prior to extraction, the samples were crushed into a powder using a mortar and pestle.

Extraction of sample

About 0.5 g of finely ground sample was weighed into conical flasks in duplicate. The sample was reconstituted with 5 ml distilled water and the flask was wrapped using aluminum foil, then placed in the refrigerator for about 5–10 min. In one of the duplicates, 1 ml of internal standard (trans-\( \beta \)-apo-8-carotenal) was added. Extraction was performed repeatedly by shaking for 5 min with equal amounts of acetone and methanol (acetone 20 ml and ethanol 20 ml) containing 0.01% w/v butylated hydroxytoluene until the residue was colourless. The extracts were decanted into a separator funnel containing 30 ml petroleum ether and 40 ml 25% w/v NaCl solution, while swirling the flask gently.

The lower layer was drawn off and repeatedly washed with 20 ml petroleum ether until the petroleum ether layer appeared colourless, after which it was discarded. The upper layer containing carotenoids and chlorophyll in petroleum ether was retained. The final volume was then noted. To the pooled extract, an equal volume of 30% methanolic potassium hydroxide was added and allowed to stand for 4 h at room temperature to remove the
chlorophyll. The carotenoid mixture was washed five times with distilled water (200 ml) to remove the alkali, then dried by passing it through anhydrous sodium sulphate (15 g). The extract was evaporated to dryness in a rotary vacuum evaporator at 35°C (maximum temperature). The residue was dissolved in 10 ml mobile phase solvent and filtered prior to injection.

The extracted sample was analysed for β-carotene using high-performance liquid chromatography (HPLC). The HPLC method was adopted from Mulokozi et al. (2004).

Statistical analysis
SPSS 12 for windows was used in analysis. Means were compared using the independent samples t-test at 5% level of significance. A one-way ANOVA analysis was carried out on HPLC data obtained between the sub-counties of Ikumbya and Makuutu.

RESULTS
The β-carotene concentration of five indigenous green leafy vegetables studied is shown in Table 2.

DISCUSSION
Generally, leafy vegetables from Makuutu sub-county had a higher β-carotene concentration than those from Ikumbya sub-county. The concentration of β-carotene in Colocasia esculenta and Cucurbita maxima from Makuutu sub-county was significantly higher at $P < 0.05$ than that in vegetables from Ikumbya sub-county. This could be explained by the fact that Makuutu sub-county, being nearer to the lake, has richer soil than Ikumbya.

The β-carotene in Colocasia esculenta and Cleome gynandra was on average 13.48 ± 3.30 and 14.25 ± 3.83 mg/100 g dry weight respectively. These two vegetables exhibited higher amounts of β-carotene compared with the other vegetables analysed. In other vegetables, β-carotene levels ranged from 10.00 ± 1.40 to 12.07 ± 1.42 mg/100 g dry weight. The findings of this study tally with what Marisiddaiah et al. (2007) discovered in the carotenoid composition and vitamin A activity of medicinally important leafy vegetables. They showed that β-carotene levels in leafy vegetables ranged from 3.85 to 43.82 mg/100 g. Beta carotene

<table>
<thead>
<tr>
<th>Leafy vegetable</th>
<th>Ikumbya sub-county</th>
<th>Makuutu sub-county</th>
<th>$P$ (Ikumbya vs. Makuutu)</th>
<th>Ikumbya and Makuutu (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthus dubius</td>
<td>12.46 ± 1.59</td>
<td>11.68 ± 1.25</td>
<td>0.848</td>
<td>12.07 ± 1.42</td>
</tr>
<tr>
<td>Colocasia esculenta</td>
<td>11.55 ± 3.50</td>
<td>12.82 ± 8.42</td>
<td>0.015</td>
<td>12.18 ± 5.96</td>
</tr>
<tr>
<td>(white variety)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colocasia esculenta</td>
<td>15.51 ± 1.62</td>
<td>14.46 ± 4.98</td>
<td>0.182</td>
<td>13.48 ± 3.30</td>
</tr>
<tr>
<td>(red variety)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucurbita maxima</td>
<td>8.08 ± 1.31</td>
<td>11.93 ± 1.48</td>
<td>0.022</td>
<td>10.00 ± 1.40</td>
</tr>
<tr>
<td>Cleome gynandra</td>
<td>13.59 ± 4.33</td>
<td>14.91 ± 3.33</td>
<td>0.244</td>
<td>14.25 ± 3.83</td>
</tr>
</tbody>
</table>
in *Cucurbita maxima* was reported to be 10.27 mg/100 g, similar to the present study result of 10.00 ± 1.40 mg/100 g dry weight. Micozzi et al. (1990) also found that beta carotene from fresh, green, leafy vegetables was moderately high and ranged from 0.5–14.6 mg/100 g. Kibiwot et al. (2011), in a study entitled ‘Compositional attributes of the leaves of some indigenous African leafy vegetables commonly consumed in Kenya’, found beta-carotene content in *Cleome gynandra* to be 8.73 mg/100 g. This figure is lower than the results of the current study, which are 13.48 ± 3.30 mg/100 g dry weight. According to Belanger et al. (2010), a number of factors influence the carotenoid concentration among species, including timing of collection, seasonality, climate, growing conditions, geographic location, varieties (genetic variation) and cultivars. This explains why there appear to be some variations in species and regions.

**CONCLUSION**

In general, the beta-carotene content of selected indigenous leafy vegetables in Iganga and Luuka districts was moderately high, and comparable with other studies conducted elsewhere. The beta-carotene content of the green leafy vegetables is adequate to meet the vitamin A needs of children aged under five. Further research should be carried out to determine the *in vitro* accessibility and intake of beta-carotene from these indigenous leafy vegetables.

**COMMUNICATION STRATEGY AND IMPACT**

I work for the National Council for Science and Technology of Uganda (UNCST), which is mandated by Government to develop policies and advise the Government of Uganda on issues pertaining to science and technology. This will give me a platform from which to widely distribute a policy brief which will be shared by policy-makers and be published on the UNCST website. This move will compel the relevant ministries to protect the biodiversity around Lake Victoria. There will also be an increase in the consumption of these indigenous green leafy vegetables once the public are educated as to their nutritional value. This would go a long way to increasing the cultivation of these vegetables and will in turn reduce infant mortality due to vitamin A deficiency in the region.

This information will be widely disseminated in print and electronic media. Talk shows will also be broadcast on television and radio stations.

**ACKNOWLEDGEMENTS**

I would like to thank the Lake Victoria Research Initiative (VicRes) for sponsoring this research. Many thanks also to my academic supervisor, Dr Agnes Namutebi, and Dr Margaret Kababhenda for her guidance. I would also like to acknowledge the Government Chemists Analytical Laboratory where I carried out the analysis.

**REFERENCES**


DEVELOPMENT AND PROMOTION OF SUSTAINABLE SOIL AND WATER CONSERVATION TECHNOLOGIES IN SEMI-ARID AREAS OF KENYA: THE CASE OF VEGETATIVE MACRO CONTOUR LINE

M.W. Baaru1 and C.K.K. Gachene2
ABSTRACT

Soil erosion is a major problem in semi-arid regions, often characterised by low and erratic rainfall and long dry periods. Increased cultivation in these fragile areas without effective conservation measures has worsened the situation, increasing the need to develop management practices that are productive and sustainable. The objective was to evaluate farmers’ perceptions of soil erosion and runoff and soil and water conservation technologies, and by incorporating their views, develop farmer-friendly soil and water conservation technologies that offer multiple benefits. This was carried out at Kathekakai Settlement Scheme, Machakos county, Kenya. Farmers’ perceptions were evaluated through focus group discussions and farmer interviews. To determine the effectiveness of the technology, a trial experiment was conducted using three treatments: terraced, vegetative, macro contour line with maize monocrop and terrace ditch; unterraced, vegetative, macro contour line with maize–dolicos intercrop; and terraced, vegetative, macro contour line with maize–dolicos intercrop and terrace ditch. Soil and plant samples were collected at three different slope positions – upper, middle and lower slope – on the terraced area. The percentage of soil moisture content was determined gravimetrically. Results indicated soil erosion as a major challenge, and that most farmers rely on advice from other farmers (65%) rather than experts (40%) to control runoff. Terraced treatments recorded higher soil moisture compared with unterraced treatments. Upper and lower slope positions gave significantly ($P \leq 0.05$) higher soil moisture compared with middle positions. Taller plants and higher biomass yield were observed at upper and lower slope positions compared with middle slope positions. Results indicate the effectiveness of terrace ditches to conserve soil moisture, leading to increased land productivity. Thus this technology should be considered when advising on and implementing land management practices.

KEY WORDS: EROSION, LAND PRODUCTIVITY, MOISTURE, MULTIPLE BENEFITS, TERRACE DITCH

AFFILIATIONS

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2 University of Nairobi, Nairobi, Kenya.
INTRODUCTION

Dwindling investments in the agriculture sector, a rising population and the vagaries of climate change and variability have contributed to a steady decline in agricultural productivity in recent years, threatening food security. The problem is more severe in arid and semi-arid areas, where population pressure has forced many farming communities to settle (Reynolds et al., 2007). Inappropriate farming activities in these fragile areas without effective conservation measures lead to land degradation, potentially affecting 2.5 billion people living in drylands worldwide (Reynolds et al., 2007). This threatens the achievement of the Millennium Development Goals (MDGs) (Mortimore, 2006), especially MDG1, eradicating extreme poverty and hunger, and MDG7, ensuring environmental sustainability. Despite this, many farmers remain unconvinced of the value of soil and water conservation measures.

In Kenya, a largely agricultural country, soil erosion was identified as a major environmental issue in 1935, and in 1940 the colonial government introduced the first soil and water conservation programme. However, implementation was based on forced communal labour, a move that made farmers resist the intervention, so that little happened until 1970, when the Kenyan government initiated national soil and water conservation campaigns under the National Soil Conservation Programme. Again, the approach disregarded farmers' knowledge and hence failed to achieve its objectives. Most farmers did not identify with the measures, indicating the importance of integrating both farmers’ views and scientific knowledge in developing sustainable soil and water conservation technologies.

The rationale of this study was to unlock the agricultural potential of arid and semi-arid lands by developing, in a participatory way, a soil and water conservation technology offering multiple benefits. Vegetative macro contour lines present benefits including high fodder quality, fuel wood, nitrogen fixation, improved soil fertility through litter fall, and reduced competition for resources, thus overcoming prevailing agricultural production challenges and addressing chronic poverty levels, food insecurity and environmental degradation.

MATERIALS AND METHODS

The study was undertaken at Kathekakai, Machakos county, Kenya, an area with average annual rainfall measuring between 400 and 700 mm. The site was selected by stakeholders from the Ministry of Agriculture, farmer representatives, the Kenya Agricultural Research Institute and the University of Nairobi, based on the fact that it is a new settlement and has not benefited from most agricultural activities implemented by the government. The area has witnessed land-use change from bush clearing and tree cutting, exposing land to soil and water erosion (Gathaara et al., 2010). Inappropriate, traditional cropping systems have worsened the situation, creating an urgent need for remedial action.

A sensitisation meeting with the stakeholders and community to present the purpose and objectives of the project was held in September 2009. Fifteen households from each of the five villages in the area were interviewed, giving a sample size of 75 individuals. Questionnaires were administered to elicit social capital and household income information. Focus group discussions were conducted to establish the cropping systems and soil and water conservation measures used. An experiment was set on four selected farms, each serving as a block. A terrace ditch, 100 cm wide and 60 cm deep, was laid with the assistance of Ministry of Agriculture staff, as described in the Soil and Water Conservation Manual for Kenya (Thomas, 1997). After careful consideration, farmers settled for the trial depicted in Figure 1. Crops planted along the terrace were either a maize monocrop or maize and dolicos (Lablab purpureus) intercrop.
The experiment involved three treatments: terraced, vegetative, macro contour line with maize monocrop and terrace ditch (TVMD); unterraced, vegetative, macro contour line with maize–dolicos intercrop (UVMD); and terraced vegetative macro contour line with maize–dolicos intercrop and terrace ditch (TVMDD). The three treatments were arranged in a randomised complete block design, giving a replica of four for each treatment. Agronomic practices were carried out according to the local conditions. Soil samples were collected at 0–30 cm depth, at critical stages of crop growth and when the crop was exhibiting water stress. Plant height was measured at tasseling stage by taking an average of five randomly selected maize plants. Crop biomass was harvested at maturity stage from an area of 3 × 3 m in each plot and oven-dried to constant weight. All samples were collected at three slope positions on the terraced area, i.e. upper, middle and lower slope positions (Figure 1). Field soil moisture was measured using the gravimetric method. Moisture content was calculated using the following formula:

\[
\text{percentage moisture content} = \frac{(\text{sample wet weight} - \text{sample dry weight}) \times 100}{\text{sample dry weight}}
\]

Data were analysed using Genstat Discovery Edition 3. An analysis of variance (ANOVA) was conducted and means tested at 5% least significant difference (LSD).

RESULTS

Status of soil erosion and soil and water conservation measures

Results indicate that most households are male-headed (76%) and male-owned (71%), and this poses a considerable threat to the adoption of technologies, considering most respondents were women (64%), as they may have to consult with and obtain the consent of their spouse before adopting any technology. Agriculture (92%) was identified as the main source of household income and consumption, and soil erosion as a serious issue (86%), which explains why most farmers (75%) said they use soil and water conservation measures. However, the majority of farmers (62%) said that they received information on soil and water conservation measures from other farmers. One drawback with farmer-laid terraces is that they could not control heavy floods (Plate 1) and proved expensive to maintain, as they needed repair after rainfall.
In addition, the terraces were found to intersect with those laid by experts, signifying they were not well laid out (Plate 2).

**Treatment effect on soil moisture and crop performance**

Generally, terraced (TVMDD and TVMD) treatments gave higher moisture than unterraced (UVMD) treatments (Figure 2). The TVMDD and TVMD recorded significantly higher soil moisture than UVMD. The TVMDD gave higher soil moisture content than TVMD, although it was not significantly different. Upper and lower slope positions gave higher soil moisture content compared with middle positions. At upper slope positions, terraced treatments had higher soil moisture than unterraced treatments, and were significantly higher in TVMDD (16%) than UVMD (11%). No definite trend was observed at middle slope positions.

At lower slope positions, TVMDD (17%) and TVMD (16%) recorded significantly higher soil moisture than UVMD (11%). The TVMDD (18%) treatment also recorded significantly higher soil moisture than TVMD (13%) at the same slope position. In terms of crop performance, taller plants were observed in terraced treatments compared with unterraced treatments, and also at upper and lower positions compared with middle slope positions, though no significant differences were observed (Figure 3A). The TVMDD treatment had plants taller by 60% than those in UVMD. The trend was similar for biomass, where higher biomass yield was observed in terraced treatments, upper and lower slope positions, than in unterraced and middle slope positions, respectively, though results were not significantly different (Figure 3B). Further, TVMDD and TVMD gave 9% and 2% higher biomass yield, respectively, compared with UVMD.

**DISCUSSION**

Farmer–farmer extension was identified as a powerful tool in extension services, suggesting that training farmers as trainers is an appropriate way in which to boost technology adoption. Exchange of ideas among farmers has been found to occur more frequently and efficiently among those familiar and similar to one another (Murphy, 1993), and hence farmer field schools (FFS) have become crucial in extension services. The FFS encourage peer learning, and by so doing develop farmer expertise that enables them to make sound land management decisions. A study by Dinpanah et al. (2010)
reported that 63.9% of farmers who participated in FFS adopted the technology, compared with only 13.3% who had not participated in FFS adopting the technology.

Higher soil moisture in terraced compared with unterraced treatments indicates that the technology conserved soil moisture. Water that could have been lost through runoff was captured and stored in the terrace ditch (Plate 3). The water infiltrated through lateral seepage to the bench, explaining higher soil moisture. Again, a bench embankment acted as a barrier to water flow, allowing water infiltration. This could be associated with reduced soil and water flow along the bench terrace, allowing more time for water to infiltrate into the soil. The high soil moisture content observed in upper and lower slope positions explains the taller plants and higher biomass yield at these positions. However, lower soil moisture recorded at lower slope positions could be attributed to soil disturbance during ditch

**FIGURE 2: SOIL MOISTURE CONTENT ACROSS TREATMENTS (VALUES FOLLOWED BY DIFFERENT LETTERS DIFFER SIGNIFICANTLY AT P ≤ 0.05)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Average soil moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/12/2009</td>
<td>16 b</td>
</tr>
<tr>
<td>9/2/2010</td>
<td>14 a</td>
</tr>
<tr>
<td>11/3/2010</td>
<td>12 ab</td>
</tr>
<tr>
<td>15/4/2010</td>
<td>10 a</td>
</tr>
<tr>
<td>3/6/2010</td>
<td>8 ab</td>
</tr>
<tr>
<td>5/8/2010</td>
<td>6 a</td>
</tr>
</tbody>
</table>

**Legend:**
- TVMDD: terrace vegetative macro contour line, maize, dolicos, ditch
- UVMD: unterrace vegetative macro contour line, maize, dolicos
- TVMD: terrace vegetative macro contour line, maize, ditch
Figure 3: (A) Average Crop Height and (B) Biomass Yield Across Treatments

TVMDD: terrace vegetative macro contour line, maize, dolicos, ditch
UVMD: unterrace vegetative macro contour line, maize, dolicos
TVMD: terrace vegetative macro contour line, maize, ditch

2009-Short rains
2010-Long rains
establishment. Soil dug from the terrace ditch formed a bench embankment, and being sub-soil, was low in soil organic matter and soil nutrients. This could also explain lower crop height and biomass yield at upper slope positions (Plate 4) compared to lower slope positions (Plate 5).

Lower soil moisture in TVMD than in TVMDD can be associated with cropping system differences. While TVMDD had a maize–dolicos intercrop, TVMD was a maize monocrop treatment. The TVMDD also had minimum soil disturbance, as dolicos was in the field for more than one season. Dolicos serves as a cover crop, reducing evaporation and increasing infiltration rate.

CONCLUSION

The following conclusions can be drawn. Firstly, soil erosion is rampant and there is a need to create awareness of soil erosion and conservation measures. Secondly, continued government intervention is critical to curb the transfer of inappropriate information from farmer to farmer. Efforts to privatise extension services pose a great threat to poor farmers who may not be able to afford these, and opt to rely on fellow farmers. Thirdly, the vegetative macro contour line is a promising innovation for resource-poor farmers, who lack the capacity to invest in expensive irrigation systems. The terrace ditch proved effective in water harvesting, leading to increased land productivity, and consequently enhancing food security and rural livelihoods and contributing to achieving MDG1. When established, trees will serve as a source of fuel wood, timber, fodder and income after sale; they also improve microclimate and soil nutrients, ensuring environmental sustainability and contributing to achieving MDG7. Promoting and upscaling the technology has the potential to enhance rural livelihoods, and therefore the need to advance this venture cannot be over-emphasised. However, more research is needed to ascertain appropriate technology design in terms of terrace ditch depth and cropping systems for optimum water conservation and water-use efficiency.

COMMUNICATION STRATEGY AND IMPACT

The findings have been communicated at different levels in various ways. At international level, one journal paper is under review and two others are in draft form; regionally, a presentation was delivered during the 2013 African Crop Science Conference in Maputo, Mozambique. At national level, a PhD thesis is available at the University of Nairobi, a
presentation was also made during the National Council of Science and Technology annual conference in Nairobi, Kenya, and a workshop for Ministry of Agriculture staff was conducted to enable them to carry on the initiative.

To deliver at local level, farmer field days, training and on-farm demonstrations have been conducted. The technology has increased demand for tree seedlings, and farmers are considering starting tree nurseries to meet demand. Kenya Forest Research Institute is on the ground to advise farmers on suitable trees for the area. Farmers now understand better the importance of well laid-out terraces, and this has increased demand for soil and water conservation experts, which is a challenge to the shrinking extension service. To resolve this, and as an exit strategy, the project trained 45 farmers from 15 groups (three representatives per group) on how to lay terraces (Plate 6) and donated a soil and water conservation laying kit to each group, with the Ministry of Agriculture as overseer (Plate 7). Many farmers have adopted the technology, and many more have shown interest. With the assistance of the Ministry of Agriculture, group representatives will first lay terraces on group members’ farms before moving to non-members. The activity is expected to have a multiplier effect with visible impact if all members, totalling 360 from 15 groups, have their farms laid out.

ACKNOWLEDGEMENTS

We wish to thank the Regional University Forum (RUFORUM), the National Council of Science and Technology (NCST) and the University of Nairobi for making this study possible through financial, logistic and moral support.

REFERENCES


PLATE 6 (LEFT): FARMERS BEING TRAINED IN LAYING TERRACES; PLATE 7 (RIGHT): GROUP REPRESENTATIVES RECEIVING LAY-OUT KIT


FOOD SECURITY IN AFRICA: AN INNOVATIVE COWPEA STORAGE TECHNIQUE

C.B. Dabiré¹, A. Sanon², M. Ba¹, C. Yelemou³ and D. Baributsa⁴
ABSTRACT

Cowpeas (*Vigna unguiculata* L. Walp.) are a staple food product for West Africans. Those working in the sector used to make constant reference to how hard it was to store seeds, which, in turn, jeopardised food security. Achieving a pest-free cowpea storage system was therefore a key concern in the bid to boost producers’ incomes, enhance food security, and reduce public health risks associated with the overuse of pesticides. The triple bagging technology was developed through laboratory tests and then widely disseminated in record time. It was shown that when cowpea seeds are wrapped in two 80-µm-thick bags, weevils can no longer propagate. Rolled out in pilot villages and extended nationwide, the outreach strategy managed to cover 4,217 villages within the space of three years. A functional bag supply chain involving manufacturers, distributors and sellers helped to bring the technologies closer to the producers. These activities succeeded in resolving three key problems hindering attempts to achieve a pest-free storage system: (1) enjoying the availability of and access to good storage equipment; (2) safe usage; and (3) a reduction in the level of post-harvest losses. The bagging technology take-up rate two years after the initiative was launched was 30%, with the female participation rate being over 40%. This led to increased cowpea availability, higher incomes for women, and the cowpea crop being included in the government National Food Security Consolidation Programme.

KEY WORDS: OUTREACH, PEST FREE, POSTHARVEST LOSSES, TRIPLE BAGGING, WEEVILS

AFFILIATIONS

1 Environment and Agricultural Research Institute (INERA), Burkina Faso.
2 Ouagadougou University, Burkina Faso.
3 Provincial Department of Agriculture, Sourou, Burkina Faso.
4 Purdue University, USA.
INTRODUCTION

Tailored to ecologically sensitive areas and native to Western Africa, which accounts for 70% of the world’s estimated production of 3.7 million tonnes, Vigna unguiculata L. Walp. is a staple foodstuff, widely eaten in Africa (Langyintuo et al., 2003). Grown throughout Burkina Faso, the cowpea’s properties as a source of food, fertiliser and fodder are highly prized by local communities. It is also the main cash crop for small-scale producers outside cotton-growing areas. However, because the seeds are difficult to store, the scope for growing and marketing the crop on a wider scale is severely limited (Statistika, 2002).

The sharp decrease in the commercial value of the seeds is attributed to their susceptibility to weevil damage during storage, with stocks being destroyed within a few months of storage, jeopardising the food security of rural communities. This means that farmers have to sell their crops just after harvest, at very little profit. The toxic insecticides used for a long time to protect foodstuffs held in stock, or their misuse, created health problems for the producers and traders, who were often illiterate and so unable to read the instructions. This is why it was vital to develop an efficient and straightforward technology, followed up by a distribution system to reach the greatest number of cowpea sector stakeholders.

A major achievement is the outcome of an action research project carried out by the Environment and Agricultural Research Institute (INERA) in Burkina Faso, in cooperation with Purdue University, Indiana, in the United States. The initiative provided a means of: (1) developing technology involving triple bagging or triple layer bags, or PICS (Purdue improved cowpea storage) bags, for the storage of cowpea seeds without using insecticides; (2) ensuring the faster dissemination of the technology on a wider scale; and (3) making it easier to roll out a sustainable bag and distribution system.

The overall aim was to enhance food security and nutritional security by boosting national cowpea production and increasing the incomes of small-time producers from sales of production surpluses and supporting sub-regional trade.

METHODOLOGY

Laboratory experiments

This involved comparing six plastic thicknesses: 25, 50, 60, 80, 90 and 100 µm, in single or double layers, in relation to the survival of adults and the multiplication of Callosobruchus maculatus F., the cowpea seed pest. The plastic sheets were cut to uniform sizes of 192 x 165 mm, designed to contain 700 g batches of cowpea seeds. Each batch of seeds was infested through all the weevil development stages, with a total of 130 weevils being introduced per bag to produce an initial infestation rate of 5% (Ouédraogo et al., 1996). Each bag was resealed using a sealing machine and placed inside a mosquito-netting bag to contain the weevils perforating the bag. This process was repeated four times for each type of layer. After 7 months, calculations were made of the total number of weevils (dead or alive), seeds perforated in a sample of 100 seeds selected at random, the number of holes in the plastic bag, and the weight of seeds in each batch.

Technological dissemination

An experiment was undertaken with the Purdue team, in 100 pilot villages, during the first year (2007) to validate the technology, the widespread dissemination approach, and the impact of radio broadcasts. The dissemination process focused on 4,000 villages from 2008 to 2009. The level of infestation and cowpea prices were assessed at the start and the end of the storage operation in order to gauge just how efficient the triple-layer bags were in field conditions, as well as their cost-effectiveness.
In each village, five volunteers (three men and two women) were selected as pilot producers. A producer was selected primarily on the basis of their ability to store a minimum of 50 kg, for at least 4 months. Three key stages set the context for the village activities: (1) awareness-raising/demonstration; (2) follow-up; and (3) opening ceremony.

The media

The media helped to raise awareness of stakeholders in the cowpea sector and of the political authorities. With a view to facilitating the media coverage, contracts were concluded in each province with private or community radio stations, and with nationwide radio and television stations. All the demonstration sessions were preceded by press releases to the media with the biggest audiences in the dissemination area. Articles and posters about triple bagging and the contact details for the bag sellers were carried in the press.

Contractual outreach organisations

Primarily accountable to the departments of the Ministry of Agricultural and Water Management (MAH), ensuring wide geographical coverage for the country and non-governmental organisations, these outreach entities were: Africare, Catholic Relief Service, Organisation Catholique pour le Développement et la Solidarité (Catholic Development and Solidarity Organization – OCADES), the Song Koadba Association, the Conseil Régional des Unions du Sahel (Regional Council of Unions in the Sahel – CRUS) and the coordination of women’s agencies in Sourou province.

Capacity-building for partners

Several nationwide training sessions for technicians and female outreach workers were held in the countdown to the launch of the large-scale outreach process for the awareness-raising/demonstration, follow-up and bag opening sessions. Exhibitions were also staged in public places, during agricultural trade fairs, the National Scientific Research and Technological Innovations Forum (FRSIT) and National Farmers’ Days, and with the head of state. Both regional and provincial directorates were responsible for ensuring the activities were brought to a successful conclusion within the context of the monitoring system. Within INERA, this oversight was applied to the routine inspections of storage sites and the advice dispensed thanks to the efforts of the researchers covering several regions, while each technician was responsible for five provinces. These supervisors were tasked with collecting data sheets, concluding contracts with the most popular community radio stations, and ensuring the bags were properly distributed.

RESULTS

Technological development

When the seeds were wrapped in two layers of plastic between 80 and 100 µm thick, the weevil count and level of seed damage was much less relative to the lower oxygen rate (Figure 1) (Sanon et al., 2011). The exterior plastic is never perforated.

Impact of technological dissemination

Extensive nationwide coverage was achieved. Twelve out of 13 regions and 34 out of 45 provinces of Burkina Faso have been educated in the triple bagging technology process (Dabiré et al., 2008). At least 426 technicians were involved in implementing the schemes in over 4,217 villages. Over 21,217 households, including at least 8,434 women, were involved in assessing how the technology performed in the rural environment. An optimum storage life for the seeds due to the use of triple bagging was confirmed in all the villages. Low weevil counts continued to be reported at the end of the storage period. Triple bagging did not affect the germination capacity of the seeds.
The media
Press releases, advertising spots, reports on national television and radio, together with 24 community radio stations and 12 end-of-storage bag opening ceremonies, helped to drive the message home to those involved in the value chain that the bags could be relied on for efficiency. Nine articles were published in widely read newspapers in the area, including the online review of the African Union (Dabiré and Sanon, 2009). 4,500 PICS posters in French and in the national languages were distributed to users and also included as inserts in newspapers enjoying a wide circulation.

Take-up of the technology and trading activities
Positively affected by the outreach programmes, the take-up rate was estimated to be 30% in Burkina Faso in the third dissemination year, the highest rate in West Africa (Moussa et al., 2010). Producers and traders built up stocks of cowpeas with the PICS bags during the harvesting season to sell them 4 to 5 months later. The technology also created business and trading opportunities for the private sector, owing to the bag manufacturing and marketing activities, while creating jobs in Burkina Faso. It involved the manufacturing plants, those selling farm inputs, and itinerant traders during the weekly market in the countryside and at cowpea fairs. The plastic-manufacturing factor, Fasoplast produced at least 500,000 PICS bags for delivery both inside and outside Burkina Faso (Senegal, Mali and Niger).

Impact on national cowpea production
As a result of the success in resolving the storage problem, the national level of cowpea production rose from 241,113 T in 2007 to 626,113 T in 2010 (DPSAA, 2011). In Sourou, the focus of an intensive triple bagging campaign, the output rose sixfold, from 7,045 T in 2007 to 44,806 T in 2010.

FIGURE 1: OXYGEN RATES DEPENDING ON WHETHER THE BAG IS SINGLE-PIECE OR LINED

![Diagram showing oxygen rates depending on whether the bag is single-piece or lined.](image-url)
Impact on national agricultural policy

The technology take-up reaped enormous rewards. The unit selling price for cowpeas doubled at the end of 6 months, thereby boosting the incomes of small-time producers and processors. The take-up helped to improve the living conditions of the producers. Female producers were the focus of particular attention as they were the key players in cowpea seed storage. The project’s anticipated participation rate of over 40% was achieved due to the input of the female outreach workers, who provided specific training.

The technology dissemination process embarked upon in 2007 with women in Komki Ipala (Centre region village) and Sourou province received such an enthusiastic response from women living in rural areas that they made preparations to develop activities involving seed production, cowpea fairs, and competitions focused on triple-bagging storage and the culinary arts (Baributsa et al., 2013). These tangible achievements led to the Burkina Faso government’s decision to (1) lend support to 1,000 women, in each of the 45 provinces, for cowpea production in 2011; and (2) step up our efforts to promote this technology by supplying female producers with 35,000 bags in 2011 and 170,000 in 2012. Cowpeas have also been factored into the National Food Security Consolidation Programme currently being prepared. The government assigned rice, cowpeas and maize the status of priority crops within the context of this programme.

DISCUSSION

The many factors that made such a success of the triple bagging technology take-up in Burkina Faso include the efficiency of the technology, and the development of an effective and large-scale outreach strategy with the right partners. The bag supply chain that was created made it easier for users to gain access to the bags. The cost-
effectiveness of the technology, coupled with the determination of the people involved in the research and outreach activities, along with the producers, to tackle the crucial storage challenges, contributed to the project’s resounding success. On the economic front, the upturn in national production coincided with a waning concern about cowpea losses.

Apart from the increased benefits achieved with the use of the bags and the reduction in postharvest losses, mention should also be made of the combined effects on the value chain: higher sales, higher incomes and better quality cowpeas being stored, products obtained from processing, and fewer cases of poisoning. Pest-free cowpeas are now available to feed families and supply food stores and canteens.

Using its extensive support network and employee training programmes in agricultural colleges, the Ministry of Agricultural and Water Management was able to achieve more than the NGOs and other producer organisations. There were some regrettable delays in signing the cooperation protocols. The main lesson drawn from the partnership experience was that the supervision and control activities offered a clear understanding of the situation to ensure the success of the dissemination process, irrespective of whether the tasks were assigned to NGOs or agricultural staff. It was also shown that women represent a key link in the chain to be taken into account when disseminating new technologies.

**CONCLUSION**

Against this background, it is evident that the development of the triple bagging system and the dissemination schemes have played a key role in (1) improving the storage of the cowpeas produced, thus increasing availability and contributing to boosting food and nutritional security, while enhancing the value-adding opportunities; (2) increasing the incomes of the population; and (3) boosting national production. The success is attributable to the project being able to bring on board partners and ensure efficient coordination of the research and outreach activities. Experiments are being conducted in the laboratory and in farming areas in order to tailor the technology to other economically important crops in Burkina Faso, such as maize, sesame and Hibiscus sp. seeds. The issue of reusing bags, and of processing them to minimise the environmental damage these quantities of plastic can cause in the wild, is also being investigated.

**COMMUNICATION AND IMPACT STRATEGY**

The communication strategy adopted has played a key role in the successful dissemination of our research findings. Accordingly, the information about triple bagging circulated within the agricultural structures and the MAH was instrumental in promoting the triple bagging system. The design and distribution of the technical data sheets, and the rigid user-friendly A4 format posters in French and the national languages, Mooré and Jula, were enormously helpful in disseminating the technology to educated people. Every single meeting and training opportunity was seized upon to distribute the posters.

Attendance during agricultural trade fairs and the National Farmers’ Day (Figure 3) ensured that the technology was widely disseminated throughout all sections of the population. Finally, one of the key components of the activities for promoting triple bagging was the phasing in of the bag opening ceremonies, which enjoyed wide media coverage and were presided over by the administrative authorities: the Minister for National Ceremonies, the Governor of the region, the provincial High Commissioner, and the Prefect in the case of the village. The ceremonies were held in markets and other public places. As they are close at hand, the
community radio stations turned out to be more effective than the national stations in facilitating the technology take-up (Moussa et al., 2011).

ACKNOWLEDGEMENTS

We would like to thank our partners from Purdue University (USA), the Ministry of Agriculture and Water Management, the coordination of women’s agencies in Sourou province, the head of the INERA, the current Minister for Scientific Research and Innovation, who spared no effort to support the technology dissemination process, and the Bill & Melinda Gates Foundation.

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IMPACT OF CAPACITY-BUILDING ON THE QUALITY OF MILK AND MILK PRODUCTS IN WOLAYTA, SOUTH ETHIOPIA

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ABSTRACT

In rural areas of Wolayta District in Ethiopia, traditional milk production and handling techniques are generally poor, resulting in low-quality milk. Good hygiene practices are key to obtaining high-quality milk products with a longer shelf life. A study was therefore conducted to evaluate the impact of capacity-building for smallholder milk producers on good hygiene practices. Thirty women were selected and trained on hygiene practices associated with milk production and handling. They were also given milk-handling equipment such as aluminium cans. Milk samples handled by the selected women were taken pre- and post-training. Training had a positive impact on hygienic milk production. Udder washing improved by 32%, and 53% of the women used separate towels to dry the udder. The training resulted in 60% of the women dipping the teats into a salt solution after milking. Cleaning milk cans and vessels using hot water was improved by 63.6%. The average shelf life of milk, buttermilk and cottage cheese (1.27, 1.36 and 5.73 days, respectively) was enhanced by 2.17, 2.57 and 7.17 days, respectively. The mean scores of the milk taste, aroma and appearance improved by 29.8, 27.7 and 23.9%, respectively. The mean total bacterial and coliform loads of milk were reduced significantly by 13.8 and 31.8%. The percentages of total solid, solid not fat, fat, protein, lactose and ash contents of the milk produced in the study area were 13.8, 8.95, 5.35, 3.24, 4.53 and 0.71, respectively. Empowering the target group through training and improving handling of milk and milk products increased the quality and thus the marketability of milk and milk products in the study area.

KEY WORDS: EMPOWERING, HYGIENE, SHELF LIFE, SMALLHOLDER, WOMEN

AFFILIATIONS

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INTRODUCTION

Milk secreted from a healthy cow’s udder is germ-free (O’Connor, 1994), and contamination occurs during and after milking. Dirty udders, equipment, uncleanliness of the milker, the water being used on the farm, and the general sanitation are the most important sources of milk contamination (Giffel, 2003). The components of milk and its properties provide a very favourable environment for the multiplication of microbes, which are the common contaminants (O’Connor, 1994). Their rapid growth, particularly at high ambient temperatures, can result in a short shelf life and deterioration of milk for consumption or processing. This can be avoided by adopting the simple, basic rules of clean milk production (Lore et al., 2006).

The first step to achieving high-quality milk products with a longer shelf life is to ensure that the production and handling conditions are hygienic, which will result in fewer spoilage organisms in the products (Yilma and Faye, 2006). In Ethiopia, various factors combine to compromise the hygienic quality of milk products: unhygienic production, handling, processing and marketing, absence of a cooling system, prolonged transport time, and the ineffectiveness of quality control structures (Lore et al., 2006). In order to ensure the quality and safety of milk and milk products, the various stages in the milk value chain from production to consumption have to be under strict hygienic control.

In Wolayta, much of the dairy farming is undertaken by women (Mekonnen, 2006). The impact of female-targeted training on dairy practices has been overlooked. In this area, milk production techniques are traditional, and innovative methods are limited. To improve the handling of milk and milk products, it was necessary to re-examine the existing practices in the value chain. Therefore the aims of this study were to evaluate the traditional and improved milk and milk product handling practices adopted by smallholder farmers, and to evaluate the quality of milk and milk products from traditional practice and compare it with improved practices adopted through training for further technological intervention.

MATERIAL AND METHODS

The study was conducted in three villages of Wolayta District, South Ethiopia. Thirty volunteer women farmers who own at least one milking cow were purposively selected and given training on hygienic milking, processing and handling of milk products according to Lore et al. (2006). They were also supplied with aluminium cans for milking and handling. They were closely monitored on handling practices before and after receiving the training. Data were collected from each household regarding the traditional and improved practices of milk handling and processing. Accordingly, the collected samples were evaluated for quality properties, so as to evaluate the impact of the training on the quality of milk and milk products. Comparisons were later made among those farmers before and after the training, regarding milking practices, the hygienic handling of milk cans, as well as milk quality and shelf life.

Triplicate raw milk samples were aseptically taken for microbial and chemical analysis and organoleptic tests. Organoleptic tests were conducted on-farm. The other two samples were kept in an icebox and transported to Hawassa University dairy laboratory for microbial and chemical analyses.

Sample analysis

Microbiological tests

A total bacteria and coliform count was taken after plating 0.1 ml of milk sample from appropriate dilutions on plate count agar and violet red bile lactose agar, respectively. The plates were then incubated at 32°C for 24 h and 35°C for 48 h (Richardson, 1985).
**Chemical tests**

Titratable acidity was determined using the percentage lactic acid method (O’Mahony, 1988). Protein, fat, solids-not-fat content and the specific gravity of the milk samples at 20°C were determined using a milk composition analyser (LactiCheck). Total solid and ash were determined using the standard procedure (O’Connor, 1994). Lactose content was calculated by deducting the protein, fat and ash contents of the milk from the total solid.

**Organoleptic tests**

Five women were trained in scoring methods and tasked with judging the appearance, taste and aroma of the milk samples. The parameters were evaluated on a scale of 1–5 (Hedonic scale), where 5 was the best and 1 the worst score.

**Data analysis**

The data collected during the monitoring work were summarised using descriptive statistics. Chemical, microbial and sensory score data for the milk produced before and after the training were analysed using one between-subject and one within-subject factor repeated measure ANOVA model (SPSS, 2004). Mean comparison by Tukey’s test was performed for variables whose F value was statistically significant at 5% significance level. Microbial counts were log transformed prior to statistical analysis. The model used for the statistical test was: 

\[ Y_{ijk} = m + (training)_i + (village)_j + (training*village)_{ij} + e_{ijk} \]

where, \( Y_{ijk} \) = individual observations for quality of milk, \( m \) = overall mean, \( training_i \) = \( i^{th} \) training effect, \( village_j \) = \( j^{th} \) village effect, \( training*village_{ij} \) = \( ij^{th} \) training*village interaction effect and \( e_{ijk} \) = random error term.

**RESULTS**

**Milking and milk-handling practices**

A higher proportion of women adopted hygienic milking practices after receiving training than prior to the training (Table 1). Udder washing was adopted by 30% of the women. Similarly, most of the women began to use individual udder towels (53.3%). In particular, the practice of dipping teats in a salt

| TABLE 1: HYGIENIC PRACTICES DURING MILKING BEFORE AND AFTER PROVISION OF TRAINING IN THE STUDY AREA (N = 30) |
|---------------------------------------------------------------|---------------|---------------|
| Milking procedure                                            | Before training | After training |
| Udder wash                                                   | 63.3           | 93.3          |
| Dry the udder using                                          |                |               |
| individual towel                                            | 23.3           | 53.3          |
| hand                                                         | 40             | 36.7          |
| any cloth                                                    | 3.3            | 10            |
| Clean body of milking cows                                   | 46.7           | 76.7          |
| Using dusty bedding material                                 | 53.3           | 36.7          |
| Using salt solution as teat dip                              | 0              | 60            |
| Using hot water for cleaning                                 | 26.7           | 80            |
solution after milking had become customary in most households (60%) after the training, whereas none of the households was aware of the benefits of this practice prior to the training.

After receiving the training, 80% of the respondents were found to use hot water for washing milk vessels, whereas traditionally only a few of the women were accustomed to using hot water (26.7%) for washing milk vessels (Table 1).

Fermentation

The traditional milk-processing system in Wolayta was based on fermented milk. A small amount of fresh whole milk was added to the previously fermented milk each time until sufficient was obtained for churning. Fermentation occurred spontaneously when the milk was kept at a high ambient temperature, whereas after the training women began to use a starter culture, which was made on the farm. Evidently, the fermentation time using the starter culture was relatively short. However, women preferred to use the starter culture during the rainy season, when the ambient temperature is low (Table 2).

Milk products preservation and shelf life

In Wolayta, women kept milk and buttermilk in a clean and smoked vessel with the plant additives. The respective average shelf life of milk, buttermilk and cottage cheese in Wolayta was 1.27, 1.36 and 5.73 days under traditional systems of preservation customarily practised in the area. After training and employing hygienic handling with additives, the average shelf life of fresh milk, buttermilk and cottage cheese improved to 2.17, 2.57 and 7.17 days, respectively, at an ambient temperature considerably longer than under the traditional practices used before the training (Table 2).

Organoleptic tests of raw milk

The mean scores given to the taste, aroma and appearance of raw milk produced after the training were 4.03, 3.97 and 4.02, respectively. These values were significantly ($P < 0.05$) higher than those of the corresponding mean scores of 2.83, 2.87 and 3.06 given to whole milk before the training (Table 3).

| Table 2: Average Shelf Lives of Fresh Milk, Buttermilk and Cottage Type Cheese and Fermentation Time Evaluated Under Traditional and Improved Practices in Wolayta, Ethiopia |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Milk products                                   | Traditional practices                           | Improved practices                              |
|                                                 | (before training $N = 30$)                       | (after training $N = 30$)                        |
|                                                 | Mean ± SE                                       | Mean ± SE                                       |
| Fresh milk (days)                               | 1.27 ± 0.08                                     | 2.17 ± 0.13                                     |
| Buttermilk (days)                               | 1.36 ± 0.12                                     | 2.57 ± 0.19                                     |
| Cottage cheese (days)                           | 5.73 ± 0.34                                     | 7.17 ± 0.45                                     |
| Fermentation time (days)                        | 1.43 a ± 0.10                                   | 0.96 b ± 0.01                                   |

Note: row means designated by different superscript letters are significantly different from each other at $P < 0.05$, SE = standard error, $N =$ number of respondents.
Error bars are 95% CI values; non-overlapping error bars indicate the presence of significant differences between the corresponding means.

**Microbial count in raw milk**

The mean total microbial load of whole milk produced after the training on improved practice (6.47 log CFU (colony-forming unit)/ml) was significantly lower ($P < 0.05$) than that of milk produced using the traditional method (7.51 log CFU/ml). Similarly, the average values of CFU/ml of milk were 4.03 and 2.75 (Figure 1) for milk produced under traditional and improved practices, respectively, and the difference was also significant.

**TABLE 3: SENSORY SCORES, pH AND ACIDITY (% LACTIC ACID) OF MILK BEFORE AND AFTER PROVISION OF TRAINING IN WOLAYTA, ETHIOPIA**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Score Before training (mean ± SE)</th>
<th>Score After training (mean ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>3.07 b ± 0.17</td>
<td>4.02 a ± 0.11</td>
</tr>
<tr>
<td>Aroma</td>
<td>2.87 b ± 0.20</td>
<td>3.97 a ± 0.12</td>
</tr>
<tr>
<td>Taste</td>
<td>2.83 b ± 0.19</td>
<td>4.03 a ± 0.11</td>
</tr>
<tr>
<td>pH</td>
<td>6.50 b ± 0.03</td>
<td>6.60 a ± 0.02</td>
</tr>
<tr>
<td>Acidity (% lactic acid)</td>
<td>0.22b ± 0.011</td>
<td>0.18 a ± 0.004</td>
</tr>
</tbody>
</table>

Note: row means for each parameter designated by different superscript letters are significantly different from each other at $P < 0.05$. 

**FIGURE 1: MEAN TOTAL PLATE COUNT AND COLIFORM COUNT (LOG CFU/ML) OF WHOLE MILK BEFORE AND AFTER THE TRAINING IN WOLAYTA, ETHIOPIA (N=30)**

![Graph showing mean total plate count and coliform count (log CFU/ml) of whole milk before and after the training in Wolayta, Ethiopia (N=30).](image-url)
Acidity and pH of raw milk
The mean titratable acidities of raw milk from traditional and improved practices were 0.22 and 0.18%, respectively, and those of the corresponding pH values were 6.50 and 6.6 (Table 3). The mean values from traditional practices were significantly different ($P < 0.05$) from those of improved practices.

Gross composition of raw milk
The overall mean percentage total solids, solid-not-fat, milk fat, protein, lactose and ash contents of whole milk were 13.8, 8.95, 5.35, 3.24, 4.53 and 0.71, respectively. The gross composition of milk did not differ before and after the training ($P > 0.05$).

**DISCUSSION**
Training had a positive impact on the hygienic handling of milk and milk products. Dipping the teats in a salt solution after milking significantly reduced the entry through teat openings of microbes that could make the animal susceptible to infection (Phillips, 2000). Using hot water to clean milk cans helped to remove fat that could collect in the rough surface and would facilitate the multiplication of biofilm organisms, as traditional milking equipment is reported to be often porous and therefore a reservoir for many organisms and difficult to clean (O’Connor, 1994). Biofilms present on the surface of milk equipment threaten the quality and safety of dairy products (Giffel, 2003).

The extended shelf life of the milk products was probably attributable to the effect of additives, coupled with the improved hygienic practices performed during milking and processing. Similarly, the high sensory score and lower microbial count of milk after the training were due to improved hygienic milking procedures; the low contamination of milk by cows’ hair, dust particles and flies; as well as the hygienic handling of milk, milk vessels and use of aluminium cans (easy to sanitise) which were adopted after training, instead of clay pots. Good general hygiene had a positive effect on the overall quality of the final product (DeLaval, 2001).

On the other hand, Yilma and Faye (2006) reported a higher microbial count in milk samples obtained from small-scale and large-scale farms compared with samples taken from a research centre, where hygienic procedures were strictly observed during production and processing. Similarly, Tola (2002) reported a high microbial load (7.60 log CFU/ml) in milk produced under a traditional system. Usually the source of coliform bacteria is faecal contamination of the bedding or udder (Giffel, 2003), and this could be the result of poor hygiene. Generally, the level of bacterial contamination in milk is determined by the quality of the hygiene during milking, temperature and storage period (DeLaval, 2001).

**CONCLUSION**
The results indicate that the ability of smallholder dairy farms to improve the quality and marketability of milk and milk products will depend to a large extent on the support and training which the farmers receive. The focus should therefore be on empowering the target audience, women in this case, through training, and on implementing dairy development projects aimed at improving milk production, processing and handling as well as the quality of the products, to contribute to alleviating food insecurity in the study area and across the whole country.

**COMMUNICATION STRATEGY AND IMPACT**
The study findings were communicated to various stakeholders. Academics from Hawassa, Nekemt and Haramaya Universities and researchers from the national research system reviewed this work in
a series of seminars. A manuscript was sent to an international journal after the peer review sessions. Outreach programmes, including training of trainers’ workshops for extension agents and presentations to district-level professionals, were also organised in the Wolayta region. Moreover, copies of the full write-up were forwarded to the local bureau of agriculture, the Ethiopian Institute of Agricultural Research, and Hawassa University. Flyers and brochures were also prepared in two local languages and dispatched during the training sessions.

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DEVELOPING CAPACITY FOR FARMER-LED INTERVENTIONS IN THE MONITORING AND EVALUATION PROCESSES OF INTEGRATED SOIL FERTILITY MANAGEMENT IN EASTERN ZIMBABWE

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ABSTRACT

Development practitioners have postulated that participatory monitoring and evaluation can bridge the gap between scientific research and farmers’ technological preferences. A 2-year study was conducted in smallholder farming areas of Eastern Zimbabwe. The objectives of the study were: (1) to jointly develop indicators and monitoring plans for the implementation and evaluation of integrated soil fertility management (ISFM) technologies with farmers; and (2) to investigate farmers’ evaluation criteria in comparing technologies. Participatory research methods were employed to mobilise farmers for experimentation. Farmers’ preferred ISFM technologies were tested and evaluated through field-based learning centres (LCs). Farmer indicators of ISFM use and non-use were used for monitoring and evaluation. These indicators were then categorised as either ISFM or agronomic parameters. Preferences of ISFM technologies were underpinned by prospects for multiple benefits, low cost of accessing a technology, its ready availability, and access to knowledge on its use. Criteria for ranking the technologies were influenced by gender and financial considerations. Use of LCs showed the ability of farmers to consistently follow through their indicators in the monitoring and evaluation process. Farmers’ understanding of ISFM technologies provided scope for employing their criteria in assessing uptake rates. The study showed that capacity can be developed for farming communities to conduct monitoring and evaluation processes to measure the success of new interventions and identify any areas for improvement. Farmer interactive platforms such as LCs were useful in supporting strong participation of farming communities in the evaluation of complex technologies.

KEY WORDS: INTEGRATED MANAGEMENT, INTERACTIVE PLATFORM, LEARNING CENTRE, PARTICIPATORY, SOIL FERTILITY

AFFILIATIONS

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INTRODUCTION

The use of integrated soil fertility management (ISFM) in improving soil and crop productivity for food security has been the focus of considerable attention from agricultural research, development agencies, policy-makers and donors in recent years (Sanchez et al., 2000; Gentile et al., 2009). However, the expected impact has not yet materialised due to low adoption of the technologies. One of the reasons cited for low uptake rates is lack of suitable mechanisms for transferring the available knowledge on ISFM from researchers to farmers in ways that promote innovation and uptake (Mapfumo, 2009). Over the years, researchers and development agencies have continued to invest in participatory action research approaches as an alternative to traditional top-down approaches (Rhoades and Booth, 1982; CGIAR, 2006).

Although the thrust of agricultural research now centres on participatory action research (PAR), researchers and farmers still lack a common framework of results indicators against which to measure the success of different ISFM innovations (World Bank, 2002). Conventionally, the monitoring and evaluation of technologies has remained the domain of scientists (Horton, 1998; Probst, 2002). However, community participation is increasingly being recognised as an integral component of the monitoring and evaluation process, since it offers new ways of assessing and learning from change that are more inclusive, and more responsive to the needs and aspirations of those most directly affected (Franzel et al., 2001; World Bank, 2002). The inclusion in the monitoring and evaluation process of direct beneficiaries of innovations, such as farmers, is termed participatory monitoring and evaluation (PM&E).

In order to empower farmers to carry out PM&E, they must be given the opportunity to experiment with technologies and fully participate in technology development and evaluation. In line with these research developments, the Soil Fertility Consortium for Southern Africa (SOFECSA) has advocated for the promotion of diverse ISFM technologies using the learning centre (LC) approach (Mapfumo, 2007). The LC approach was used in this study to allow farmers to experiment with different ISFM technologies according to their socio-ecological circumstances. The LC is based on an innovative, participatory, learning-by-doing approach where host farmers manage the ISFM plots. The approach shifts from targeting farmers with preset technologies, instead seeking to empower farmers by allowing them to experiment with and evaluate diverse ISFM technologies.

This study was based on the hypothesis that engaging farming communities in learning alliances for ISFM through participatory action research will lead to increased testing of ISFM technologies by farmers. The broad objective of the research was to evaluate the effectiveness of facilitated farmer learning alliances in participatory testing and evaluation of different ISFM technologies in farmers’ fields. The specific objectives were: (1) to jointly develop indicators and monitoring plans for the implementation and evaluation of ISFM technologies with farmers; and (2) to investigate farmers’ evaluation criteria in comparing technologies.

MATERIALS AND METHODS

Study sites

The study was conducted under the auspices of SOFECSA’s research for development initiatives, which centre on the promotion of ISFM technologies using the LC approach (Mtambanengwe and Mapfumo, 2008) in the Dendenyore and Goto wards of Wedza district (18°4’S and 31°42’E) in Zimbabwe. Wedza (natural region II) is approximately 160 km south-east of Harare and receives an average of >750 mm rainfall per annum between November and March. Over 80% of the households derive their livelihoods from maize-based subsistence farming (Mtambanengwe and Mapfumo, 2005).
Research design

The study involved participatory meetings, focus group discussions and participatory field experiments led by farmers. In the first diagnostic phase, visioning exercises were conducted with the community, which included problem analysis and exploratory field experiments. A joint co-learning process with researchers, farmers and local extension agents was initiated to explain the principles and benefits of ISFM, train farmers on how to conduct trials, develop indicators for PM&E and teach them how to carry out PM&E.

Formation of farmer groups and development of indicators for monitoring ISFM innovations

Focus group discussions were used to identify indicators for monitoring and evaluation, including identification of farmers’ sources of ISFM information, which were then used to categorise farmers into different groups consisting of both men and women. Apart from the control group (composed of non-participant farmers), participants of ISFM co-learning alliances consisted of: (1) the farmer-led group; (2) the extension-led group; and (3) the independent group (without researcher, extension agent or lead-farmer input). Each group consisted of 10 farmers, with one farmer hosting the LC. The LC served as a learning point where farmer groups exchanged knowledge and experiences of ISFM. Apart from the LC, each farmer would have individual plots on which to conduct adaptive testing of ISFM technologies. These plots allowed farmers to test technologies under different management conditions. The ISFM options tested were identified by farmers according to their particular circumstances and included legume–cereal rotations with maize, cowpea and soya bean as test crops; and organic × inorganic nutrient resources (mainly manure, woodland litter, termitaria, mineral fertilisers).

Evaluation of a farmer practising ISFM was carried out through joint observation of field crops by farmers, extension agents and researchers. The evaluation was also coupled with one-to-one informal interviews with the participating farmers. A qualitative scoring system using a three-point Likert-type scale (Bertram, 2012) (1 = poor; 2 = average; 3 = good) was employed for qualitative assessment of agronomic and ISFM parameters.

RESULTS AND DISCUSSION

Identified indicators for monitoring and evaluation: a farmer’s criteria

One of the important findings was the high degree of knowledge of ISFM practices that farmers already had, which emerged when they were asked to identify indicators for monitoring an ISFM-practising farmer. A farmer was considered to be practising ISFM when he/she combined two or more of the following practices: pit-stored manure, leaf litter, termitaria soil, moisture conservation, inorganic fertilisers, green manures (sunn hemp, mucuna), and cowpea/soya bean/maize rotations. Through dialogue and participatory facilitation, these indicators were classified into two main categories: ISFM indicators and agronomic indicators (Table 1). Further dialogue also established that a successful ISFM farmer would also be able to: (1) demonstrate new knowledge; (2) keep farm records; and (3) maintain a matching cereal/legume area for systematic cereal/legume rotations. This knowledge could be attributed to the co-learning process and exposure of farmers to technologies in their adaptive experiments. Interaction with farmers at LCs confirmed that effective communication platforms for farmers were an important aspect that influenced perceptions about soil fertility management.

A qualitative scoring system using a three-point Likert scale showed that farmers performed better on agronomic categories, with the majority of farmers in the ‘average’ to ‘good’ categories.
difficult to give a qualitative value to ISFM parameters such as use of inoculants and mineral fertilisers, with farmers citing unavailability on the local market. Parameters ranged from ‘poor’ to ‘average’, and in most instances quantities of mineral fertilisers used were far below those recommended by the extension personnel, making it difficult to qualify knowledge gained. This confirmed the concerns raised by the World Bank (1995) about challenges related to access to and use of agronomic inputs as key constraints to adoption.

**Farmers’ evaluation of different ISFM technologies**

With assistance, both men and women were able to produce a list of positive and negative aspects of particular ISFM components (Table 2). Cattle manure was the most popular among all farmer categories, irrespective of their financial situation. It was ranked highly by both cattle owners and non-cattle owners. Organic nutrient resources such as woodland litter and termitaria were preferred by resource-constrained farmers because they were

<table>
<thead>
<tr>
<th>Indicator type</th>
<th>Identified indicators</th>
<th>How assessment was performed during PM&amp;E</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISFM</td>
<td>Combined use of leaf litter, manure or termitaria and inorganic fertiliser</td>
<td>Through review of farm records on amount of nutrient resources applied</td>
</tr>
<tr>
<td></td>
<td>Combined use of green manure and inorganic fertilisers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organic nutrient use on legume crops</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Legume/cereal intercropping and rotations</td>
<td>Field observation. For rotations, the legume area should be equivalent to the cereal area to allow for systematic rotations</td>
</tr>
<tr>
<td></td>
<td>Inoculant use with legumes</td>
<td>Presence of effective nodules on legume roots</td>
</tr>
<tr>
<td></td>
<td>Presence of soil and water conservation structures in the field</td>
<td>Field observations for presence of contour ridges, pot holes, etc.</td>
</tr>
<tr>
<td>Agronomic</td>
<td>Correct plant spacing (maize: 90 cm inter-row, 30 cm in-row; legumes: 45 cm inter-row, 5 cm in-row)</td>
<td>Field observations and measurements to ascertain correct plant spacing</td>
</tr>
<tr>
<td></td>
<td>Plant condition</td>
<td>Field observation for uniform crop size, dark green colour of leaves and plant vigour in relation to time of planting</td>
</tr>
<tr>
<td></td>
<td>Pests and diseases</td>
<td>Field observation for presence of pests and diseases in plants</td>
</tr>
<tr>
<td></td>
<td>Weed management</td>
<td>Weed control measures in place</td>
</tr>
</tbody>
</table>

Note: row means designated by different superscript letters are significantly different from each other at $P < 0.05$, SE = standard error, N = number of respondents.
locally available and cheap. Mineral fertiliser was popular among the moderately well off and wealthier farmers because they had access to cash for purchases. On the other hand, female farmers preferred technologies that were less labour-intensive and less cash-hungry, such as legume/cereal intercropping and rotations with legumes. However, grain legumes such as cowpea and soya bean were more popular compared with green manures due to labour constraints associated with applying the green manures to the soil. Farmers evidently also did not wish to invest in a crop that is not edible. Although use of inoculant was preferred for use by all farmer categories, its use was restricted by its scarcity on the local market, which meant that it was difficult to qualify knowledge gained on its use.

**CONCLUSIONS**

The study showed that capacity could be developed for farming communities to conduct monitoring and evaluation processes, offering them the opportunity to measure the success of new interventions as well as to identify possible areas for improvement. The main criteria determining preference of ISFM technologies were the prospects for multiple benefits, the low cost of accessing a technology, its ready availability, and access to knowledge on how to use it. Criteria for ranking the technologies were evidently influenced by gender and financial considerations. Farmer interactive platforms such as LCs were useful in supporting stronger participation of farming communities in the evaluation of complex technologies.

**TABLE 2: FARMERS’ ASSESSMENT OF ISFM TECHNOLOGIES IN WEDZA SMALLHOLDER AREA, ZIMBABWE**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Positives</th>
<th>Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodland litter</td>
<td>Improves soil fertility</td>
<td>Labour-intensive</td>
</tr>
<tr>
<td></td>
<td>Locally available</td>
<td>Limited quantities due to population pressure</td>
</tr>
<tr>
<td></td>
<td>Conserves soil moisture</td>
<td>Poor-quality litter</td>
</tr>
<tr>
<td>Cattle manure</td>
<td>Residual effects can last up to three seasons</td>
<td>Spread weed seeds and/or plant diseases</td>
</tr>
<tr>
<td></td>
<td>Improves soil fertility</td>
<td>May result in “burning” of plants when there is insufficient soil moisture</td>
</tr>
<tr>
<td></td>
<td>Improves soil structure and reduces acidity</td>
<td>Available to cattle owners</td>
</tr>
<tr>
<td>Cereal/legume rotations</td>
<td>Improves soil fertility</td>
<td>Green manure is labour-intensive</td>
</tr>
<tr>
<td></td>
<td>More food-secure households due to several options for available food</td>
<td>Legumes such as sunn hemp are not edible</td>
</tr>
<tr>
<td>Inorganic fertilisers</td>
<td>Quick supply of plant nutrients</td>
<td>Expensive – need to be applied yearly</td>
</tr>
<tr>
<td></td>
<td>High yields</td>
<td>Causes soil acidity</td>
</tr>
<tr>
<td>Use of inoculants</td>
<td>High yields of legumes</td>
<td>Scarce and not available on the local market</td>
</tr>
<tr>
<td></td>
<td>Saves on costs of top-dressing fertilisers</td>
<td>Difficult to handle</td>
</tr>
</tbody>
</table>

*Note: row means designated by different superscript letters are significantly different from each other at P < 0.05, SE = standard error, N = number of respondents.*
COMMUNICATION STRATEGY AND IMPACT

This research is part of an ongoing study entitled ‘Translating integrated soil fertility management knowledge into crop productivity benefits through farmer learning and participatory action in Eastern Zimbabwe’. Innovation platforms established by SOFECSA at local, district and national levels will be the major pathways for dissemination of the results. At local and district levels, results have so far been shared through farmer meetings, field days and agricultural shows. Further results will be disseminated through various scientific fora and peer-reviewed journals. The initiative has succeeded in increasing the participation of the previously marginalised resource-poor farmers in the study areas.

ACKNOWLEDGEMENTS

This research was made possible thanks to funding from RUFORUM, through grant no. RU2009 GRG-05, and SOFECSA-CIMMYT. The participation of farmers in Goto and Dendenyore wards was greatly appreciated.

REFERENCES


CLIMATE CHANGE TECHNOLOGIES FOR IMPROVED LIVELIHOODS OF SMALLHOLDER CROP–LIVESTOCK FARMERS IN EASTERN AND CENTRAL AFRICA

ABSTRACT

A project was implemented in Uganda, Kenya, Tanzania and Burundi from 2009–11 to promote the use of drought-tolerant forages, rainwater harvesting, and the use of soil fertilisers as coping mechanisms against climate change shocks, especially in the dairy and vegetable production systems. The project involved 280 smallholder dairy–vegetable production system farms, most of which were managed by women. The trials were laid out in a randomised complete block design, with three replications. This paper presents data for one site, namely Masaka in Uganda. Introducing 0.5 ha of a mixture of *Brachiaria* and *Clitoria ternatea*, on farms previously dependent on 0.5 ha of a mixture of *Pennisetum purpureum* and *Centrosema pubescens*, provided year-round feed supply to dairy cattle. Drought-tolerant forages and water harvesting technologies increased fodder availability (76%), water offered to animals (46.3%), milk yield (78.7%) and cash incomes (52.4%). Application of goat, cattle and poultry manure with drip irrigation significantly (P < 0.05) increased cabbage yields by 9, 49 and 95%, respectively. In conclusion, the integrated management of climate change adaptation technologies in dairy–vegetable production systems improved household food security and income.

KEY WORDS: *BRACHIARIA*, DROUGHT TOLERANT, FORAGE LEGUMES, WATER HARVESTING

AFFILIATIONS

1 National Livestock Resources Research Institute, Tororo, Uganda.
3 Kenya Agricultural Research Institute, Machakos, Kenya.
4 Livestock Research Centre, Mwanza, Tanzania.
5 Institut des Sciences Agronomiques du Burundi, Bujumbura, Burundi.
6 National Agricultural Research Laboratories, Kampala, Uganda.
7 Makerere University, Kampala, Uganda.
INTRODUCTION

Smallholder crop–livestock farming systems dominate in rural Eastern and Central Africa (ECA), and employ over 70% of the region’s population (Njarui et al., 2012). Moreover, the systems account for 70–90% of the region’s total meat and milk output. Small-scale dairy–vegetable production systems play a crucial role in food security, human health and overall household livelihoods, particularly among the climate change-prone resource-poor population. Zero-grazing dairy systems are increasingly promoted owing to progressive grazing land shortages and intensive dairy production requirements. Women are the major contributors to and beneficiaries of these dairy–vegetable production systems (Njarui et al., 2012), which, unfortunately, are gradually being devastated by climate change and extreme weather conditions. Among the most affected are rural household food supplies, livestock feed and water resources. The situation is exacerbated by community dependence on indigenous adaptation technologies with minimum scientific backup efforts. The inadequate adaptation to these adverse effects of climate change is likely to jeopardise the achievement of Millennium Development Goals 1 (eradicating extreme poverty and hunger), 7 (ensuring environmental sustainability) and 3 (promoting gender equality and empowering women).

There is therefore a need for determined regional efforts to address the above scenario, by leveraging from best climate change adaptation practices and innovations anchored in the targeted indigenous technology platforms in the ECA. In this respect, regional capacity-endowed agriculture-based research and development organisations would be better positioned to coordinate and direct the process. A regional project was thus designed and implemented in ECA countries (Burundi, Kenya, Tanzania and Uganda) with the following objectives: (1) to develop economically feasible strategies for year-round feed supply to dairy cattle in order to elevate household milk consumption (nutrition) and income sourcing; (2) to increase the availability of water for domestic uses and livestock production, drip irrigation and investment of manure from smallholder dairy units into vegetable production to provide a quick income to the farmer; and (3) to establish regional communication infrastructure to enhance community awareness and knowledge of climate change manifestations and available cost-effective coping tactics. This paper presents the findings from Masaka, one of the sites in Uganda.

METHODOLOGY

Description of the project site

Masaka lies between 0°15’ and 0°43’ south of the equator and at a longitude of between 31° and 32° east, with an average altitude of 1,150 m above sea level. The annual average rainfall is 800–1,000 mm with 100–120 rainy days, in two seasons (Mugerwa et al., 2011). Mean temperature ranges between 16 and 30°C, while relative humidity is 62.1%. The district is typically dependent on crop–livestock systems, with vegetable production as a key income earner.

Forage availability in ECA

Napier grass (Pennisetum purpureum) is the major forage in zero-grazing production systems in the ECA region (Njarui et al., 2012). The grass is constrained by long droughts, poor agronomic practices, and pests and diseases, resulting in a reduction in fodder yield of up to 100% during the dry season. Brachiaria is also widely available in the region. Hybrid cv. Mulato (Brachiaria) has a high biomass yield and tolerates long periods of drought and poor soils (CIAT, 2001). The most common forage legumes include Centrosema pubescens (Centro) and Clitoria ternatea (Clitoria). It is generally recommended, however, that forages are grown in grass–legume mixtures in order not only to ensure...
calorie–protein balance for livestock, but also to harness atmospheric nitrogen (N) fixation for the production systems by the legume component (Thomas, 1995).

The forage study
This component targeted zero-grazing dairy farmers with one or two cows and having at least 2 ha of land. The treatments involved mixtures of grass species (Brachiaria or Napier) and legumes (*Clitoria ternatea* or *Centrosema pubescens*). The forages were established on 48 households (50% female-headed) using methods described by Humphreys (1995) and CIAT (2001). The forage technologies were compared with the farmers’ practice of growing Napier grass alone. Farmers participated in all stages of project implementation to ensure instantaneous uptake of emerging knowledge and practices.

The study was laid out in a randomised complete block design with household farms as replications. Data were collected on fodder production and milk yield from 24 randomly selected household farms. Fodder dry matter yield and associated feeding period were estimated using methods described by Humphreys (1995). Data were analysed using analysis of variance using GenStat (version 4) software. Data relating to the costs of inputs and returns from milk (including that consumed by the family) were recorded for profitability evaluation using partial budgeting.

Water harvesting innovation
Roof catchment underground water harvesting tanks with a capacity of 35,000 litres were introduced on 24 farms to improve water availability for agricultural and domestic use. The project provided dam liners and treadle pumps, while the farmers contributed labour and roofing materials. Farmers recorded the number of 20-litre water jerry cans harvested and used per season.

Soil fertility enhancement and irrigation for vegetable production
This trial, established at a farmer training school and on 24 farms, involved the use of cattle, goat and poultry manure for vegetable production. Compost manure was applied at a rate of 0 and 2.5 t ha$^{-1}$ on plots measuring 10 by 10 m. The study used a randomised complete block design with three replications. Cabbage (*Brassica oleracea* var. Glory), which is a popular vegetable in ECA, was used as the test crop. Drip irrigation using 70 litres day$^{-1}$ was conducted using a 500-litre plastic dram as the reservoir, and equidistant perforated pipes laid out in the plots regulated water delivery to the plants. The plants were irrigated routinely at 6:00 and 18:00 h. The no-manure and irrigation plots constituted the control. Data were collected on cabbage head weight and overall yield, and analysed using the SAS (2001) package. Beneficiaries of the above technologies ensured the dissemination and demonstration of the promoted technologies to at least 20 new beneficiaries.

RESULTS
Drought-tolerant forages and fodder availability
Intercropping forage legumes with Napier grass increased fodder availability by 50%, crude protein (CP) content by about 20%, and feeding period (number of days a cow was able to feed on fodder from a given area of land) by about 30% (Table 1). Additional fodder obtained from establishing 0.5 ha of Brachiaria and Clitoria mixture on the same farms containing Napier grass and Centro mixture was able to sustain a crossbred dairy cow (470 ± 27 kg live weight) throughout the year.
Water harvesting and household water availability

Water harvesting enabled farmers to harvest up to 35,000 litres of water per season to cater for a family of four people keeping two milking cows and irrigating 0.1 ha of vegetable plot over dry periods lasting 4–6 months.

Manure amendments and cabbage yield

Cabbage heads from plots fertilised with poultry manure were 9, 49 and 95% heavier than the heads obtained from goat (416.7 g), cattle (305.6 g) and the control plots (233.3 g) (Table 2).

Beneficiary perceptions of climate change adaptation technologies

There were no significant ($P > 0.05$) differences in land size and number of cattle kept between the beneficiaries and non-beneficiaries of the interventions (Table 3).

Introduction of water harvesting and drought-tolerant forage technologies improved milk yield and household income by 79.7 and 52.4%, respectively. Area under forage production, fodder quantity and water availability increased by about 134, 76 and 46%, respectively. Farmers were able to harvest 56 kg$^{-1}$ day$^{-1}$ of fresh fodder for one cow. Rainwater harvesting stretched water availability from 4 to

### Table 1: Fodder availability and feeding period of different forage banks

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Napier grass and Centro mixture</th>
<th>Brachiaria and Clitoria mixture</th>
<th>Napier grass monocrop</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean DM yield (kg ha$^{-1}$)</td>
<td>15,790</td>
<td>12,119</td>
<td>10,354</td>
<td>307</td>
</tr>
<tr>
<td>Feeding period (days) from 0.5 ha</td>
<td>254.6</td>
<td>195.5</td>
<td>167.0</td>
<td>20.9</td>
</tr>
<tr>
<td>Crude protein content (%)</td>
<td>8.4</td>
<td>12.1</td>
<td>7.0</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*SEM, standard error of mean.

### Table 2: Effect of manure type on cabbage production

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight per head (g)</th>
<th>Cabbage yield (kg$^{-1}$ ha$^{-1}$) (fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry manure</td>
<td>455.6$^a$</td>
<td>19,156.3$^a$</td>
</tr>
<tr>
<td>Goat manure</td>
<td>416.7$^a$</td>
<td>17,084.2$^a$</td>
</tr>
<tr>
<td>Cattle manure</td>
<td>305.6$^{ab}$</td>
<td>9,948.7$^{ab}$</td>
</tr>
<tr>
<td>No manure application</td>
<td>233.3$^b$</td>
<td>5,982.8$^b$</td>
</tr>
</tbody>
</table>

$^a$,$^b$Means with different superscripts in the same column are significantly different at $P < 0.05$. 

**CLIMATE CHANGE TECHNOLOGIES FOR IMPROVED LIVELIHOODS OF SMALLHOLDER FARMERS IN EASTERN AND CENTRAL AFRICA**
6 months, while drip irrigation and soil water management enabled beneficiaries to have vegetables throughout the year.

**DISCUSSION AND CONCLUSION**

**Drought-tolerant forages and fodder availability**

Higher total fodder yields and CP content in intercrops could be attributed to the presence of forage legumes that improved grass growth. The legume acted as a cover crop to control weeds and conserve soil moisture during the dry periods, apart from the possibility of augmenting nitrogen (N) supplies to the grass component through symbiotic N fixation (Thomas, 1995). This study showed that the currently recommended acreage of 0.5 ha of a mixture of Napier grass and forage legumes (Samanya, 1996, p. 34) cannot sustain a dairy cow and its calf for a full year. The additional development of 0.5 ha of a mixture of Brachiaria and forage legumes is recommended during the dry season when the production of Napier grass monocrop suffers from the negative effects of drought and poor agronomic practices.

**Water harvesting and availability**

The ability of farmers to store up to 35,000 litres of water per season led to a shift in family labour from fetching water to other income-generating activities. Moreover, increased availability of water improved milk yield considerably. Water shortage during the dry season is a major constraint in smallholder crop–livestock systems in the ECA region, and women and youngsters travel up to 6 km daily in search of water (ASARECA, 2011). Initiatives targeting water harvesting therefore presented great potential for alleviating poverty and food security in the climate change-stressed region. Nevertheless, there is a need to identify optimal water application systems aimed at achieving high production efficiencies, coupled with evidence-based economic potential.

### TABLE 3: SOCIO-ECONOMIC BENEFITS OF CLIMATE CHANGE ADAPTATION TECHNOLOGIES

<table>
<thead>
<tr>
<th>Household characteristics</th>
<th>Beneficiaries ((n = 24))</th>
<th>Non-beneficiaries ((n = 24))</th>
<th>(F)-test</th>
<th>IA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Land size (ha)</td>
<td>1.7</td>
<td>1.2</td>
<td>1.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Cattle (number)</td>
<td>1.5</td>
<td>0.5</td>
<td>1.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Fodder area (ha)</td>
<td>1.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Feed offered cow(^{-1}) day(^{-1}) (fresh)</td>
<td>55.4</td>
<td>12.3</td>
<td>31.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Water offered (l/day(^{-1}))</td>
<td>106.1</td>
<td>57.4</td>
<td>101.4</td>
<td>20.5</td>
</tr>
<tr>
<td>Milk yield (l/day(^{-1}))</td>
<td>10.6</td>
<td>7.2</td>
<td>5.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Revenue (US$) from milk yield cow(^{-1}) year(^{-1})</td>
<td>676.9</td>
<td>48.2</td>
<td>444</td>
<td>64.1</td>
</tr>
</tbody>
</table>

*** Significant at 1%, ** significant at 5%; NS, not significant; SD, standard deviation; IA, intervention advantage.
Manure amendments and water for production

Poultry manure supplemented with drip irrigation produced a higher cabbage yield than goat and cattle manure (Table 2), possibly due to a higher microbial mineralisation rate attributed to relative nitrogen richness owing to spillage of N-rich feeds into the litter (Mugerwa et al., 2011). However, farmers preferred to use cattle manure because poultry production was presumed to be uneconomic because of the high cost of associated feeds due to prevailing consumer prices. Nevertheless, Mugerwa et al. (2011) reported that investing in cattle manure for vegetable production at a rate of 3–4 t ha⁻¹ year⁻¹ increased net returns by more than US$1,415 ha⁻¹ per season in smallholder production systems in Uganda.

In conclusion, supplementing the Napier grass and forage legume mixture with Brachiaria and forage legume mixtures by 0.5 ha on farms elevates household production levels and generates economic returns of US$676.9 per cow per year (Table 3). Increased availability of household water for production through innovative rainwater harvesting, and utilisation of livestock manures, further extends the agronomic and socio-economic benefits of the communities, particularly through vegetable production. Further studies are recommended to explore the best irrigation production efficiencies within the socio-economic frameworks of the affected communities as a basis for further scaling out and up these novel technologies across the region. In order to meet the high demand for the technologies, there is a need to establish forage seed multiplication sites and to train local artisans on drip irrigation and water harvesting technologies. Relevant policies should be bolstered to boost the adoption levels of climate change-coping technologies, as a strategy for improving livelihoods.

COMMUNICATION STRATEGY AND IMPACT

The regional implementing research teams have communicated the research achievements through regional and national review and planning meetings, farm visits, field days, publications (nine leaflets, a farmer manual, eight posters, 12 daily newspaper articles, eight conference papers, two published papers, an MSc thesis, four undergraduate special project reports, and regional and country progress reports), four audiovisuals, and eight radio and television programmes. Four leaflets were translated into Kiswahili to reach more stakeholders and increase adoption of the innovations. Three scientific conferences bringing together over 3,000 stakeholders from eight countries were held to share project achievements and lessons learnt. The ASARECA website (www.asareca.org), email and other ICT tools (LinkedIn, Dropbox and mobile phones) were used to share information within and outside implementing countries. A ‘One-Stop Climate Change Adaptation Dissemination Centre’, where all technologies were demonstrated, was established in project sites to educate stakeholders on the impact of climate change and to promote mitigation and adaptation strategies. Over 30,000 stakeholders in the region have been trained. According to Mrs Daaki of Masaka: ‘Home gardens have improved my household food security, nutrition and income because previously I waited for two rain seasons to grow vegetables, but now I can have vegetables all year round because of improved soil fertility and year-round water supply.’ (ASARECA, 2011). A 75-year-old widow with 20 orphans stated: ‘Improved cattle feeding and availability of clean water has increased milk yield, nutrition and income and reduced workload. I have been able to educate the orphans and pay our bills.’ It is also important to note that due to the many project achievements and its impact, a second phase (2012–13) of a regional
project (US$905,523) was approved by ASARECA and launched in Uganda in February 2012 to consolidate project successes and to scale-out and scale-up the technologies.

ACKNOWLEDGEMENTS

This publication is the result of a regional project funded by ASARECA. We wish to thank the farmers, local leaders, implementing institutions and district staff for their commitment.

REFERENCES


RESPONSE OF BLISTER BEETLES (*HYCLEUS APICICORNIS*) TO VISUAL AND OLFACTORY CUES IN THE FIELD

L.N. Lebesa¹,²,³, A. Hassanali⁴, K. Krüger², T.J.A. Bruce⁵, Z.R. Khan¹, J.A. Pickett⁵
ABSTRACT

Blister beetles, *Hycleus apicicornis*, pose a threat to the seed production of *Desmodium* spp. grown by smallholder farmers and used as intercrops for maize and sorghum in Western Kenya. The beetles feed on the flowers and developing seeds of *Desmodium* and other crops such as sweet potato (*Ipomoea batatas*), thereby affecting their seed setting. The objective was to evaluate the effectiveness of the simple prototype water bucket traps to capture adult *Hycleus* spp. Water bucket traps in two colours, sky-blue and grey, were used. The traps were either not baited, or baited with phenylacetaldehyde (PA) or 2-phenylethanol (2PE) compounds that were previously found to be attractive to *H. apicicornis* in laboratory bioassays. The sky-blue prototype trap baited with PA captured the highest number of beetles and differed significantly from the grey traps but not the other (sky-blue baited) traps. These results show that the sky-blue traps usually can be used alone for trapping the beetles, although the addition of attractive olfactory compounds may enhance trapping efficiency. The ability of such traps to control these beetles could result in increased seed production, which is crucial for push–pull sustainability to increase maize and sorghum productivity. Further studies are required to evaluate which plant volatiles are attractive to *Hycleus* species for the development of efficient traps for mass trapping.

KEY WORDS: BAIT, BLISTER BEETLES, PROTOTYPE TRAPS, SEMIOCHEMICALS, SKY-BLUE

AFFILIATIONS

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INTRODUCTION

The significance of the threat posed by blister beetles, *Hycleus apicicornis* (Coleoptera: Meloidae) to the production of *Desmodium* spp. (Fabaceae) seeds in East Africa has been reported by smallholder seed-bulking farmers in Western Kenya (Lebesa et al. 2012). Production of *Desmodium* seeds in East Africa is crucial for the sustainability of the stem-borer push–pull technology (Khan et al., 2008) where *Desmodium* spp. are used as intercrops for maize (*Zea mays* L., Poaceae) and sorghum (*Sorghum bicolor* L., Moench, Poaceae) due to their ability to repel the moths of maize stem borers (Lepidoptera) (Khan et al., 2000; Amudavi et al. 2009).

Blister beetles feed on the flowers and leaves of several crops, weeds and fruits, and are often considered a minor pest (Singh and van Emden, 1979), except where they attack crops that flower early or those that are cultivated on smallholdings. Seed production of *Desmodium* spp. in East Africa is undertaken by smallholder farmers, and the damage caused by blister beetles affects seed setting, which eventually results in reduced seed production. These are resource-poor farmers who may not be able to afford a high-input management strategy (Khan et al., 2010) such as the use of conventional pesticides. Controlling blister beetles by using chemical pesticides is possible, according to *Desmodium* farmers, but lack of affordability has been cited as a factor discouraging their constant use (Lebesa et al., 2012). Drawbacks to pesticide use, such as insects developing resistance (Isman, 2002), the increasingly harmful environmental impact associated with the exclusive application (Smart et al., 1994), and lack of economic viability (Van den Berg and Nur, 1998), contribute to the need for the development of affordable alternative strategies.

Because phytophagous insects locate their hosts using both visual and olfactory cues (Bernays and Chapman, 1994), one alternative is the use of semiochemicals and visual cues in the trapping system for pest management. Semiochemicals can be used alone or in conjunction with visual stimuli to send messages that attract insect pests to their source (Hesler and Sutter, 1993). Previously, Lebesa et al. (2011) demonstrated that *H. apicicornis* (Guér.) (Coleoptera: Meloidae) is attracted to sky-blue. These findings were therefore combined with the olfactometer results (Lebesa, 2012), where attraction was displayed towards some host plants, to design a simple trap to test both visual and odour cues. Therefore the simple prototype sky-blue water bucket trap was used to determine if the trap could be used alone or together with semiochemicals (two volatile compounds) to attract beetles, by comparing *H. apicicornis* adult catches of the lured and non-lured buckets.

MATERIALS AND METHODS

Study site

A field-sampling programme was undertaken in Bungoma (0°34’S, 34°30’E, approx. 1,700 m a.s.l.), Western Kenya, in November 2008.

Evaluation of water traps in the field

The efficiency of water bucket traps (20 cm diameter × 20 cm length) was evaluated on five different blocks of *Desmodium uncinatum* seed-bulking fields in Bungoma. The olfactory and visual cues were tested separately and in combination. Buckets tightly secured to a stick by a thread were suspended on wooden sticks half a metre above the ground. The lure was attached to the cross-junction of the thread and suspended in the middle of the basin above the water.
The chemical compounds phenylacetaldehyde and 2-phenylethanol were formulated singly on rubber septa. Their use was based on laboratory bioassays results which found that 2-phenylethanol was more attractive than phenylacetaldehyde (Lebesa, 2012). Treatments were as follows: (1) a sky-blue trap with no chemical (BB); (2) a sky-blue trap with 2-phenylethanol (BPE); (3) a sky-blue trap with phenylacetaldehyde (BPA); (4) a grey trap with 2-phenylethanol (GPE); and (5) a grey trap with no chemical (GG).

Traps were set out in a straight line to represent one replicate (row) spaced 5 m apart along the edges of the field. Re-randomisation of traps was carried out every day after removing, counting and identifying the captured insects. The different species of blister beetles and their gender were recorded. Traps were emptied daily for 10 consecutive days.

Statistical analyses

The field data did not satisfy the assumptions of ANOVA of data fitting normal distribution and homogeneity, therefore data were transformed using log base 10 \((x + 0.5)\). Tukey’s studentised range test was used for mean separation where significant differences were detected between means. Results were reported with the untransformed means and standard errors.

RESULTS

Beetle catches were low throughout the 10-day period. The total number of beetles caught throughout the sampling period did not differ between sexes (Wilcoxon’s \(T = 3914.5, Z = 0.36, P = 0.72\)), therefore data for both males and females were combined for analyses.

Catches were high during the first 6 days, with the peak activity observed between days 5 and 6 for *Hycleus apicicornis* and *H. dubiosus* Marseul, respectively (Figure 1a,b). From days 7 to 10, no beetles were recorded in any of the traps for *H. dubiosus* (Figure 1b). With the exception of days 1 and 2, trap 3 (sky-blue bucket baited with phenylacetaldehyde) caught the highest number of *H. apicicornis* beetles, followed by trap 1 (sky-blue bucket only), trap 2 (sky-blue bucket with 2-phenylethanol), trap 4 (grey trap with 2-phenylethanol), trap 4 (grey trap with 2-phenylethanol) and trap 5 (grey bucket, no lure) (Figure 1a). When data for both species were combined, the same trend of *H. apicicornis* beetle capture by different traps was observed (Figure 1c).

For *H. dubiosus*, trap 3 caught the highest number throughout, except on day 5, when trap 4 had the highest number of beetles (Figure 1b). Generally, trap 5 caught the least number of beetles throughout the trapping period for both species, although on day 5 it recorded the second highest number of beetles for *H. dubiosus* (Figure 1a,b).

There was an overall significant difference of captures of blister beetles between the traps \((F_{4,241} = 0.11, P < 0.001)\). Mean separation shows that with the exception of trap 1, trap 3 had significantly higher catches than all other traps for *H. apicicornis* (Figure 2a). However, for *H. dubiosus*, catches did not differ between traps (Figure 2b). For combined data, the overall pattern to emerge followed the observation of *H. apicicornis*, where trap 3 had the highest catches (Figure 2c).
FIGURE 1: TOTAL NUMBER OF ADULTS OF *HYCLEUS* SPP. CAUGHT IN FIVE BAITED AND NON-BAITED WATER BUCKET TRAPS OVER A 10-DAY PERIOD (6–15 NOVEMBER 2008)

(a) Total number for both species; (b) total number for *H. apicicornis*; (c) total number for *H. dubiosus*.

Note: 2PE = 2-phenylethanol and PAA = phenylacetaldehyde.
**FIGURE 2. MEAN (±SE) CATCHES OF ADULT BLISTER BEETLES, HYCLEUS SPP., RECORDED IN FIVE WATER BUCKET TRAPS (BAITED AND NON-BAITED) OVER A 10-DAY PERIOD (6–15 NOVEMBER 2008)**

### (a) H. apicicornis

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<th>Traps</th>
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<td>T5</td>
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Note: T1–T5 are trap types: T1 = non-lured sky-blue bucket; T2 = sky-blue bucket lured with 2-phenylethanol; T3 = sky-blue bucket lured with phenylacetaldehyde; T4 = non-lured grey bucket; T5 = grey bucket lured with 2-phenylethanol. Similar letters above error bars denote no significant differences between bars.

### (b) H. dubiosus

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### (c) Both species

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DISCUSSION AND CONCLUSIONS

Only two species, *H. apicicornis* and *H. dubiosus*, were included in this study. Adults of *H. dubiosus* were caught in very low numbers (fewer than 10 beetles per day) and were recorded for only 6 days. From the fifth day there was some rainfall, and thereafter the catches dropped for both species. The sky-blue trap laced with phenylacetaldehyde caught more beetles than the other traps. A similar trend was observed for *H. dubiosus*, although there was no significant difference when compared with the other traps. An increase in the numbers of beetles caught by the trap baited with phenylacetaldehyde shows potential for the synergy between the visual and the olfactory cues, although the catches were too low to be able to assert this with confidence.

Phenylacetaldehyde is a key component that attracts moths to floral odours (Burguiere et al., 2001; Meagher and Landolt, 2008) and its attraction to some beetle species has also been documented (Bartlet et al., 2004). The addition of other compounds to phenylacetaldehyde enhances its attractiveness (Meagher and Landolt, 2008) because insects are drawn more to a blend than to a single compound (Webster et al., 2010). The fact that more beetles were attracted to phenylacetaldehyde in the field than to 2-phenylethanol as observed in the laboratory might be the result of a higher concentration of phenylacetaldehyde in the blend due to the release of volatiles released around the traps from *Desmodium* plants or volatiles in the atmosphere (Webster et al., 2010), or the combined effect of phenylacetaldehyde and the visual cue (Smart et al., 1994).

Based on these results, it is likely that *H. apicicornis* adults use both visual and olfactory cues to locate their plant food resources, but the visual cues may play a major role, as has been observed with some Lepidopteran species (Balkenius et al., 2006). These results have also shown that the sky-blue trap has the potential to be used alone to capture the beetles, although the addition of a suitable semiochemical may boost capture rates (Bueno and Jones, 2002). Blue traps were noted previously by Hall (1984) as the most effective colour for trapping red-banded blister beetles, *Mylabris designata var. hacolyssa* Rochebrune, compared with traps of any other colour.

Water traps are also easier to handle in the field than other types of trap, and therefore can easily be managed by farmers (Boo and Jung, 1998), even though they can be too general and capture untargeted, even beneficial insects (Bueno and Jones, 2002). It is therefore possible for *Desmodium* seed producers to use the water bucket for monitoring purposes. However, it will be desirable to conduct studies that will further evaluate the attractiveness of blends that include phenylacetaldehyde as one of the components for incorporation into the trapping system. Although this study provided necessary baseline information and yielded promising results for the potential use of traps, additional studies undertaken over two or more seasons are necessary to validate these findings.

COMMUNICATION STRATEGY AND IMPACT

Although additional complementary studies may strengthen the results of the current study, dissemination of the combined results from this study and those of the visual cue study can facilitate adoption and use by resource-poor farmers. If results are used for monitoring purposes, there is a strong probability of limiting the damaging impact of *Hycleus* spp. and thus increasing *Desmodium* seed yield. Consequently this will translate to increased maize yields due to reduced pest risk.
The work presented in this study complements work that has already been published and some that is about to be published in scientific journals. In addition to presenting the results to local colleagues, further reports should be made to all stakeholders, including researchers/scientists at regional and international levels, policy-makers and end users, through the use of journals and print and audiovisual media. Further reporting will help to foster collaborations in order to advance this work or similar initiatives to boost food security in Africa. Not only does this work support one of the main Millennium Development Goals of poverty eradication, but it also promotes environment and biodiversity conservation by minimising the use of chemical pesticides known to have adverse effects on the environment and biodiversity.

ACKNOWLEDGEMENTS

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REFERENCES


DEVELOPMENT OF LABOUR-SAVING FORAGE CHOPPER FOR SMALLHOLDER WOMEN DAIRY FARMERS IN UGANDA

F.L. Kiyimba¹,*
ABSTRACT

Labour-saving tools have been advocated as critical to increasing production and improving the quality of life of rural Africans. They can be very useful in reducing domestic drudgery, especially during peak production seasons when labour requirements are high. However, these tools have not been evaluated from a gender perspective for their social and technical impact. The objective of this study was to evaluate the effectiveness of the forage chopper as a labour-saving device for women, and to establish how existing gender relations influenced the nature, use and ultimately the impact of the technology. The machine was developed with the assumption that it would reduce the workload of rural women, giving them control over their own labour and freeing them for other income-generating activities. Adopting a technographic approach, the study evaluated the introduced forage choppers in four dairying sub-counties of Masaka district in Uganda, and showed that: (1) forage choppers were redesigned and adapted; (2) use and effectiveness depended on the social composition of households, community structure and support facilities; and (3) the socio-technical dynamics were not anticipated or evaluated by the introducing agencies. It was concluded that empowering women by giving them access to labour-saving tools requires ‘design-in-the wild’. The design process needs to be grounded and implemented by interdisciplinary teams in line with the reality on the ground.

KEY WORDS: DRUDGERY, GENDER RELATIONS, SOCIO-TECHNICAL CHANGE, TECHNOGRAPHIC

AFFILIATIONS

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* PhD work was supervised by Prof. Paul Richards, Dr Ir. Harro Maat and Dr Ir. Margreet Zwarteveen of Wageningen University and Research Centre (WUR), The Netherlands.
INTRODUCTION

In countries with agriculture-based economies, efforts to reduce rural poverty have prioritised labour-saving technologies for households (NARO, 2001; MAAIF, 2005; Carr and Hartl, 2010). These technologies are particularly important during the peak production season when labour requirements are high, and are aimed at reducing production costs for manual and hired labour. Women have been specifically targeted in the development and dissemination of these technologies because they are central to overcoming rural poverty (Carr and Hartl, 2010). The aim is to help them to redirect time spent on farming and domestic activities towards income-generating activities. Many technology development efforts have assumed that women would benefit if designs simply took into account women’s roles (Doss, 2001). The forage chopper is one such technology that was developed with a focus on women’s role in forage processing for zero grazing. The intention was to maximise efficiency of scarce labour time, and to ensure that women and their families directly benefit in terms of improved welfare.

This paper presents a study on the introduction of a forage chopper in Masaka district, Uganda, focusing on the way in which forage chopping was taken up by household members, with particular emphasis on the role of women. The study was triggered by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) review of technologies existing within the National Agricultural Research Systems (NARS) (MAAIF, 2005). The review showed that whereas Uganda had no shortage of improved technologies, some of these technologies remained ‘on the shelf’ because they were not commercially developed, packaged and marketed for the benefit of the majority of subsistence farmers.

Traditionally, farmers chop forage with a panga (a machete, see Figure 1A), cutting it into small pieces for easy consumption by livestock. In addition to low output capacity and inconsistent sizing, the hand method is tedious, time-consuming and quite dangerous to the operator. A labour-saving forage chopper (Figure 1B) was therefore developed by the National Agricultural Research Organization (NARO) to address these issues. When developing the forage chopper, the design team assumed that taking women’s roles in livestock production into consideration would guarantee its use and reduce women’s labour time in forage processing (Lubwama et al., 2001).

The study had the following objectives:

• to evaluate the extent to which the forage chopper improved women’s lives by lessening their workload;
• to determine how women can make a greater contribution to the development and dissemination of labour-saving technologies to increase their use; and
• to establish what is needed to make technology uptake and its use successful and conducive to broader goals of women’s empowerment.

METHODOLOGY

The methodology is based on insights from technology studies, anthropology and gender studies. In most studies, technology is regarded as an external factor that has a (measurable) impact after introduction. However, technology develops in interaction with its (social) environment. Studying this interaction is termed technography. Technography is the ethnography of technology (Jansen and Vellema, 2011); an attempt to map out actors, processes and client groups (Richards, 2003). Technography seeks to gather relevant information in order to understand broadly how tools, machines and social systems are combined and interact in any socio-technical system or process. This approach showed how technology works dynamically with human actors (Kien, 2008, 2009). Following this approach, the study mapped out different social entities and gathered information on domestic groupings, individuals/task groups.
including activity profiles of smallholder dairy farmers to understand what and how resources are being mobilised to evaluate use of the forage chopper. An in-depth qualitative realistic evaluation (Pawson and Tilley, 1997) was conducted to explore how the forage chopper interacted with its social milieu when it was introduced among smallholder women dairy farmers of Masaka District in Uganda.

The study was conducted in four dairying sub-counties, Kkingo, Kabonera, Mukungwe and Bukulula, that had benefited from the work of Send a Cow (SAC) and Heifer Project International (HPI). The study population comprised smallholder dairy farmers, owning one to five animals that grazed in the backyard of their homestead. Respondents included farmers and purposively selected key informants. Farmers with forage choppers (study group) were purposively sampled to provide information-rich cases that could be studied in depth for gender–technology relations. Farmers without forage choppers (control group) were randomly selected to ascertain what is typical of smallholder dairy farmers as a whole. At a later stage, two additional groups of farmers were purposively selected to gain a better understanding of the relevant actors in zero grazing. These were farmers with local animals, and farmers who grew forage to sell to smallholder dairy farmers. Sampling units were villages in the four sub-counties, and the unit of analysis was the household. Both villages and households were randomly selected.

Primary data (including other information) were obtained through in-depth, semi-structured and informal interviews, plus observations for both individuals and focus group discussions. A total of 120 farmers and 12 key informant interviews were conducted, plus four focus group discussions (FGDs). Data for all interviews were recorded in the form of detailed notes as well as digital recording. Data recording for FGDs was mainly in the form of detailed notes, made by farmers themselves, coupled with audio/video recordings of the process and events. Data recording for observations was mainly in the form of detailed notes, filming events and taking photographs to accurately capture settings. Data analysis was based on document analysis and cross-checking of documents, field notes and stored audio/video recordings. Computer Aided Qualitative Data Analysis Software (CAQDAS) – Atlas.ti 5.0 – was used for qualitative analysis.
RESULTS

Forage choppers were redesigned and adapted in their use

Analysis of the 35 households with forage choppers revealed that users deal with introduced tools differently. Simple adjustments and modifications, such as the removal of the plate, replacing bolts with nails, and using stepping blocks for children, facilitated easy usage of the machine (Figure 2). Beyond redesigning, analysis revealed a revolving process (designing) that largely involved mobilisation of community resources (manufacturers, materials) to facilitate use of the technology (Figure 3). Farmer interviews revealed that this allowed farmers to work within their financial constraints.

It was observed, however, that the design and redesign processes were independent of household categories. Rather, the processes were dependent on farmers’ access or proximity to welding and/or carpentry services, as well as access to materials. Similarly, the different farmers’ technology development roles were influenced more by the type or model of machine they used than the household category to which they belonged. Farmers’ technology development roles ranged from receiving the machine as an incentive, or purchasing the finished product, to sourcing materials and paying labour costs for manufacturing the machine.

Use and effectiveness depends on the social composition of households, community structure and support facilities

Analyses of labour use in 65 households (with and without chopper) showed that hired labour was an important factor in almost every household. It was expected that the introduction of labour-saving technologies would have resulted in a reduction in that type of labour, with hardly any impact on the workload of women. Interview material confirmed this tendency. Furthermore, analysis of major factors driving the use and uptake of forage choppers, based on interviews among all 35 using households, showed that access to artisans (welders and carpenters) was among the most cited factors. Interestingly, the presence of and access to local artisans was entirely overlooked in the project.
The socio-technical dynamics of the forage chopper were neither anticipated nor evaluated by the introducing agencies.

Analysis of users’ activities and household members revealed that the gender ideology no longer described the reality. The variable nature of users and households in terms of their composition and activities implied that the introduction of the chopper saved the labour not only of women. Interviews revealed that what mattered for the women, however, was their ability to redirect saved labour for their own benefit. However, these gender relations were not analysed before introducing the machine.

Interview data revealed that economic gains were derived from increased milk yields (from quality forage feeding) and a reduction in hired labour, as well as increased expenditure related to the costs of purchase, repair and maintenance. With such economic implications, one can expect farmers to make adjustments within their financial budget. The more selective and discriminating nature of users that emerged from the observations and interviews was a confirmation of coping with limited financial resources – an aspect that was overlooked as a factor which might impact the uptake and use of forage choppers.

**FIGURE 3: THE DESIGN PROCESS (MOBILISATION OF COMMUNITY RESOURCES)**
DISCUSSION AND CONCLUSION

Farmers’ ability to play an active role in the design and redesign processes of the forage chopper means that there is no ‘out-of-the-box’ technology. It is also a demonstration of users’ ability to mobilise local resources to address their needs. This indicates a need to rethink design procedures and allow for observational feedback as users interact with technology to enhance its practical usefulness. Users and designers should interact effectively to incorporate societal issues alongside technological ones, so as to broaden researchers’ practice. Although designers make some predictions about the social practices involved in use of technology during the design phase, there is still scope for people to use technology in other ways than those envisaged in the design process. It therefore becomes important to follow the process of integrating the technology within the user’s environment, because in that process, the technology may be transformed along with the users themselves.

Although the design and redesign processes were independent of household categories, these domestic groupings provide useful information on the incentives of both men and women for investing in labour-saving tools. This means that when introducing a machine, developers should be well informed about the resources available to users and how these are likely to be mobilised to facilitate usage. In technology development, women (users) are part of a socio-technical system, and within this system social elements and machines combine or intertwine to determine usage and outcomes. Hence targeting women with a device is, in itself, not sufficient to guarantee that women will benefit, let alone to lead to empowerment.

Mechanisation that reduces women’s drudgery in agriculture is one step towards their empowerment. However, increasing the efficiency of women’s labour time in agriculture requires a detailed understanding of how a new technology could be embedded into existing production strategies. It is concluded that empowerment of women with labour-saving tools requires ‘design-in-the wild’. The design process needs to be grounded and implemented with the reality on the ground by interdisciplinary teams.

COMMUNICATION STRATEGY AND IMPACT

Several communication strategies have been adopted to disseminate the findings of this research, including conference posters and presentations, newsletter articles, and a PhD thesis (Kiyimba, 2011). Demonstrated impact includes enhanced farmers’ awareness and understanding of the need to be part of the design processes if labour-saving tools are to work for them; and enhanced awareness among technology users and designers that technologies may not always serve the purpose for which they are intended, unless the social environment of users allows them to benefit from the intervention. The potential impact of current research lies in influencing: the training of agricultural engineering students; the design and development of labour-saving technologies; and the implementation strategies of women’s empowerment policies.

Recommendations of this research have already changed the design process of the manual forage chopper. As a means of improving technology uptake and use, engineers are developing a wooden manual chopper for the NARO/ASARECA project entitled ‘Harnessing crop-livestock integration to enhance food security and livelihoods resilience to effects of climate variability and climate change in Eastern and Central Africa’ (ASARECA LFP PRJ 12, funded by ASARECA). The aim is to reduce the cost of the machine as well as its size in order to facilitate its storage and portability.
ACKNOWLEDGMENTS

We wish to thank the Women in Science competition organisers/funders; the Netherlands Government (NUFFIC); the WUR supervisors; NARO; AEATREC colleagues; and the farmers and key respondents.

REFERENCES


INDIGENOUS AND CONVENTIONAL GENETIC RESOURCE CONSERVATION METHODS: STRATEGIES FOR CLIMATE CHANGE ADAPTATION IN MALAWI

M. Mngoli¹, D. Mkwambisi² and Y. Elhadi¹
ABSTRACT

Smallholder farmers in Malawi use traditional seed conservation methods as they lack access to high-quality seeds. Household interviews were conducted with 150 respondents in Chikhwawa district in Malawi to evaluate how different traditional conservation methods affect the quality and viability of seeds. Seed samples from each conservation method were collected and tested for seed viability using the germination test. Seed quality was then compared with that of seeds conserved conventionally at Chitedze Research Station. Results (given in percentages) show that the farmers were still using various traditional seed conservation methods, which include mixing seeds with ground nkina/neem (*Azadirachta indica*) leaves (27%), drying the seeds to reduce moisture (18%), mixing seeds with ash from burnt bean shells (14%), mixing seeds with ash from burnt animal dung (9%), and subjecting seeds to kitchen smoke (7%). The highest germination rates were obtained from samples conserved using ash from burnt bean shells, followed by those conserved with cow dung ash and ground nkina/neem leaves. Samples that were sun-dried (no treatment) and subjected to kitchen smoke were of a poor quality. There were no significant differences in the samples conserved by pirimiphos-methyl (Actellic) and ash from bean shells. It was recommended that efforts be directed towards promoting traditional seed conservation methods as a strategy for climate change adaptation and for achieving food security.

KEY WORDS: BEAN SHELLS, GERMINATION RATE, SEED QUALITY, VULNERABILITY AND FOOD SECURITY

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INTRODUCTION

Agriculture plays a very important role in Malawi’s economy, accounting for 39% of GDP, 85% of the workforce and 83% of foreign exchange earnings, with 80% of the food produced by smallholder farmers (Chirwa et al., 2006). However, the smallholder farming sector is threatened by several challenges, such as climate change and weather variability, poor quality seeds, pests and diseases. Consequently, productivity in this sector is generally low, with farmers failing to meet their food entitlements (Kerr et al., 2007). Adaptation to climate change is important in the agricultural sector, where there is a need for impact and vulnerability assessment and for the development of a climate change policy (Smit and Skinner, 2002).

Despite the introduction of a subsidy programme in Malawi in 2005/06, research has shown that only a few farmers are targeted, leaving the majority to secure their own planting materials (Dorward et al., 2010). In addition, mechanisms to protect seeds from pests and diseases using chemicals in storage are costly, forcing many farmers to depend on seeds from their own sources or harvest and traditional storage (Giller et al., 2009), which makes indigenous genetic resource conservation a strategy to contribute towards food security and achieve Millennium Development Goal (MDG) number one, which is to halve extreme poverty and hunger by 2015.

Conservation of genetic resources has allowed resource-poor farmers to meet their food production requirements (Mugabe, 1998). Chikhwawa district, the location of this study, was identified by the National Adaptation Programme of Action as among the most vulnerable in terms of climate change variability (Nangoma, 2007). The study was conducted to determine the effect of traditional seed conservation methods on seed quality and viability. A comparison of the effectiveness of maize and sorghum seeds (the main food crops for the area) conserved using indigenous and conventional genetic resource conservation methods was undertaken through a laboratory viability test.

MATERIALS AND METHODS

Study area

The study was conducted in Chikhwawa district in the southern part of Malawi. The district is located between latitude 16°12'42"S and longitude 34°40'34"E. The district has a total land area of 475,500 ha, of which 23,878 ha are used to cultivate sorghum (Sorghum bicolor L) and 38,818 ha to grow maize (Zea mays L). Over 80% of the population are smallholder farmers, and 65% live below the poverty line (Government of Malawi, 2002).

Research design

A semi-structured questionnaire was administered to 150 farmers selected from five villages in Traditional Authority Chapananga. Simple random sampling was used to select the sample. During these interviews, every conservation method was documented, including observing the type of materials used to construct the storage facility, treatment approaches, and associated costs. Focus group discussions were also conducted at each village, including men (10) and women (10), to gather general information on seed conservation and preservation, as well as to obtain clarification on the collected quantitative data. Quantitative data were analysed using the statistical package SPSS.

Seed samples were collected from each conservation method and transported to Chitedze Agricultural Research Station (CARS) for seed quality analysis, evaluating the germination rate, and physical and insect damage. For insect and physical damage, a sample of 100 seeds was randomly picked, the number of insect-damaged seeds were counted, and the percentage calculated.
To calculate the germination rate, 20 seeds from every sample were randomly selected and planted in a container maintained at an average atmospheric temperature of 25°C. The soil used was sterilised to kill all soil microorganisms, to ensure all the factors affecting germination were kept constant. The germination rate was calculated as follows:

\[
\text{germination rate} = \left( \frac{g}{N} \right) \times 100
\]

where \(g\) is the total number of seeds that germinated from each container and \(N\) is the total number of seeds planted in each container.

RESULTS

Inventory of existing indigenous genetic resource conservation methods

It was found that most of the farmers store their own seeds in various ways. Seed selection is based on size, pest- and disease-free status, seed colour, and other physical characteristics such as the seed being undamaged and clean. The seeds are dried to minimise seed moisture and then different conservation methods are applied. Several traditional seed conservation methods are used by the local farmers to maintain quality. Some of the methods used to conserve seeds are: mixing seeds with dried ground nkina/neem (Azadirachta indica) leaves (27%), followed by pirimiphos-methyl (Actellic) (23%) which is a modern seed conservation method, drying (18%), mixing seeds with ash from burnt bean shells (14%), ash from burnt cow dung (9%), subjecting seeds to kitchen smoke by hanging the seed above the cooking kiln (7%), and painting the seeds (2%).

Reasons for keeping their own seeds

The results (Figure 1) showed that the majority of the farmers (50%) kept their own seeds because this was the cheapest option. This was followed by those who indicated that their seeds provided resistance to pests and diseases (25%). Other reasons included drought tolerance and taste. This clearly showed that despite advocating for hybrid seeds, farmers still depend on their own
sources of seeds. For example, one female farmer from Mateuzo village said, during focus group discussions: “It is cheaper to use our own seeds because we are assured of their quality and we do observe their productivity while in the field. In addition, sorghum or millet seeds are hard to find in the market.”

The costs involved in conservation methods are relatively low and locally available, compared with conventional ways of conserving seeds. Tools commonly used are leaves, bags, hides and skins to dry the seeds; cow dung, and neem, which are burnt to yield ash to preserve the seeds; and clay pots for storage. Most of these seeds are stored in houses, trees and granaries constructed from locally available materials.

Germination results

Seed germination results are presented in Figure 2. Based on processing approaches and comparing between varieties, the results show that there were no statistical differences for seeds treated with Actellic (95% for maize and 87% for sorghum), this was also observed for those treated with ash from burnt cow dung (90% for maize and 70% for sorghum), and ground nkina/neem leaves (95% for maize and 60% for sorghum). However, the results indicate that seeds subjected to kitchen smoke had the lowest germination rate.

The standard (conventional) minimum germination rates for maize and sorghum being used at Chitedze Agricultural Research Station are 90 and 70%, respectively, as laid down by the Malawi Seed Act 2005 (No. 9 of 1996 Amended), meaning that a maize seed with an average germination rate below 90% is not considered to be viable, and likewise for a sorghum seed with a germination rate below 70%.

DISCUSSION AND CONCLUSION

The results showed that many farmers were conserving their own seeds using traditional techniques despite the availability of hybrid seeds. Farmers preferred traditional varieties as they are more resilient and lessen the plant’s vulnerability to pests and local climatic stresses. Apart from reducing input costs, conserving their own seeds also preserves the biodiversity of the area.

FIGURE 2: GERMINATION PERCENTAGES FOR MAIZE (LEFT) AND SORGHUM (RIGHT) SEEDS
Actellic proved to be very effective in seed preservation, but most farmers could not afford it; on the other hand, there were no significant differences in seed viability with seeds conserved using cow dung ash, ash from burnt bean shells and Actellic, since germination percentages for seeds which were conserved by cow dung ash were 90 and 70% for maize and sorghum, respectively. Ash from burnt bean shells yielded 100 and 75% for maize and sorghum, respectively. This is in line with a study by Wright et al. (1994), who reported that ash is effective in controlling insect damage to seeds as it damages the cuticle of the insects, causing them to dehydrate.

Maize conserved using ground (powdered) nkina/neem leaves passed the germination test at 95%. While sorghum seeds failed the germination test with a score of 60%, this could have been due to variations in seed longevity among species because of differences in genotype and origin. However, the method of conserving seeds by simply drying and subjecting them to kitchen smoke is not ideal, since this resulted in poor germination (17% for maize and 2% for sorghum). As observed during storage, these seeds had high levels of insect damage. Seeds stored above the fireplace were of poor quality due to variations in moisture content (Thamaga-Chitja et al., 2004). Therefore drying limits need to be introduced as over-drying affects seed quality because the most rapid deterioration occurs at high temperatures and humidity levels. Biochemical processes and other processes leading to deterioration are generally slowed down at low temperatures; in addition, low temperatures inactivate most seed insects and storage fungi (Schmidt, 2000).

The traditional seed conservation methods can act as a tool in improving food security, but if seeds continue to be incorrectly handled, this can lead to poor quality seeds being produced for longer periods (Delouche and Baskin, 1973). The traditional conservation methods require continuous observation and improvements and careful handling, as seed deterioration occurs at every stage of seed conservation and is influenced by handling from collection and transport through processing.

Subjecting seeds to kitchen smoke should be discouraged as it results in poor germination. Seeds need to be stored in airtight containers to reduce air circulation, which reduces the number of insects (Wambugu et al., 2009). Furthermore, artificial insecticides such as Actellic must be handled carefully as they can be hazardous to health if recommended amounts are exceeded. High concentrations of Actellic in foods can result in poisoning and sometimes death (Omoyakh and Ohuruata, 2009). Lastly, women in the area are more involved in the process of seed conservation than men, thus there is a need to empower women in seed conservation.

**COMMUNICATION STRATEGY AND IMPACT**

The study team organised a local workshop as a way of giving back and sharing the findings with the local communities. The workshop was attended by local leaders, extension workers and farmers’ representatives. Recommendations were made for the participants to share with other farmers. In addition, this paper was presented at the National Symposium on Climate Change and Environment in Lilongwe, Malawi, on 20 October 2011, which was attended by various stakeholders including government officials, NGOs and academics, among others, demonstrating the importance of traditional seed conservation and how they can assist.
ACKNOWLEDGEMENTS

We are very grateful to the Developing Partnerships in Higher Education (DelPHE) project, through the Department for International Development (DFID), for funding this project. Many thanks to Chitedze Agricultural Research Station staff for providing guidance throughout the lab analysis. Our sincere thanks also to the Chikhwawa district farmers for allowing us to use their seeds and for sharing their knowledge and ideas.

REFERENCES


RESISTANCE TO SPOTTED STEM BORER IN COMMERCIAL MAIZE HYBRIDS AND OPEN-POLLINATED VARIETIES IN KENYA

S.W. Munyiri¹,² and S.N. Mugo³
ABSTRACT

Lepidoptera stem borers are major maize insect pests estimated to be responsible for annual losses of around 15% in sub-Saharan Africa and 13.5% in Kenya. The spotted stem borer (Chilo partellus Swinhoe, Lepidoptera: Crambidae) is the most widespread and damaging field pest. The objective of this study was to evaluate the resistance of commercial maize hybrids and open-pollinated varieties (OPVs) to C. partellus. Eighty-five hybrids, 15 OPVs, and selected stem borer-resistant hybrids were evaluated for resistance to stem borers using artificial infestation in the field for two seasons at KARI Kiboko Centre, Kenya. The α-lattice design replicated three times was used in 2 × 5 m row plots spaced at intervals of 0.75 × 0.25 m. Ten plants in each plot were artificially infested with five stem borer neonates 3 weeks after planting. The remaining plants were concurrently treated with a pesticide. Data were collected on leaf damage score, stem borer exit holes, stem tunnelling, plant height and grain yield. A selection index based on damage parameter traits was computed and used to group the genotypes into susceptible and resistant categories. Data were analysed using the SAS package and means were separated using Fisher’s protected least significance difference (LSD) at \( P < 0.05 \).

The genotypes differed significantly \( (P < 0.05) \) in stem borer resistance. The CIMMYT resistant hybrid controls showed the highest resistance with a selection index of 0.61. Commercial hybrids DHO1, PH1 and PH3253, and OPVs ECA-STRIGOFF-VL-102-##, KDV1-1 and KDV1-2, were the most resistant with a selection index of 0.77. It was concluded that commercial hybrids and OPVs grown in Kenya display an appreciable level of resistance to maize stem borer. The new CIMMYT genotypes from the Insect Resistant Maize for Africa (IRMA) project, developed for borer resistance, remain the most superior in resistance. The resistant genotypes should be promoted for production and exploited for breeding in the relevant maize-growing ecologies.

KEY WORDS: CHILO PARTELLUS, GENOTYPES, LEAF DAMAGE, SUPERIOR, SUSCEPTIBLE

AFFILIATIONS

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INTRODUCTION

Maize insect pests are a major constraint to production in sub-Saharan Africa, causing significant yield losses and grain quality degradation (M’mboyi et al., 2010). Maize is Kenya’s staple food, with an annual consumption level of 125 kg per capita (Pingali, 2001). Resource-poor smallholders are responsible for 70% of maize production. The high population growth rate, estimated at 2.9%, has not been proportional to the very gradual maize productivity increase over the past 20 years (Kenya National Bureau of Statistics, 2009). The continuing and widespread hunger since the 1980s has been attributed to various abiotic and biotic stress constraints, including maize stem borer damage (McCann, 2006). To offset the production deficit, Kenya imports about 13% of its consumption annually. Any threat to this source of staple food endangers food security in sub-Saharan Africa, and in Kenya.

In Kenya, maize stem borers account for 13.5% of annual yield losses, but damage depends on the maize variety and the stage of attack (De Groote, 2002). Chilo partellus Swinhoe is a highly invasive pest that has become the most important maize stem borer in Kenya since its introduction in the 1930s (Mbapila et al., 2002). Reducing stem borer damage would improve maize yields, increase farmers’ on-farm income, and strengthen Kenya’s food security, thus reducing cases of hunger and malnutrition and saving on the foreign exchange used for the importation of maize.

Maize stem borer damage has been reported to affect plant growth, and specifically ear development, impacting negatively on grain yield (Afzal et al., 2009). The stem borer larva feeds on young maize leaves, producing characteristic windowing and reducing the photosynthetic area, and then bores into the stem where it feeds on the pith. This damage affects the translocation of food to the developing ear, leading to reduced grain yields (Tefera et al., 2011). Chemical control of stem borers is expensive for resource-poor smallholder farmers and is also not environmentally friendly, while cultural methods are not always effective and some require the farmers to have specialist skills.

Host plant resistance packaged in a seed constitutes a suitable pest management solution and is beneficial to the farmer as it can easily be adopted. Host plant resistance eliminates the environmental risks, is compatible with other insect pest control methods and confers many other advantages (Afzal et al., 2009). If resistance breeding works against pests, then Africa can in all likelihood reduce yield losses, thus increasing productivity and improving livelihoods.

Knowledge on levels of stem borer resistance in commercial maize hybrids and open-pollinated varieties (OPVs) is scant. Information on maize genotypes with appreciable levels of resistance to stem borer pests is needed for the diverse maize-growing ecologies of Kenya. This knowledge will assist farmers in correctly selecting which varieties of maize seeds to use, thereby improving yields and impacting positively on livelihoods. The objective of this study was to evaluate commercially grown maize hybrids and OPVs for C. partellus resistance in Kenya.

MATERIALS AND METHODS

Site description

The study was conducted at the Kenya Agricultural Research Institute (KARI) Kiboko Centre during the 2010/11 rainy seasons. Kiboko lies 950 m above sea level and receives about 530 mm of rainfall per annum, in two distinct seasons. The maximum daily temperature is 35°C and the minimum 14°C. The soils at the centre are clay sandy.

Genotypes

Eighty-five hybrids, including hybrids developed by the International Maize and Wheat Improvement Centre (CIMMYT) under the Insect Resistant Maize
for Africa (IRMA) Project, and 15 improved OPVs were evaluated for resistance to C. partellus using artificial infestation in the field for two growing seasons. All of the commercial varieties were sourced from commercial suppliers of certified hybrid maize seeds. Among the controls used were five hybrids developed for resistance to stem borers and released in Kenya, but which were not yet fully commercialised, and other experimental insect-resistant hybrids.

**Experimental design, infestation, data collection and agronomic practices**

The α-lattice design replicated three times was used in a 2 x 5 m row plot spaced at intervals of 0.75 m between rows and 0.25 m between plants. The first 10 plants in each plot were artificially infested with five stem borer neonates 3 weeks after planting. The remaining 16 plants per row were concurrently treated with a pesticide (Buldock® 25 EC = 25 g/l beta-cyfluthrin a.i.) to act as a control.

The crop was grown under rainfed conditions with additional irrigation provided as needed. Fertilisers were applied at the rate of 60 kg/ha N and 102 kg/ha P₂O₅ at planting. The crop was top-dressed at the rate of 48 kg/ha N 30 days after planting. Data taken included stem borer leaf (on a scale of 1–9 on an individual basis, where 1 = no visible leaf damage and 9 = plants dying as a result of leaf damage; Tefera et al., 2011), number of borer exit holes (counts), cumulative stem tunnelling (cm), stem lodging (%), plant height (cm) and grain yield (t/ha).

**Data analysis**

Data were analysed using the SAS package (SAS 2001). Analysis of variance was carried out and the means compared using Fisher’s protected least significant difference test (LSD) at (P < 0.05). A selection index based on the damage parameters evaluated was computed and used to group the cultivars into susceptible and resistant categories as described by Tefera et al. (2011).

**RESULTS**

The genotypes showed significant (P < 0.05) differences in stem borer damage resistance levels. The means for leaf damage score, borer exit holes and cumulative tunnel length were 2.23, 6.52 and 23.61 cm, respectively. The selection index categorised the hybrids and OPVs into 20 resistant (<0.8), 37 moderately resistant (0.8–1.0), 27 moderately susceptible (1.0–1.2), and 16 susceptible cultivars (>1.2) (Figure 1). The three topmost resistant genotypes were CIMMYT resistant checks, CKIR09007, CKIR06009, CKIR09006, CKIR06006 and CKIR09005, with selection indices of 0.50, 0.59, 0.62, 0.66 and 0.67, respectively. The best commercial hybrids and OPVs were DH01, PH1, ECA-STRIGOFF-VL-102-#, KDV1-2-# and PH 3253, with indices of 0.67, 0.76, 0.77, 0.79 and 0.8, respectively (Table 1). Susceptible varieties were mainly the commercial hybrids H628, H6213 and H626, with indices of 1.85, 1.72 and 1.61, respectively.

The highest grain yield under infestation was in CKIR09007, a CIMMYT moderately resistant hybrid (9.70 t/ha), while the lowest was commercial hybrid DH02 (3.12 t/ha) (Table 1). It was also the lowest yielding under protected conditions (3.56 t/ha). The highest yielding under protected conditions was H629 (10.03 t/ha), a susceptible commercial hybrid. Susceptible commercial hybrid H629 gave the highest yield under both infested (9.44 t/ha) and protected conditions (10.03 t/ha), even though it was highly susceptible (1.47). The mean plant height was 135 cm in protected plots and 126 cm in infested plots, a reduction of 7%. Mean plant height in protected plots was 224.52 cm, and 215.69 cm in infested plants.
DISCUSSION

The CIMMYT hybrids, bred specifically for stem borer resistance, scored the highest resistance levels. Some commercial hybrids performed well in spite of the high borer susceptibility. The resistant commercial varieties gave lower yields (4.93 t/ha) than those of resistant CIMMYT hybrids (7.90 t/ha). Borer damage reduced the mean plant height by 8.5 cm in the genotypes. Plant height is a major yield component in maize, and a reduction translates to lowered yields. Plant height was negatively correlated to all the damage parameters (leaf damage, number of exit holes and tunnel length). Grain yield decreased with increasing leaf damage. In Afzal et al.’s (2009) study, leaf damage was a good indicator of borer susceptibility and was reported to negatively affect grain yield in maize.

Six commercial hybrids and OPVs demonstrating appreciable levels of resistance and tolerance to C. partellus stem borer were identified from all the maize production ecological zones; the majority, however, were located in the low altitude (PH1) to mid-altitude ecological zones (DH1, ECA- STRIGOFL-102-#, KDV1-1, KDV1-2). Susceptible cultivars were mainly the late-maturing, high-altitude ecologies, including commercial hybrid H629, which was highly susceptible with a selection index of 1.46, but also high-yielding under both protected (10.00 t/ha) and infested conditions (9.44 t/ha). Muturi et al. (2012) reported tolerance to stem borers in several sorghum genotypes. The yield in the commercial varieties could probably be enhanced through enhanced stem borer resistance.

FIGURE 1: CATEGORIES OF COMMERCIAL HYBRIDS AND OPVs EVALUATED FOR RESISTANCE TO CHILO PARTELLUS STEM BORER

<table>
<thead>
<tr>
<th>Categories</th>
<th>No. of hybrids and OPVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistant</td>
<td>30%</td>
</tr>
<tr>
<td>Moderately resistant</td>
<td>45%</td>
</tr>
<tr>
<td>Moderately susceptible</td>
<td>35%</td>
</tr>
<tr>
<td>Susceptible</td>
<td>20%</td>
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</table>
### TABLE 1: MEANS OF THE SIX MOST RESISTANT AND SUSCEPTIBLE HYBRIDS AND OPVs TO CHILO PARTELLUS BORER DAMAGE

<table>
<thead>
<tr>
<th>CIMMYT hybrid controls</th>
<th>Index</th>
<th>LD</th>
<th>EH(#)</th>
<th>TL</th>
<th>IGY</th>
<th>PGY</th>
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<tr>
<td>CKIR09007</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>7.31</td>
<td>7.21</td>
<td>7.96</td>
</tr>
<tr>
<td>CKIR06009</td>
<td>0.59</td>
<td>1.49</td>
<td>3.84</td>
<td>11.99</td>
<td>6.83</td>
<td>8.19</td>
</tr>
<tr>
<td>CKIR09006</td>
<td>0.62</td>
<td>1.74</td>
<td>3.28</td>
<td>13.76</td>
<td>5.74</td>
<td>7.72</td>
</tr>
<tr>
<td>CKIR06006</td>
<td>0.66</td>
<td>1.38</td>
<td>4.11</td>
<td>17.09</td>
<td>6.88</td>
<td>7.46</td>
</tr>
<tr>
<td>CKIR09005</td>
<td>0.67</td>
<td>2.18</td>
<td>3.33</td>
<td>12.49</td>
<td>7.62</td>
<td>8.18</td>
</tr>
<tr>
<td>Mean for CIMMYT controls</td>
<td>0.61</td>
<td>1.76</td>
<td>3.31</td>
<td>12.53</td>
<td>6.86</td>
<td>7.9</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Resistant hybrids and OPVs</th>
<th></th>
<th></th>
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<th></th>
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<tr>
<td>DH01</td>
<td>0.67</td>
<td>2.55</td>
<td>3.35</td>
<td>8.42</td>
<td>4.44</td>
<td>6.16</td>
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<td>PH1</td>
<td>0.76</td>
<td>2.21</td>
<td>4.05</td>
<td>16.02</td>
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<td>ECA-STRIGOFF-VL-102-#-</td>
<td>0.77</td>
<td>2.24</td>
<td>4.34</td>
<td>15.21</td>
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<td>5.55</td>
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<tr>
<td>KDVI-2-#</td>
<td>0.79</td>
<td>2.46</td>
<td>4.99</td>
<td>12.05</td>
<td>3.42</td>
<td>3.86</td>
</tr>
<tr>
<td>KDVI-1-#</td>
<td>0.81</td>
<td>2.09</td>
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<td>18.96</td>
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<td>4.57</td>
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<td>PH 3253</td>
<td>0.81</td>
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<td>4.55</td>
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<td>Mean resistant hybrids and OPVs</td>
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<td>2.36</td>
<td>4.3</td>
<td>14.15</td>
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<td>H628</td>
<td>1.85</td>
<td>2.59</td>
<td>14.21</td>
<td>52.23</td>
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<td>H6213</td>
<td>1.72</td>
<td>2.38</td>
<td>13.7</td>
<td>47.06</td>
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<td>9.23</td>
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<td>1.61</td>
<td>2.5</td>
<td>11.22</td>
<td>47.04</td>
<td>8.54</td>
<td>9.05</td>
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<td>611D</td>
<td>1.55</td>
<td>3.09</td>
<td>10.68</td>
<td>38.63</td>
<td>7.45</td>
<td>7.93</td>
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<td>H6210</td>
<td>1.48</td>
<td>2.31</td>
<td>10.38</td>
<td>42.69</td>
<td>7.78</td>
<td>8.55</td>
</tr>
<tr>
<td>H629</td>
<td>1.46</td>
<td>2.34</td>
<td>10.34</td>
<td>41.12</td>
<td>9.44</td>
<td>10</td>
</tr>
<tr>
<td>Mean for susceptible genotypes</td>
<td>1.61</td>
<td>2.53</td>
<td>11.75</td>
<td>44.8</td>
<td>8.17</td>
<td>8.78</td>
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<thead>
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<td>CV</td>
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<td></td>
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<tr>
<td>P</td>
<td>&lt;0.0001</td>
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<tr>
<td>LSD</td>
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<td>2.69</td>
<td>11.77</td>
<td>1.79</td>
<td>2.16</td>
<td></td>
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</tbody>
</table>

**LD**, leaf damage; **EH**, number of exit holes; **TL**, tunnel length (cm); **IGY** (t/ha), infested grain yield; **PGY** (t/ha), protected grain yield; **IPHT**, infested plant height (cm); **PPHT**, protected plant height (cm); **CV**, coefficient of variation; **LSD**, least significant difference.
CONCLUSIONS

It was concluded that diversity for resistance and tolerance to *Chilo partellus* stem borer existed among the commercial hybrids and OPVs. The CIMMYT hybrids developed for stem borer resistance showed the highest resistance. Some commercial hybrids yielded well despite the presence of insect damage, indicating tolerance. The OPVs exhibiting resistance to the borer could be promoted for production and, in addition, used to strengthen maize resistance to *C. partellus*. The commercial hybrids identified as resistant or tolerant should be promoted for production in the relevant zones for improved maize productivity.

COMMUNICATION STRATEGY

It is envisioned that the results of this research will be communicated to farmers through the Ministry of Agriculture’s research–extension liaison division. Where appropriate, hard copy materials (pamphlets) and/or electronic communications (emails) will be distributed, and subject-matter specialists will be trained as trainers. The results will also be published in a peer-reviewed journal for the wider scientific audience.

The findings of this study will be dispersed to producers and breeders. It is expected that the dissemination and adoption of the information on resistant/tolerant commercial hybrids and OPVs in the Kenyan market will help to reduce borer-related losses. Farmers will earn more from improved yields at no extra cost, leading to improved nutrition, food security and better livelihoods. This empowerment is especially critical for resource-poor small-scale farmers.

ACKNOWLEDGEMENTS

We wish to thank the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and the Syngenta Foundation for Sustainable Agriculture through the Development of Resistant Maize to Stem Borer and Storage Insect Pests for Eastern and Southern Africa (IRMA III Project) for co-funding this research.

REFERENCES


IDENTIFICATION, ISOLATION AND FUNCTIONAL CHARACTERISATION OF A SORGHUM SECRETORY PEROXIDASE RESPONSIVE TO DROUGHT AND SALT STRESSES

R. Ngara¹*, M.G. Du Plessis² and B.K. Ndimba³⁴
ABSTRACT

Plant cells secrete proteins into the extracellular matrix. These proteins play important roles in cell–cell communication, cell growth and development, and in responses towards both internal and external stimuli. An experiment was conducted to analyse and characterise proteins that are secreted into the culture medium of sorghum cell suspensions in response to salt and drought stresses. Sorghum cultured cells were treated for 6 h with 200 mM NaCl and 400 mM sorbitol, simulating salinity and drought stresses, respectively. After stress treatments, the secreted proteins were extracted from the spent medium using filtration and acetone precipitation methods. The protein extracts were then separated by one- and two-dimensional gel electrophoresis (1DE and 2DE) and visualised after staining with Coomassie Brilliant Blue stain. Western blotting analysis of the secreted protein extracts against β-tubulin and Hsp70 indicated that there were no cytoplasmic protein contaminants in the secretome preparations. Gel analysis of the 2DE expression profiles of the treated samples indicated that a protein spot, CF1 (identified as a secreted peroxidase), was responsive to both salt and drought stresses. This protein was subsequently identified by matrix-assisted laser desorption/ionisation time-of-flight-/time-of-flight (MALDI TOF-TOF) mass spectrometry (MS) as a putative secreted peroxidase. Peroxidases are known oxidative stress-responsive proteins, a common secondary stress of both salinity and drought stresses. Preliminary polymerase chain reaction (PCR) of the entire CF1 gene showed the production of two co-amplifying bands, both matching the mass spectrometry identified gene products with 84 and 100% levels of identity denoted as Pex1 and Pex2, respectively. Molecular cloning and over-expression of Pex2 in bacterial systems is currently under way, with the ultimate aim of structurally and functionally characterising the purified CF1 protein.

KEY WORDS: ABIOTIC STRESSES, MASS SPECTROMETRY, PEROXIDASE, SECRETOME, TWO-DIMENSIONAL GEL ELECTROPHORESIS

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INTRODUCTION

Abiotic stresses such as drought and high soil salinity affect the growth, development and ultimately the productivity of crops (Wyn Jones, 1981; Zhu, 2001). This impacts negatively on the human food supply chain, and millions of people living in marginal areas worldwide are experiencing constant hunger. The world population is increasing very rapidly. Currently it is estimated to be about 7 billion, and by 2050 is projected to hit the 9.3 billion mark (United Nations Population Fund, 2009). In order to feed this ever-growing population, the use of biotechnological research initiatives such as genomic and proteomic approaches, which are aimed at increasing crop productivity in marginal areas that are worse hit by the effects of climate change, should be encouraged.

Proteomics is the large-scale study of proteins expressed by an organism, tissue, cell or cellular compartment at a given time under specific conditions (Blackstock and Weir, 1999). Proteomics technologies may be used for the identification of biotic and abiotic stress-responsive proteins. Thereafter, expressed genes of interest may be used to genetically engineer other susceptible crops, thus improving their stress-tolerance levels and increasing crop productivity in marginal areas. Proteomics tools may also be used to study stress-responsive elements of the plant secretome. The secretome is a group of proteins secreted out of the cell into the extracellular matrix. They play important roles in cell growth and developmental processes, as well as in signal perception and transduction of internal and external stimuli (Showalter, 1993). Although the secretomes of crops such as maize and rice under a range of abiotic stress conditions have been studied, as reviewed by Agrawal et al. (2010), it appears that no similar studies on sorghum have been researched and reported to date.

This study reports on the proteomic analysis of the sorghum secretome in response to salinity and drought stresses. Sorghum is a naturally drought-tolerant and moderately salt-tolerant cereal. Its genome sequence is publicly available and provides genetic resource material for the identification of responsive elements in proteomics studies. As such, sorghum is a potentially readily available model system for proteomics studies in drought and salt tolerance. The main objective of this work is to identify stress-responsive proteins of the sorghum secretome using proteomic tools. The second objective is to characterise them using molecular biology tools; and the third, to determine their involvement in abiotic stress responses using transgenics. The results of these three objectives will help us to gain a better understanding of sorghum stress-response mechanisms. The knowledge acquired in the study will provide invaluable information on the array of expressed genes, which could be used for the genetic manipulation of salinity and drought tolerance of susceptible crops, in an effort to improve crop productivity and food security in dry and arid and semi-arid lands (ASAL) worldwide.

MATERIALS AND METHODS

Maintenance of cell cultures, stress treatments and protein extraction

Sorghum cell suspension cultures were initiated and maintained in liquid culture as previously described by Ngara et al. (2008). At 10 days post-subculture, 100 ml cultures were divided into three subcultures and subsequently treated with water, 200 mM NaCl or 400 mM sorbitol, simulating the control, salt and drought stresses, respectively. The treated cells were incubated at 25°C for 6 h under dark conditions while being shaken at 130 rpm. After stress treatments, secreted proteins were extracted from the spent culture media using filtration and acetone precipitation methods, and resolubilised in urea buffer as previously described (Ngara et al., 2008, 2011). The secreted protein extracts were quantified using a modified Bradford assay and assessed for cytoplasmic protein contamination by Western blotting analysis against β-tubulin and Hsp70 as previously described (Ngara and Ndimba, 2011).
Protein separation by 2DE and identification by MALDI TOF-TOF MS

The secreted proteins were separated by 2DE using 7-cm immobilised pH gradient strips of linear pH range 4–7 (Bio-Rad, Hercules, CA, USA) as previously described (Ngara et al., 2011). Three biological replicate gels were run for each treatment group. After electrophoresis, the gels were stained with Coomassie Brilliant Blue for protein visualisation and imaged using the Molecular Imager PharosFX Plus System (Bio-Rad). Protein expression changes between the control, salt and hyperosmotic stress treatments were visually assessed. One reproducible protein spot was selected for identification by MALDI-TOF-TOF MS as previously described (Ngara et al., 2012).

RNA extraction, cDNA synthesis and PCR amplification of the target gene

Total RNA was extracted from sorghum suspension cultured cells using the RNeasy Plant Mini Kit (Qiagen, Valencia, CA, USA) according to the manufacturer’s instructions, and run on a 1% (w/v) agarose gel to assess sample purity and integrity. cDNA was synthesised from the RNA extracts using the Transcriptor First Strand cDNA Synthesis Kit (Roche Applied Science, Werk Penzberg, Germany) according to the manufacturer’s instructions. The cDNA was subsequently used as a template for PCR amplification of the entire gene of interest using gene specific primers: Forward_5´-ggatccATGGCGGCGAGCAAGGTGC-3´ and Reverse_5´-ctcgagCTAGTTGACGACCCGGCAG-3´, with BamH1 and Xho1 restriction sites, respectively. The amplicon was cloned into a pTZ57R/T cloning vector using the InstAclone PCR cloning kit (Thermo Scientific, Rockford, IL, USA).

RESULTS

Sorghum plant material

Sorghum cells in suspension were propagated and maintained in culture in our laboratory for use in secretome studies. Figure 1 illustrates sorghum callus from which cells in suspension were initiated.
Protein separation by gel electrophoresis and identification by mass spectrometry

After stress treatments, secreted proteins were extracted from the spent culture media and separated by both 1DE and 2DE. Western blotting analysis of the secreted protein extracts against two cytoplasmic proteins, β-tubulin and Hsp70, showed that the secretome preparations were free from cytoplasmic contaminants. An example of a stress-responsive protein, CF1, is highlighted in Figure 2. This protein spot was identified by MALDI-TOF-TOF MS as gi|242040821, a hypothetical protein SORBIDRAFT_01g034420, which is similar to a Class III peroxidase.

PCR amplification of the CF1 gene

PCR amplification of the entire gene of interest using gene-specific primers consistently yielded two gene products denoted as Pex1 (top band) and Pex2 (bottom band) as illustrated in Figure 3(A). These PCR products were subsequently separated by band excision and re-amplified by PCR as shown in Figure 3(B), gel purified and sent for sequence analysis to verify their similarity to the gene of interest gi|242040821.

BLAST searches of the DNA sequencing results using the National Center for Biotechnology Information blastx program indicated that both PCR products were similar to Sb01g034420, with 84 and 100% levels of identity for Pex1 and Pex2, respectively. For this reason, Pex2 was selected for subsequent molecular cloning experiments. To date, Pex2 has been cloned into a pTZ57R/T cloning vector. Positive recombinant clones have been analysed by both colony PCR and restriction enzyme digestion using BamH1 and Xho1. Both these methods indicated that the desired PCR fragment of about 1 kb has been successfully cloned into the vector.
DISCUSSION AND CONCLUSION

Secreted proteins free from cytoplasmic protein contaminants were extracted from the spent media of sorghum suspension cells. This indicated that the experimental system was suitable for subsequent use in protein expression studies of the secretome. 2DE analysis of the extracts following 200 mM NaCl and 400 mM sorbitol treatments revealed that a protein spot CF1, identified as a secreted peroxidase, was responsive to both salt and drought stresses. The results are consistent with the knowledge that peroxidases are involved in stress-responsive roles against oxidative stress, a secondary stress of hyperosmotic stresses such as salinity and drought/dehydration. Preliminary PCR amplification of the CF1 gene yielded two gene products with high similarity to the gene of interest, an indication that the laboratory procedures and processes used succeeded in isolating the gene of interest from the sorghum genome. Molecular cloning and the over-expression of CF1 in a bacterial system using the pGEX 6P-2 vector is currently under way. The over-expressed protein will be purified and characterised for its molecular function using in vitro tests. The CF1 gene will subsequently be used to assess its action on the stress tolerance of other drought- and salinity-susceptible crops using transgenic approaches.

FIGURE 3: PCR AMPLIFICATION OF THE CF1 GENE: (A) CO-AMPLIFICATION OF TWO GENE PRODUCTS, Pex1 (TOP BAND) AND Pex2 (BOTTOM BAND) IN LANE 1; (B) SEPARATION AND AMPLIFICATION OF Pex1 (LANES 1 AND 2) AND Pex2 (LANE 3 AND 4) PCR PRODUCTS AS INDIVIDUAL GENE PRODUCTS
INFORMATION AND
COMMUNICATION STRATEGY

This sorghum proteomics work is being documented in scientific journals for dissemination to research communities worldwide. Some of the research outputs in sorghum proteomics include Ngara et al. (2008, 2012); Ngara and Ndimba (2011); Ndimba and Ngara (2013). Following the genetic engineering experiments, we intend to collaborate with plant breeders and seed producers so that the transgenic plants are evaluated for their potential to grow under different environmental conditions. If the transgenic crops are adopted and accepted by farming communities, crop productivity and food security may be improved.

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REFERENCES


RICARDIAN ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON CROPLAND: THE CASE OF THE SUDANO-SAHELIAN AREA OF CAMEROON

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ABSTRACT

Rising temperatures, combined with declining rainfall and frequent droughts, have resulted in a succession of bad cropping years in the Sudano-Sahelian Area (SSA) of Cameroon. The prevailing climate change scenario has further exacerbated the situation. A study was therefore designed to determine the impacts of long-term climate change on crop farming activities and to identify suitable adaptation options for the SSA of Cameroon. The Ricardian model was used, and 708 cultivated plots from 303 cotton producers in SSA were selected during a survey carried out as part of the Water Soil Tree (Eau Sol Arbre, ESA) project between 2008 and 2009. Annual crop net revenue was regressed on climate and other variables. Results showed that an annual increase in temperature will impact negatively on irrigated and dryland farms in the Lake Lagdo watershed. Simulations showed that improving access to irrigation could increase productivity gains to above 20%. Most of the farmers were aware of climate change and some had taken adaptive measures. These findings provide information about increasing temperatures and decreasing precipitation that are detrimental to agricultural productivity, and also suggest that Cameroon should start to plan for climate contingencies.

KEY WORDS: CROP REVENUE, DRYLAND, IRRIGATED, PRECIPITATION, RICARDIAN MODEL

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INTRODUCTION

In Cameroon, the agricultural sector contributes to 30% of gross domestic product, generates about 15% of the country’s revenue and employs about 60% of the population. Moreover, agricultural activity induces most of the spread effects on other sectors of the economy, thus contributing to export diversification, job creation and poverty reduction (INS, 2005). In the Sudano-Sahelian Area (SSA), climate change is associated with causing difficulties for resource-poor, small-scale farmers. In fact, subsistence crop production in Cameroon is traditionally rainfed, with very limited areas left for irrigation. Low rainfall in 1997 in SSA directly affected crop yields and caused livestock deaths, leading to hunger and triggering the need for food aid. In March 2005, the SSA was again hit by food shortages, requiring external intervention from international aid agencies (Molua, 2008). In addition to directly affecting crop yields, drought has prompted an increased migration of pastoralists and nomads from SSA to the south of Cameroon (Abou et al., 2006).

The link between agriculture and climate change is widely recognised in the literature. Many research findings indicate that climate change has a significant impact on tropical regions; poor countries are particularly vulnerable to its harmful effects. The vulnerability of poor countries is attributable to their technological, resource and institutional constraints (Kurukulasuriya and Mendelsohn, 2006). The impact of climate change on agriculture in developing countries has been increasing. Some attempts have been made to estimate this impact (Mendelsohn and Dinar, 2003). The impact of climate change in Africa is a new area of research. A well known study in this respect is the one carried out under the Global Environmental Facility (GEF)/World Bank project entitled ‘Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa’. This study covers the key agro-climatic zones and farming systems of the study countries (Kurukulasuriya and Mendelsohn, 2006).

The study showed that many African countries which have economies largely based on weather-sensitive agriculture are vulnerable to climate change. This vulnerability has been demonstrated by the devastating effects of recent flooding and the various prolonged droughts of the twentieth century. Higher temperatures and changing precipitation levels caused by climate change have depressed crop yields. This is particularly true in low-income countries, where adaptive capacities are low.

The SSA of Cameroon, which is dependent on rainfed agriculture and has a low level of socio-economic development, is highly affected and vulnerable to climate change. There has been minimal research on the effects of climate change with respect to the SSA of Cameroon. Moreover, the available literature on climate change impacts on agriculture is not comprehensive, particularly in terms of a lack of economic assessment that takes into consideration the climate, soil and socio-economic aspects of small-scale, resource-poor farmers. A well known study for Cameroon is that by Molua (2008), which was conducted using sub-regional (agro-ecology) agricultural data rather than household-level data. The scope of his analysis ignored basic household-specific characteristics that are potentially the key to designing effective adaptation strategies. This study attempts to fill the existing research gap in the literature by examining the impact of climatic variables such as temperature and precipitation on crop farming activities of irrigated and dryland farms. Insufficient variation (spatial variation) on key climatic variables (precipitation and temperature) in cross-sectional data is one of the major limitations on climate change impact studies. This is particularly true in developing countries, where one meteorological station covers a wide geographic area (Yesuf et al., 2008).
The objective of this study was to determine the impacts of long-term climate change on agriculture and to identify options for adaptation in the SSA of Cameroon. The specific aims of the study were to: (1) evaluate the extent of the relationship between agricultural income and climate variables; (2) determine the impact of temperature and precipitation on agricultural income; (3) identify choices for adaptation measures that farmers are using to mitigate the potential effects of climate change; and (4) predict the range of potential future impacts on agriculture under uniform climate change scenarios.

MATERIALS AND METHODS

The Ricardian model was used to capture the influence of economic and environmental factors on farm incomes or land values. The empirical models developed for this study follow the work of Mendelsohn and Dinar (2003) and take into account the climate in the SSA of Cameroon. The models examined how long-term farm profitability varies with climate (temperature and precipitation) and soils, while controlling for other factors. Relevant socio-economic variables were also assessed to gauge the extent to which they control or exacerbate the adverse impact of climate change on crop agriculture.

Two main models were formulated: ‘without’ adaptation and ‘with’ adaptation. The former included only climate and soil variables, while the latter, in addition to these variables, included relevant socio-economic variables such as whether the farm irrigated, cropland area, livestock ownership, distance to nearest market for obtaining inputs and selling products, access to formal extension, farm-to-farm extension, access to formal credit, household size, years of education of the household head, and farming experience.

The data were entered in SPSS version 14.0 software and first analysed using descriptive statistics to show the characteristics of the farmers. A statistical and econometric package (STATA) was used to estimate the Ricardian model for the SSA of Cameroon.

Data and variables included

The analysis was performed on household-level data relating to farm activities, climate, soils and socio-economic information. Farm household data were obtained from a cross-sectional household survey of farmers carried out in the framework of the Water Soil Tree (Eau Sol Arbre, ESA) project during the 2008/09 production year on 303 cotton producers in 10 villages of the Lake Lagdo watershed in the SSA of Cameroon. This sample allowed us to obtain data relating to 708 (182 irrigated and 526 dryland) cultivated plots corresponding to cotton crops and the main food crops of the area: maize (corn), peanuts, millet, cowpeas, sorghum and rice.

The survey sought to capture information on the pertinent variables required to calculate crop net revenues and to explain the variation in net revenues across representative sample villages. The study relied on monthly temperature data collected from US Department of Defence satellites. The monthly precipitation data came from the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank, 2003). Different soil types (sandy, clay, and dark) were included in the study.

RESULTS

Farmers’ perceptions of and adaptation to climate change

Concerning farmers’ perceptions of climate change, a summary of descriptive statistics showed that 53% of the selected households have perceived changes in the mean temperature, while the corresponding response to rainfall accounts for 76% in the past two decades. Regarding the
direction of the change in temperature, 77% of
the sample households perceived an increase
in mean temperature, and 3% a decrease.
The remainder (20%) did not know the direction
of the mean change in temperature.

With regard to rainfall, 12% of the sample households
had observed an increase and 72% a decrease,
while 16% had not observed any change. The
results also showed that farmers’ abilities to adapt
are limited by their lack of economic and technical
resources, land tenure and level of education.
Their vulnerability is accentuated by their heavy
dependence on the climate because of the
rainfed system and their poverty.

Farmers were asked to describe any action they
had taken to counteract the negative impact of
climate change. Regarding adaptation to changes
in rainfall patterns and temperatures, about
39% had no adaptation strategy. The adaptation
strategy most commonly used was soil conservation
(29%). Other adaptation strategies adopted by
farmers were planting trees (5%), using different
crop varieties (13%), irrigation (3%), and early and
late planting (11%). There were five major constraints
for adaptation in the SSA of Cameroon. These were
inadequate information (13%), lack of access to
credit (22%), shortage of labour (16%), land tenure
(43%), and poor potential for irrigation (6%).

**Results of the regression model**

The effects of the seasonal climate variables varied
across the models. Both linear and squared terms
were significant in certain seasons, implying that
climate had a nonlinear effect on crop net revenues.
The effect of quadratic seasonal climate variables
on crop net revenue was not obviously determined
by looking at the coefficients, as both the linear and
the squared terms played a role (Kurukulasuriya
and Mendelsohn, 2006). Therefore the climate
coefficients were interpreted based on the
marginal effects of climate variables.

The inclusion of socio-economic variables improved
all models with adaptation, as indicated by the
relatively higher $R^2$ for all models, ranging from 6.36
to 9.70%. The livestock variable was not statistically
significant, while the sign and the magnitude was
the same for the entire area, including irrigated and
dryland farms. The distance to the market place for
inputs was negative, as farmers incurred more cost
in terms of money and time as the market place was
located further from their farm plots. Extension
services helped to improve crop net revenue.
Access to credit affected crop net revenue
negatively. The educational level of the household
head and farming experience, measured as the
number of years respondents had been in farming
activities, were not significant in any of the models.
The effects of the dark soils are positive, which may
be explained by the fertility level and water retention
capacity of the soils. However, sandy and clay soils
have negative effects. The introduction of the soil
variables improved the quality of the regressions,
though many of them were not statistically significant.

**Marginal impact of climate**

In order to interpret the climate coefficients,
the marginal effects of the climate variables
are estimated in Table 1.

Comparing the two models, one would expect
that including adaptation-related variables (socio-
economic variables) if they were significant would
increase the magnitude of the relationship between
climate variables and crop net revenues for positive
values, while reducing the negative values. This
appears to be true for full sample and dryland farms
for an increase in temperature. For the full sample,
the net effect of a 1°C increase in temperature
on crop net revenue has increased from
$-5358.20$ FCFA (francs of the African Financial
Community) to $-5128.95$ FCFA, and for dryland
farms from $-8485.46$ FCFA to $-7473.13$ FCFA.
For the rest of the results, this increase in crop net revenue did not occur either for the increase in temperature or for precipitation.

**Impact of projected climate scenarios**

The uniform climate scenarios used are based on the projections made by IPCC (2001). According to these projections, the world’s average surface temperature should increase by 1.4 to 5.8°C during the period from 1990 to 2100. For this reason, there is a logical need to simulate a reduction in precipitation and an increase in temperature.

The simulations for this study were based on scenarios used in the study by Kurukulasuriya and Mendelsohn (2006). On the basis of this information, this study examined the effect of climatic change for the following scenarios: an increase in temperature by 2.5 and 5°C, and a reduction in average rainfall by 7 and 14%.

It is evident that further changes in adverse climate variables, i.e. temperature and rainfall, are detrimental to crop production. However, there was the possibility that adaptation could mitigate these negative effects. As indicated in Table 2, dryland farms were affected most by further increases in temperature and decreases in rainfall. An increase in temperature and a decrease in precipitation appeared to be comparatively beneficial for farms with irrigation, implying that irrigation was important for sustaining agricultural production and as an adaptation option for smallholder farmers.

<table>
<thead>
<tr>
<th>Climate change scenario</th>
<th>Full sample</th>
<th>Irrigated</th>
<th>Dry land</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5°C increase in temperature</td>
<td>−10993.05</td>
<td>9655.12</td>
<td>−11995.01</td>
</tr>
<tr>
<td>5°C increase in temperature</td>
<td>−13885.54</td>
<td>−5678.91</td>
<td>−15559.00</td>
</tr>
<tr>
<td>7% reduction in precipitation</td>
<td>−5918.14</td>
<td>−2383.83</td>
<td>−8232.49</td>
</tr>
<tr>
<td>14% reduction in precipitation</td>
<td>−6919.44</td>
<td>−5763.98</td>
<td>−10833.36</td>
</tr>
</tbody>
</table>

Significance levels at *** 1%; ** 5%; * 10%.
DISCUSSION AND CONCLUSION

The regression results indicated that irrigation has a positive and significant influence on crop farming in the SSA of Cameroon. As indicated in the study by Abou et al. (2006), irrigation may be one way of adapting to climate change that can be practised during the dry season and provides farmers with additional income. This study indicated that socio-economic variables were important in explaining crop net revenues.

According to Deressa et al. (2009), socio-economic variables were good policy instruments for policymakers to explore as tools for controlling or taking advantage of climate effects; they were useful to see the importance of these variables in explaining crop net revenue. They also control or worsen the adverse impacts of climate change on crops (Deressa et al., 2009). Comparison of the marginal effects of the climate variables with and without the adaptation model indicated that, though the adaptation-related variables are important in helping to control adverse climate effects, if they were not properly implemented, they may instead aggravate the problem. One important variable taken as an adaptation option in the model is access to credit which, if not properly undertaken, may exacerbate the problem. The policy lesson for adaptation is to take advantage of the positive effects of climate change while reducing the negative effects.

This study was an evaluation of the economic impact of climate change on crop farming activities in SSA of Cameroon, using the Ricardian model. The results obtained from the analysis of marginal impact and descriptive statistics show the magnitude and direction of climate change impacts on crop agriculture. The results of this study also confirm the importance of the climate for crop revenue and the need to take actions to strengthen existing adaptation options and develop new ones.

COMMUNICATION STRATEGY AND IMPACT

The study shows that irrigation may be one way of adapting to climate change that can be practised during the dry season and provides farmers with additional income. Our communications strategy targeted four levels of audience. The first was policy-makers in Cameroon, including the Ministry of Agriculture and Rural Development (MARD), the head agency of agriculture in Cameroon. We used workshops to disseminate our results. The second audience, stakeholders in Cameroon, included regional offices of the MARD in SSA, SODECOTON, which is the Society of Cotton Development in Cameroon and plays an important role in rural development of the region and producer groups, ESA project coordination, Mission Study for Planning and Development of the Northern Province (MEADEN), and the farmers themselves. This target audience was reached through meetings and conversations with organisations and communities. We disseminated copies of the report in French and local languages to these actors. The third audience was the policy-makers involved in promoting and implementing environmental programmes globally. They include international donor and cooperation organisations active in environmental issues, such as the French Development Agency (AFD), the European Union (EU) and the World Bank, which have the ability to provide or mobilise significant resources in support of agriculture. The English version of the policy brief has been our primary means of communicating our results to this audience. Versions of these will be published in policy-oriented journals and websites that regularly cover issues of agriculture extension. Our fourth audience was the global academic community concerned with agricultural and environmental policy and market-based mechanisms for the reduction of climate change impacts on agriculture.
We intend to publish our results in peer-reviewed academic journals relevant to our respective fields (a paper has been selected for inclusion in a special issue of the African Journal of Science, Technology, Innovation and Development). We have also presented the results at academic conferences.

ACKNOWLEDGEMENTS

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REFERENCES


MACROPROPAGATION TECHNIQUE FOR PRODUCING COST-EFFECTIVE HEALTHY BANANA SEEDLINGS IN EASTERN AND CENTRAL KENYA

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ABSTRACT

Banana (Musa spp.) is one of the most important food and cash crops in various parts of Kenya. Despite its importance, banana production faces major challenges, including scarcity of high-quality, healthy and cost-effective seedlings, coupled with the problems of pests and diseases in the field. Demand for cost-effective, pest-free and high-quality planting materials is rising. This study sought to determine if a macropropagation technique could produce healthy banana seedlings. Naturally regenerated suckers, which are preferred by farmers, are more likely to carry pests and diseases, leading to reduced productivity and the shortened lifespan of new plantations. Tissue culture (TC) was introduced, but adoption rates have been low due to the high costs and skills involved. To address this constraint, macropropagation was introduced to reduce costs of seedlings, as it requires little capital or skill. A survey was conducted to identify the major diseases and pests of bananas in Eastern and Central Kenya. Macropropagation nurseries were constructed at Kenyatta University and in farmers’ fields representing different agro-ecological zones. Corms obtained in accordance with established quality assurance protocols were propagated in two cycles, and the health of seedlings monitored. Pathogenicity tests were carried out to determine the importance of microorganisms isolated from the corms. Fusarium wilt and Sigatoka were recorded as the most important diseases, with 66 and 50% incidence, respectively, while nematodes and banana weevil were major pests, occurring at 21 and 17% incidence, respectively. Endophytes were commonly isolated from the corms. Weevil infestation was found to be the major cause of rejection of farms when purchasing corms. An average of 98 and 100% healthy seedlings resulted from the first and second cycles of macropropagation. Production of healthy, low-cost bananas from this project will benefit seedling entrepreneurs and banana farmers.

KEY WORDS: DISEASES, ENTREPRENEURS, MUSA, PESTS, PLANTING MATERIAL

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INTRODUCTION

In Kenya, banana (Musa spp.) is grown mostly at small scale and constitutes a major crop for food security, nutrition and income generation. Commercial banana cultivation is greatly hindered by biotic and abiotic factors (Seshu Reddy et al., 1999). These include scarcity of high-quality seedlings, diseases and pests, inadequate agricultural inputs and limited acreage for farming. Banana is susceptible to pest infestation, leading to a decline in production. An increase in the prevalence of pests and diseases combined with a lack of effective control strategies (Kahangi et al., 2002) has resulted in poor yields. Farmers mostly rely on the natural regeneration of existing plants for propagation. These seedlings are likely to carry pests and diseases, leading to reduced production.

Tissue culture (TC) is one of the available propagation methods that produce relatively clean seedlings free from diseases and pests, with genetic purity and uniform growth (Sheela and Ramachandran, 2001). However, adoption has been low due to the high capital investment required and the subsequent high cost of TC-produced seedlings. The macropropagation technique can be used as a cost-effective method to produce a large number of high-quality seedlings (Tenkouano et al., 2006). This study was carried out to determine the efficiency of the macropropagation technique in producing healthy and affordable banana seedlings in Eastern and Central Kenya.

MATERIALS AND METHODS

A survey was carried out in eight districts in Eastern and Central Kenya (Muranga, Mathioya, Kirinyaga East, Kirinyaga Central, Kirinyaga West, Embu East, Meru Central and Imenti South) with a minimum of 10 farms in each district. The objective was to determine the most important diseases and pests affecting bananas. Farms were selected randomly at 3–5 km apart. A photo card aided identification of the diseases by farmers, and a questionnaire was used to collect the required information. A transect walk was made diagonally in the plantation to inspect plants displaying disease symptoms. Samples of diseased materials were collected, wrapped in paper towels and placed in clearly labelled plastic bags, and taken to the laboratory for isolation and identification of pathogens through pathogenicity tests.

Macropropagation nurseries were established in six sites in farmers’ fields on the basis of the different agro-ecological zones: low-altitude Mitunguu (1071 m above sea level [m.a.s.l.]) and Embu East (1265 m.a.s.l.); mid-altitude Kerugoya (1340 m.a.s.l.) and Ntharene (1360 m.a.s.l.); and high-altitude Mathioya (1915 m.a.s.l.) and Meru Central (1680 m.a.s.l.). An extra site was also established at Kenyatta University (1680 m.a.s.l.). Nurseries were constructed using locally available materials. These included wooden poles treated with preservative and polythene sheets. The roof was made using black polythene and the sides made using clear polythene to provide 50% shade. Corms of Cavendish, Gros Michel, sweet banana and Kiganda were obtained through an established macropropagation protocol (Njukwe et al., 2007). Certification of farms was undertaken for corm procurement. Farms were inspected to certify that they were free from pests and diseases that have the potential to be propagated from parent to progeny. Visibly healthy banana mats that were flowering, maiden suckers and those that had been harvested were selected to provide corms for macropropagation.

The corms were pared to remove all the sound roots, followed by removal of sheaths and scarification of the buds, prior to planting. They were then washed and disinfected in 10% Jik® (sodium hypochlorite) for 10 min, left to dry, and planted in propagators filled with sterile sawdust in a complete randomised block design. The propagator was kept moist by watering every 2 days for the first week initially, then twice a week thereafter. Samples were taken from the corm and checked for any latent
pathogenic microorganisms. Plantlets arising from the corms were monitored for development of any disease symptoms. Corms rotting in the media were recorded, removed from the propagators and the cause determined.

Plantlets were transplanted upon attaining a height of 15 cm 4 weeks after rooting in the sawdust. The soil was steam-sterilised and mixed with manure at a ratio of 3:1 (soil:manure). The plantlets were transplanted in polythene bags. They were monitored for any symptoms of disease development for a period of 12 weeks after transplanting. Plantlets exhibiting disease symptoms were taken to the laboratory for identification of the causal organism.

Microorganisms isolated from the samples were identified and their pathogenicity determined. The data were analysed using ANOVA, and means separated by least significant differences and Tukey’s test to determine where significant differences existed at \( P \leq 0.05 \), comparing between the varieties and locations.

**RESULTS**

### Disease occurrence in surveyed farms

The average disease incidences in all the areas surveyed showed that Fusarium wilt and Sigatoka had the highest incidences, at 66 and 50%, respectively. Weevils were recorded at 17% and nematodes at 20%. Nutrient stress affected 6%, and cigar end rot 4%. Banana Xanthomonas wilt, Banana streak virus and Bunchy top virus were not detected in any of the farms surveyed. Fusarium wilt incidence was high (90%) in Kirinyaga West and Embu East districts, and 80% in Kirinyaga East. Sigatoka was observed at 50% in all of the farms surveyed. Weevil percentages were 52% in Imenti south, 37% in Embu East, 25% in Meru Central, and less than 20% in Kirinyaga West, East and Central. There were no weevils recorded in Murang’a and Mathioya districts. Nutrient stress was recorded in farms where manure and fertiliser were not adequately applied, and especially in farms where tissue culture seedlings were used as the planting material. Cigar end rot incidence was higher in farms where agronomic practices such as weeding and deleafing were not undertaken.

### Certification of farms

Banana plantations in the Eastern region were observed to be highly infested by weevils. Some mats were high, and corms were not procured from such plantations. Weevil infestation was lowest in Mathioya in Central province and highest in Mitunguu in Eastern province (Table 1). In addition, there were significant differences \( (P = 0.000) \) between the varieties with regard to weevil infestation. The Kiganda variety, an East African highland banana, showed high levels of infestation compared with other varieties (Figure 1).

### Health of corms and seedlings

Samples from the corms that were rooted in the sawdust upon isolation in the laboratory showed the presence of endophytes and non-pathogenic microorganisms. Some of the endophytes isolated were *Colletotrichum* spp., *Penicillium* spp., *Trichoderma* spp., *Fusarium* spp. and *Aspergillus* spp. Fewer than 1% of the corms in all the study sites rotted (Table 2), and saprophytes were isolated from some of the corms that were rotting in the media. There was no significant difference \( (P = 0.936) \) in the number of corms that rotted between the varieties; nor was there any significant difference \( (P = 0.194) \) among the locations in the proportion of corms that rotted. Seedlings from all the study sites were free from plant-parasitic nematodes and weevils. However, pathogenic *Fusarium oxysporum* f.sp. *cubense* (Foc) was isolated from samples of two corms of sweet banana in Mitunguu and Embu East, and in one corm of the Gros Michel variety. These corms were
promptly removed from the nursery. 100% of the seedlings survived after transplanting in all the study sites. None of the seedlings developed symptoms of disease. Isolating seedlings from the corm indicated the presence of endophytes, some of which were similar to those isolated from the mother corm.

Pathogenicity tests

Plantlets of the Gros Michel cultivar inoculated with varying densities of Foc developed wilting symptoms. There was a significant difference ($P \leq 0.001$) in the height, basal circumference and

<table>
<thead>
<tr>
<th>Location</th>
<th>Cavendish</th>
<th>Gros Michel</th>
<th>Kiganda</th>
<th>Sweet banana</th>
<th>Overall mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embu east</td>
<td>1.90ab</td>
<td>1.70a</td>
<td>2.40a</td>
<td>1.80a</td>
<td>1.95 ± 0.094a</td>
</tr>
<tr>
<td>Kenyatta University</td>
<td>1.40c</td>
<td>1.50b</td>
<td>2.10ab</td>
<td>1.60b</td>
<td>1.65 ± 0.092bc</td>
</tr>
<tr>
<td>Kerugoya</td>
<td>1.70bc</td>
<td>*</td>
<td>2.30a</td>
<td>1.70ab</td>
<td>1.90 ± 0.13ab</td>
</tr>
<tr>
<td>Mathioya</td>
<td>1.50c</td>
<td>1.40c</td>
<td>1.90ab</td>
<td>1.60b</td>
<td>1.60 ± 0.093c</td>
</tr>
<tr>
<td>Meru Central</td>
<td>1.60bc</td>
<td>1.40c</td>
<td>1.90ab</td>
<td>1.50b</td>
<td>1.60 ± 0.10c</td>
</tr>
<tr>
<td>Mitunguu</td>
<td>1.90ab</td>
<td>1.70a</td>
<td>2.60a</td>
<td>1.80a</td>
<td>2.0 ± 0.095a</td>
</tr>
<tr>
<td>Ntharene</td>
<td>2.00a</td>
<td>1.50b</td>
<td>2.40a</td>
<td>1.80a</td>
<td>1.93 ± 0.097a</td>
</tr>
</tbody>
</table>

Means ± standard error (SE) separated using Fisher’s LSD test. Means in a column followed by the same letter are not significantly different at $P < 0.05$. * Variety not present in the study area.

![Figure 1: Weevil Infestation in the Different Banana Varieties](image)
number of leaves between the different treatments and the control (Table 3). The disease progression 14 weeks after inoculation, as indicated by the height and number of leaves, was significantly different ($P \leq 0.001$) with time. However, the basal circumference between the different treatments was not significantly different ($P = 1.000$) with time.

Inoculation of plantlets with *Radopholus similis* showed that the control had fewer dry roots and more functional roots compared with the inoculated plants. There was a significant difference ($P = 0.001$) between the dry roots and the functional roots ($P \leq 0.005$) in the inoculated plants and the control. The basal circumference, height and number of leaves of the plantlets were significantly different ($P < 0.001$) after inoculation with different levels of *Radopholus similis*.

### TABLE 2: PROPORTION (%) OF CORMS THAT ROTTED IN THE NURSERIES

<table>
<thead>
<tr>
<th>Variety</th>
<th>Corms that rotted (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiganda</td>
<td>1.67</td>
</tr>
<tr>
<td>Cavendish</td>
<td>0.89</td>
</tr>
<tr>
<td>Sweet banana</td>
<td>2.63</td>
</tr>
<tr>
<td>Kampala</td>
<td>1.54</td>
</tr>
</tbody>
</table>

### TABLE 3: MEAN HEIGHT, BASAL CIRCUMFERENCE AND NUMBER OF FUNCTIONAL LEAVES IN DIFFERENT INOCULUM LEVELS 14 WEEKS AFTER INOCULATION WITH *Foc*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Height (cm)</th>
<th>Basal circumference (cm)</th>
<th>No. of functional leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mycelia discs</td>
<td>43.78 ± 1.16b</td>
<td>11.76 ± 0.20b</td>
<td>5.44 ± 0.13b</td>
</tr>
<tr>
<td>20 mycelia discs</td>
<td>44.36 ± 0.81b</td>
<td>11.57 ± 0.32b</td>
<td>5.34 ± 0.17b</td>
</tr>
<tr>
<td>30 mycelia discs</td>
<td>38.57 ± 2.56c</td>
<td>9.75 ± 0.46c</td>
<td>3.21 ± 0.19c</td>
</tr>
<tr>
<td>Control</td>
<td>50.83 ± 1.14a</td>
<td>12.33 ± 0.34a</td>
<td>6.43 ± 0.14a</td>
</tr>
</tbody>
</table>

$P <0.001$ $P <0.001$ $P <0.001$

Data are mean ± standard error (SE). Means separated using Fisher’s LSD test. Means within a column followed by the same letter are not significantly different at $P < 0.05$.

### DISCUSSION AND CONCLUSION

Diseases and pests are the major constraints affecting banana production in Eastern and Central provinces. Fusarium wilt was high in areas where susceptible varieties such as Gros Michel and sweet banana are preferred by farmers and are demanded by the market. The disease can be easily spread through infected planting material as the symptoms may not be apparent in the daughter suckers. This can be rectified by planting banana varieties that are resistant to the disease, such as East African highland banana and the Cavendish sub-groups (Ploetz and Pegg, 2000).
Weevil incidences were higher in lower agro-ecological zones (Mitunguu and Embu East). This is because the high temperature (25–30°C) coupled with irrigation creates a favourable environment for weevils. This is consistent with the results of Gatarayiham et al. (2003), who found that the adult weevil population is high in low-altitude areas (900–1100 m). Gold et al. (1994) found that the East African highland banana was more susceptible to weevil attack. The current study confirms that finding, since the Kiganda variety, an East African highland banana, was found to be most susceptible.

Endophytes are regarded as biological control agents and potential genetic vectors in plant biotechnology (Pereira et al., 1999). Many endophytes produce antibiotics and probably inhibit the growth of latent pathogenic fungi, thus affording the plants protection. Mutual association between the endophytes and the host plants has been reported to be beneficial to plant growth (Clay and Scharld, 2002). There is a possibility that banana plantlets produced through macropropagation benefit from the endophytes in the corm. Tenkouano et al. (2006) found that the seedlings are less prone to post-establishment stress and loss in the field.

The macropropagated seedlings had a high survival rate in the hardening nursery and in the field. However, fewer than 5% of the seedlings that were rootless had a lower survival rate. The high survival rate of the seedlings after transplanting indicates that macropropagation technology is effective in producing healthy seedlings.

The effects of diseases that affect banana production can be reduced by supplying healthy and affordable seedlings to farmers. Macropropagation technology can be employed to produce clean and cost-effective seedlings. The seedlings need to be supplied with well decomposed manure during transplanting to maintain the required level of fertility.

**COMMUNICATION STRATEGY AND IMPACT**

The targets were farmer groups involved in banana production. Contacts were made with the agriculture offices in each district to identify banana farmers in the area and the challenges faced in banana production. The research was participatory, thus the farmers had first-hand experience of its benefits. It was also conducted in collaboration with the Kenya Agricultural Research Institute. The seedlings that resulted were distributed to group members, and more were given to farmers during the field days. The farmers say that the seedlings are responding well and they are waiting for the harvest.

During the period of study, there was creation of awareness among farmers on the benefits of planting disease free banana seedlings, to curb the risk of disease spread and to ensure high yields; suitable banana varieties for different areas; and sources of clean planting material. Awareness was created through farmer field days – on average, 300 farmers visited our stand in each district; demonstration sites – days were set aside to explain the technology to farmers; and workshops, conferences and seminars targeting farmers and seed entrepreneurs. Tools used included posters, PowerPoint presentations and publications.

The impact of the study was appreciation by the farmers of the need for using clean planting material, their accepting the technology due to the reduced cost of seedlings, and planting of the seedlings in their farms, thus increasing the area under banana production.

**ACKNOWLEDGEMENTS**

The authors wish to thank RUFORUM for financial support, KARI Thika and FACT Ltd for facilitating the research, and Kenyatta University for administration.
REFERENCES


PRODUCTION OF ROASTED BAMBARA GROUNDNUT (VOANDZEIA SUBTERRANEA) BLAND FLOUR AND ITS APPLICATION IN FORTIFICATION OF BISCUIT AND TOASTED CASSAVA GRANULES

J.N.C. Okafor¹, G.I. Okafor², H. Narashima³, K. Leelavathi³ and S. Bhagya³
ABSTRACT

Fortification of starchy staples with high-protein materials has been proposed as an intervention strategy due to the prevalence of protein malnutrition related diseases in Nigeria, and in many other African countries. This has necessitated research into the development of high-protein, readily available, cheap and acceptable flour from indigenous legumes that could be utilised for food fortification. The study aimed (1) to produce protein rich, high-quality roasted bambara groundnut (BGN) flour for enrichment of biscuits and garri, and (2) to determine the quality and acceptability of the products. BGN was roasted at 140°C for 20 min to improve the nutritional quality and sensory acceptability. The flour obtained was used to enrich biscuits and garri at 10, 20, 30, 40 and 50% replacement levels. The quality of flour and products were evaluated using standard methods. Roasting significantly \((P < 0.05)\) increased *in vitro* protein digestibility from 67.4% to 81.3%, and trypsin inhibitor activity was reduced from 23.7 TIU/mg (raw) to 12.6 TIU/mg (roasted). Available lysine increased slightly from 6.3 g/16 g N (raw) to 6.8 g/16 g N (roasted). BGN fortified biscuits had significantly \((P < 0.05)\) higher crude protein \((11.42–13.96\%)\) values compared with the control \((8.18\%)\). There were no significant \((P > 0.05)\) differences between biscuits containing 10–30% BGN flour and control in relation to taste, crumb colour, crust colour, flavour and overall quality. Fortified biscuits had significantly \((P < 0.05)\) higher lysine \((40.7–57.7 \text{ mg/g protein})\), also methionine + cysteine, threonine, leucine, phenylalanine and tyrosine content also differed significantly \((P < 0.05)\). Fortification significantly increased the protein content of garri from 1.7 to 3.85–10.01%. There were no significant \((P > 0.05)\) differences in colour, taste, flavour, texture and overall acceptability between the control garri and the 20% fortified garri, which had higher mean scores in all attributes. The essential amino acids of fortified garri \((20–40\%)\) and biscuits \((20–50\%)\) met the FAO/WHO recommended dietary allowance for school children and adults.

KEY WORDS: ACCEPTABILITY, ENRICHMENT, GARRI, INDIGENOUS LEGUMES, NUTRITIONAL QUALITY, PROTEIN MALNUTRITION

AFFILIATIONS

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2  University of Nigeria, Nsukka, Nigeria.
3  Central Food Technological Research Institute, Mysore, India.
INTRODUCTION

Protein malnutrition has been identified as a major challenge in many developing countries as a consequence of frequent consumption of diets consisting mostly of carbohydrate-rich staples. One of the strategies for combating this challenge has been nutritional intervention, in particular by developing healthy and nutritious high-protein food products from blends of legumes, cereals and tubers grown in abundance in the affected countries. Producing acceptable flour from indigenous, cheap, high-protein and readily available vegetable sources such as bambara groundnut, for broad utilisation in protein enrichment of widely consumed cereal and tuber-based diets such as biscuits and garri, will help to reduce the incidence of protein malnutrition and related diseases, particularly among children.

Bambara groundnut grows on poor soils with little rainfall and is nutritionally superior to many pulses. The protein content is about 24%, it is higher in methionine (1.8%) than other grain legumes and it also contains 6.8% lysine and about 50% carbohydrate (Mkandawire, 2007). Its gross energy value is greater than that of some popular legumes such as cowpea and pigeon pea. Although highly nutritious, together with cowpea constituting 8.39 million tons of legumes produced in Africa and 2.2 million tons in Nigeria (FAO, 2002), its consumption is limited. This is due to some negative traits, which include poor digestibility, poor dehulling properties, strong beany flavour, slightly bitter taste, difficulty in cooking, the presence of anti-nutritional factors (trypsin inhibitors, tannins, phytates and lectins) and flatulence factor (Uvere et al., 1999). Its processing into nutrient-dense, readily available flour for incorporation into starch-based cereal and root/tuber food products – such as biscuits, widely consumed by children (Lorenz, 1983) and garri, a major staple in many African countries (Collins and Temalilwa, 1981; Olumwamokomi et al., 2007) – is a valuable task. This study therefore sought to produce protein-rich, high-quality, nutritious and acceptable bambara flour for use in the fortification of food products.

MATERIALS AND METHODS

Chemicals and reagents

Acetonitrile, phenyl isothiocyanate (PITC), triethylamine (TEA), phenyl-thiocarbamoyl acid (PTC), amino acid standards (Pierce H), and HPLC water were obtained from Millipore (Milford, MA, USA). Reagent grade glacial acetic acid, sodium acetate, sodium phosphate, concentrated hydrochloric acid (HCl), sodium hydroxide (NaOH), ethanol, sodium bicarbonate, diethyl ether, sodium bicarbonate (NaHCO₃), sodium carbonate (NaCO₃), sulphuric acid, toluene, methyl chloroformate, mono e-N-dinitrophenyl-lysine hydrochloride monohydrate phenolphthalein, FDNB lysine reagent, distilled and de-ionised water, pepsin and pancreatin were used.

Samples

Cream-coloured bambara groundnut seeds (Voandzeia subterranea (L.) Thouar) weighing 10 kg were purchased from Lagos market, Nigeria. They were sorted, cleaned, packaged in sealed, air-tight plastic bags, and carried to the Central Food Technological Research Institute (CFTRI) in Mysore, India. The seeds were split into two parts (dhals), dehulled using a versatile dhal mill, roasted at 140°C for 20 min in an In-Lab electric roaster (In-Lab Furnaces, Mysore, India), cooled, ground into flour using a hammer mill (Bathibol Ltd, India), sieved through a BS no. 80 mesh sieve and packaged in polyethylene bags. Wheat flour, cassava, butter and sugar were purchased from Mysore market and used to make biscuits according to the method of Leelavathi and Haridas Rao (1993), and garri using the method of Okafor (2012). The production of fortified biscuits and garri involved replacement of part of the wheat flour (for biscuit) and garri with 10–50% roasted bambara groundnut flour (BGN). Zero percent BGN formulation served as controls.
### Chemical analysis

Proximate composition of flour and products were determined by the method of AACC (1990). Trypsin inhibitor activity was by the method of Kakade et al. (1974), and the method of Bidlingemeyer et al. (1987) was used for amino acid analysis. Available lysine was determined by the FDNB reactive lysine method of Carpenter (1960) modified by Booth (1971). *In vitro* protein digestibility was determined by the method of Akeson and Stahman (1964).

### Organoleptic evaluation

The sensory qualities of products were evaluated by 20 experienced panelists. Scoring scales for biscuits were 1–20 (1 = very poor, 20 = excellent) for texture and taste, and 1–10 (1 = very poor, 10 = excellent) for crust and crumb colour, flavour, crust surface characteristics and the sum total of these scores for overall quality, while garri was analysed for colour, taste, flavour, texture and overall acceptability using a nine-point hedonic scale (9 = extremely acceptable, 1 = extremely unacceptable) (Larmond, 1977).

### Statistical analysis

Statistical significance was established using one-way analysis of variance (ANOVA) at 0.05 level of probability, and differences between means were compared using Duncan’s multiple range test (Duncan, 1955). Statistical analysis was carried out using SPSS for Windows version 14.0 (SPSS Inc., Chicago, IL, USA) and data were reported as mean ± SD.

### RESULTS

The protein content of roasted flour was significantly \( P < 0.05 \) higher than that of raw flour (Table 1). Roasting significantly \( P < 0.05 \) decreased trypsin inhibitor activity from 23.7 TIU mg/g in raw flour to 12.6 TIU mg/g (roasted). *In vitro* protein digestibility was significantly \( P < 0.05 \) increased from 67.4% (raw) to 81.29% in roasted flour, while available lysine was not affected.

BGN-fortified biscuits and garri had significantly \( P < 0.05 \) higher crude protein content with increasing levels of fortification compared to the control (Table 2). Protein levels of the samples were also significantly \( P < 0.05 \) different from each other at all levels of enrichment.

### TABLE 1: EFFECT OF ROASTING ON SOME NUTRITIONAL INDICATORS OF BAMBARA GROUNDNUT

<table>
<thead>
<tr>
<th>BGN</th>
<th>Protein (%)</th>
<th>Fat (%)</th>
<th>Carbohydrate (%)</th>
<th>Energy (kcal/100 g)</th>
<th>Avail. lysine (g/16 g N)</th>
<th>Invit. protein digest. (%)</th>
<th>Tryp. inhib. (TIU/mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>21.85b ± 1.3</td>
<td>6.90a ± 1.0</td>
<td>53.89b ± 1.3</td>
<td>365b ± 1.60</td>
<td>6.3a ± 0.5</td>
<td>67.4a ± 0.9</td>
<td>23.7b ± 1.9</td>
</tr>
<tr>
<td>Roasted</td>
<td>23.09a ± 1.0</td>
<td>7.33a ± 1.2</td>
<td>55.60a ± 1.5</td>
<td>381a ± 0.89</td>
<td>6.8a ± 0.8</td>
<td>81.3b ± 0.7</td>
<td>12.6a ± 1.2</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation \( (n = 3) \). Mean values in the same column followed by different letters \( (a, b) \) differ significantly \( P < 0.05 \).
Fortification of biscuits and garri with roasted BGN flour significantly ($P < 0.05$) increased all essential amino acids (EAA) with increasing addition of roasted BGN flour. Lysine content increased from 21.9 to 57.7 mg/g protein and from 64.7 to 73.8 mg/g protein for biscuits and garri, respectively (Table 3).

The taste profiles of BGN-fortified biscuits and garri are shown in Tables 4 and 5. Biscuits with 10–30% BGN flour were not significantly ($P > 0.05$) different from the control in all attributes except texture. Also, up to 20% BGN-fortified garri were not significantly ($P > 0.05$) different from the control in all attributes. Above these levels of BGN, inclusion significantly ($P < 0.05$) affected the taste attributes of the products, but within acceptable ranges.

### TABLE 2: PROTEIN CONTENT OF GARRI AND BISCUITS ENRICHED WITH BGN FLOUR (%)

<table>
<thead>
<tr>
<th>Samples</th>
<th>Level of enrichment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>BGN enriched garri</td>
<td>1.7±0.70</td>
</tr>
<tr>
<td>BGN enriched biscuits</td>
<td>8.18±0.45</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation ($n = 3$). Mean values in the same row followed by different letters (a, b) differ significantly ($P < 0.05$).

### TABLE 3: ESSENTIAL AMINO ACID (EAA) COMPOSITION OF BISCUITS AND GARRI ENRICHED WITH ROASTED BAMBARA GROUNDNUT FLOUR (MG/G PROTEIN)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lysine</td>
<td>21.9</td>
<td>64.7</td>
<td>40.7</td>
<td>70.1</td>
<td>47.6</td>
<td>71.7</td>
<td>53.2</td>
<td>72.4</td>
</tr>
<tr>
<td>Met + cyst</td>
<td>41.8</td>
<td>5.9</td>
<td>36.6</td>
<td>18.9</td>
<td>34.8</td>
<td>22.7</td>
<td>32.2</td>
<td>29.6</td>
</tr>
<tr>
<td>Threonine</td>
<td>36.2</td>
<td>41.2</td>
<td>28.3</td>
<td>35.0</td>
<td>29.5</td>
<td>35.0</td>
<td>30.4</td>
<td>34.9</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>35.6</td>
<td>52.9</td>
<td>35.7</td>
<td>45.8</td>
<td>37.8</td>
<td>42.0</td>
<td>38.6</td>
<td>41.4</td>
</tr>
<tr>
<td>Leucine</td>
<td>65.9</td>
<td>52.9</td>
<td>77.3</td>
<td>78.2</td>
<td>77.9</td>
<td>83.9</td>
<td>80.8</td>
<td>86.7</td>
</tr>
<tr>
<td>Valine</td>
<td>39.7</td>
<td>47.1</td>
<td>40.7</td>
<td>43.1</td>
<td>40.8</td>
<td>42.0</td>
<td>41.0</td>
<td>41.4</td>
</tr>
<tr>
<td>P + T</td>
<td>53.3</td>
<td>35.3</td>
<td>71.9</td>
<td>75.5</td>
<td>77.9</td>
<td>87.4</td>
<td>82.9</td>
<td>93.1</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>11.5</td>
<td>5.9</td>
<td>10.8</td>
<td>8.13</td>
<td>11.4</td>
<td>10.3</td>
<td>11.1</td>
<td>10.5</td>
</tr>
</tbody>
</table>

Values are mean ± SD ($n = 3$). Met + cyst = methionine + cysteine; P + T = phenylalanine and tyrosine; Bisc = biscuit.
DISCUSSION AND CONCLUSION

The crude protein, fat and carbohydrate contents of BGN flour (Table 1) were comparable to values reported by Mkandawire (2007). The slight increase in protein content of roasted flour probably is due to concentration of nutrients on moisture loss during roasting. It shows there was no significant (P > 0.05) difference in available lysine with roasting. The Maillard reaction is the major non-enzymatic sequence that causes lysine to be nutritionally unavailable when heated. Almas and Bender (1998) reported that processing conditions such as time, temperature of heat treatment and presence of moisture are significant in determining the available lysine content, which is a reliable indicator of amino acid availability. Thus, in this study, roasting treatment proved very efficient as it had no effect on lysine availability.

The significant increase in the crude protein content of fortified biscuits and garri (Table 2) was probably due to the high protein content of the roasted BGN flour. Singh et al. (1996) reported an increase in protein content of biscuits supplemented with defatted soyflour. Sulphur-containing amino acids,
lysine and tryptophan deficient in cassava increased significantly ($P < 0.05$) with addition of roasted BGN (Table 3). The EAA of 20–40% fortified garri met WHO/FAO (2002) recommended dietary requirements (RDA). The lysine content of the enriched biscuits also increased significantly. Wheat is deficient in lysine but rich in sulphur EAA, while BGN contains lysine but is deficient in sulphur EAA, therefore blending the two together had the complementary effect of producing food with balanced quantities of lysine and EAA. BGN biscuits (20–40%) contained EAA at levels that met the RDA (WHO/FAO, 2002) for children. The high mean rating and acceptability of fortified biscuit with up to 50% BGN inclusion showed that roasting significantly reduced the beany flavour, which has been a major factor limiting bambara groundnut consumption and utilisation. Garri with up to 20% BGN compared favourably with the control for taste, flavour, colour, texture and overall quality (Table 5). Twenty percent BGN garri was more acceptable than the control in these attributes, which could be due to the slight groundnut-like flavour/taste in the roasted BGN flour. In Nigeria generally, garri is normally soaked in water and consumed with roasted groundnuts as a source of protein. The enrichment of garri with roasted BGN flour improved the nutritional quality and provided a convenient, ready-to-eat, nutritious meal.

In conclusion, roasted flour with improved chemical composition, nutritional quality, sensory attributes and acceptability was successfully produced from bambara groundnut. The complementary effect of substituting wheat flour with up to 40% roasted BGN flour (biscuit) and 20% (garri) improved their nutrient composition, which is of great benefit as such biscuits could be used in school feeding programmes. This will contribute to alleviating protein malnutrition, and increase bambara groundnut consumption, industrial utilisation and cultivation. It will also enhance food and nutrition security, job creation, poverty reduction and health promotion, contributing to the realisation of Millennium Development Goal number one.

**COMMUNICATION STRATEGY AND IMPACT**

The developed technology and products are expected to significantly alleviate protein energy malnutrition incidence in Nigeria and other African countries. The technology will be communicated to entrepreneurs and women’s groups through training workshops, advocacy, and advertisements on TV and radio and in two major national newspapers, as well as social media. The technology will also be adapted for domestic use by women in a printed step-by-step guide.

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**REFERENCES**


IMPROVEMENT OF PAPAYA PRODUCTIVITY FOR COMMERCIAL APPLICATION

F.K. Rimberia Wanzala¹, L.S. Wamocho⁴, A.B. Nyende², E.M. Ateka¹, D. Shitanda³ and A.W. Kihurani¹
ABSTRACT

Kenya was ranked 128th among 169 low-income countries in 2011, with vitamin A deficiency among children aged 6 to 11 months at 40.7%. Vitamin A deficiency (VAD) is a major cause of death among children under 5 years in sub-Saharan Africa. Papaya fruits are rich in vitamin A, and thus have potential for eliminating VAD in Kenya and other countries. Production of papaya has decreased in the recent past due to lack of improved varieties and devastating viral diseases. Papaya exists in three sex types: male, female and hermaphrodite. Prior to flowering, the seedlings look alike, making it impossible for farmers to plant the desired ratio of one male to nine females for optimal productivity. The objectives were to collect and characterise papaya germplasm, agronomic evaluation, tissue culture and value addition for fruits and seeds. Germplasm was collected from Coast, Nyanza, Western, Rift Valley, Eastern and Central provinces of Kenya. Morphological data on 60 accessions were submitted to neighbour-joining cluster analysis. Seeds of 43 randomly selected accessions were evaluated for height, fruit yield and quality. Tissue culture was attempted to develop protocols for mass propagation. Morphological characterisation revealed considerable diversity among 60 papaya accessions. Plant height at 100 days and yield were significantly different among papaya germplasm. An efficient protocol for meristem culture was developed. Papaya-based yoghurts were developed. Oil with high oleic acid content was extracted from papaya seeds and used to make soap and lotion. The diversity in morphological, agronomic and fruit characteristics among papaya accessions points to the possibility of obtaining desirable traits for varieties with superior productivity. Papaya has a lot of potential to improve the health and wealth of poor farming communities and contribute to the realisation of the Millennium Development Goals.

KEY WORDS: AGRONOMIC EVALUATION, CLUSTER ANALYSIS, DIVERSITY, MORPHOLOGICAL CHARACTERISATION, TISSUE CULTURE, YOGHURT

AFFILIATIONS

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INTRODUCTION

Agriculture is the backbone of Kenya’s economy, occupying 75% of Kenya’s labour force and contributing 34% of gross domestic product (GDP) (Salami et al., 2010). The country was ranked 128th among 169 low-income countries in the United Nations Development Programme’s Human Development Index (IFAD, 2011). Vitamin A deficiency (VAD) among children aged 6 to 11 months has been reported to be 40.7% in parts of Kenya (Ngare et al., 2000). This is a major cause of death among children under 5 years in sub-Saharan Africa (SSA). Fruits have been known to form an important part of the agriculture sector. They are effective in protecting the human body against several types of cancer, cardiovascular diseases and micronutrient deficiencies (WHO, 2003). Papaya fruits are rich in vitamins A (2 mg/100 g) and C (145 mg/100 g) (Imungi and Wabule, 1990), and have the potential to reduce VAD in Kenya and in SSA more widely.

Papaya is a fast-maturing crop which starts flowering 6 months after transplanting; fruits ripen 4 to 5 months after flowering. It is also among the very few fruit crops that can produce fruits year-round. Since it is a single-stemmed tree (though some varieties have multiple stems), it can be economically grown on any size of plot, from kitchen gardens to large plantations.

Papaya exists in three gender types: male, female and hermaphrodite. The seedlings appear alike, irrespective of sex, and can only be differentiated at flowering time. Other production constraints include lack of improved varieties, and devastating viral diseases such as papaya ringspot potyvirus (PRSV) (Manshradt, 1992).

It was hypothesised that the genetic traits that are necessary for dwarfism and high fruit yield are available in the local germplasm. The second hypothesis was that papaya fruits and seeds are potential raw materials for industry. The objectives were to collect and characterise papaya germplasm, and to perform agronomic evaluation, tissue culture and value addition of fruits and seeds.

METHODOLOGY

Germplasm collection and documentation

Germplasm was collected from six major papaya-producing provinces of Kenya: Coast (Kilifi and Taita), Nyanza (Rongo and Nyamira), Western (Bungoma, Kakamega and Vihiga), Rift Valley (Baringo, Keiyo and Nakuru), Eastern (Tharaka and Embu), and Central (Kirinyaga and Maragua). The papaya germplasm was collected between June 2008 and May 2009. Each field was mapped with a global positioning system (GPS) receiver.

Characterisation of papaya germplasm

The germplasm was characterised using morphological and molecular traits. Morphological data were collected in the rural producing districts using a descriptor list from the International Board for Plant Genetic Resources (IBPGR, 1988).

Agronomic and quality evaluation of Kenyan papaya germplasm

Representative plants that were grown in a greenhouse at Jomo Kenyatta University of Agriculture and Technology were evaluated for height at about 100 days, fruit yield and fruit quality, using a completely randomised design. The data were analysed using SAS 9.1 (SAS Institute Inc., 2003) and mean separation by Duncan’s multiple range test.

Tissue culture of papaya

Apical meristems of papaya seedlings were cultured in Murashige and Skoog (MS) basal medium (Murashige and Skoog, 1962) supplemented with BAP (6-benzylaminopurine) (0–0.7 mg/l) and NAA (naphthalene acetic acid) (0–0.2 mg/l). The cultures
were maintained at 27 ± 1°C under 1200 lux with a 16 h photoperiod. The shoots were rooted on solidified MS with 2.5 mg/l IBA.

**Papaya seed oil**

Papaya seed oil was extracted using a mechanical oil extractor and a solvent (light petroleum ether (bp 40–60)) extractor. The oil was analysed for fatty acid composition.

**RESULTS**

**Germlasm collection and documentation**

Accessions from Coastal, Western, Rift Valley and Nyanza provinces showed the widest morphological diversity. *Vasconcellea cundinamarcensis* was found in Rift Valley and Nyanza provinces.

**Characterisation of papaya germplasm**

The dendrogram (Figure 1) was divided into four main clusters (C1–C4) based on the major morphological characters. The first cluster represented five accessions, the second 25 accessions, the third 12 accessions and the fourth 18 accessions.

**Agronomic and quality evaluation of papaya germplasm in Kenya**

Plant height was significantly different among the accessions and ranged from 82 to 176 cm (Table 1). There were significant differences in fruit yield among the accessions, ranging from 1,724 to 13,193 g per plant (Table 1).

**Tissue culture**

Shoot multiplication rate was best in solidified MS with 0.5 mg/l BAP and 0.1 mg/l NAA, achieving an average of 23 new shoots in 9 weeks.

**Papaya seed oil**

Seeds of the papaya germplasm yielded oil with over 72% oleic acid. The oil was used to make body lotions and soap.

| TABLE I: AGRONOMIC AND FRUIT CHARACTERISTICS OF REPRESENTATIVE ACCESSIONS OF PAPAYA GERMLASM IN KENYA |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| **Plant ID** | **Height at 100 days** | **Height at first flower** | **Fruit yield (g)** | **Brix (%)** |
| TK        | 176<sup>a</sup>         | 118<sup>abc</sup>         | 4343<sup>abc</sup>         | nd          |
| Ole       | 173<sup>ab</sup>        | 118<sup>ab</sup>         | 6261<sup>abc</sup>         | 12<sup>ab</sup>       |
| Kiz       | 164<sup>abc</sup>        | 113<sup>abcd</sup>        | 7335<sup>abc</sup>         | 11.5<sup>abc</sup>    |
| MRG       | 151<sup>abcd</sup>      | 107<sup>abcde</sup>      | 1724<sup>bc</sup>         | 12<sup>ab</sup>       |
| MTM       | 139<sup>abcde</sup>     | 90<sup>abcdef</sup>      | 13193<sup>a</sup>         | 8.4<sup>abcdef</sup>  |
| VB        | 136<sup>ab</sup>         | 87<sup>abcdef</sup>        | 4374<sup>abc</sup>         | 12<sup>ab</sup>       |
| KAD       | 116<sup>cdef</sup>      | 123<sup>a</sup>         | 2106<sup>b</sup>         | 10.9<sup>abcd</sup>   |
| WDjk      | 108<sup>cdef</sup>      | 56<sup>i</sup>        | 10431<sup>ab</sup>         | nd          |
| CPH       | 87<sup>def</sup>        | 73<sup>bcdefg</sup>      | nd                      | nd          |
| Mym       | 82<sup>f</sup>          | 48<sup>a</sup>         | 6919<sup>abc</sup>         | nd          |

Values are mean ± SD (n = 20). Means in a column with the same superscript are not significantly (P > 0.05) different.
DISCUSSION AND CONCLUSION

Carica papaya L. and a related species, Vasconcellea cundinamarcensis, were documented in various parts of Kenya. Papaya germplasm in Kenya revealed considerable diversity in morphological, agronomic and fruit characteristics that could be useful for breeding superior varieties. Ocampo et al. (2006) similarly reported diversity in the morphological and horticultural traits of Caribbean and Venezuelan papaya germplasm. Shoot tip culture of papaya has been reported (Fitch et al., 2005), but reports of commercialisation are rare. In this study, shoot tip culture of papaya regenerated plantlets that were further rooted and are being evaluated for agronomic performance.

Notes: C1–C4 are the clusters (1–4) generated in the cluster analysis. (Source: Asudi et al., 2010.)
Thus a commercially viable protocol for rapid multiplication of papaya of known sex was developed. Papaya seed oil from local germplasm yielded over 72% oleic acid, which was comparable with canola (75%) and safflower (77%) (Corbett, 2003).

Papaya is a fast-growing fruit crop, very rich in vitamins A and C, with seeds that can yield oil with potential for industrial applications. It is a ‘wonder crop’ with the potential for reducing both nutritional and financial insecurity in the rural communities of Kenya.

COMMUNICATION STRATEGY AND IMPACT

Three papers have been published in refereed journals (Asudi et al., 2010, 2013; Mumo et al., 2013), and one Master’s thesis has been produced (Asudi, 2010). A total of 11 papers have been presented at local, regional and international conferences between 2008 and 2012. The research findings were published in The Standard (Kenya’s prominent newspaper) on 19 September 2011.

Products created as part of this project were exhibited in Kenyan agricultural shows and Nairobi international trade fairs in 2009, 2010, 2011 and 2012: a protocol developed for efficient micro-propagation of papaya; tissue-cultured plantlets; papaya yoghurts rich in vitamin C; and antifungal soaps and lotions from papaya seed oil.

One PhD student, four Master’s students, four Bachelor’s students and one technician have been trained.

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REFERENCES


VALORISATION OF POULTRY LITTER TO COMPOST: AN ASSESSMENT OF THE PATHOGEN REDUCTION POTENTIAL

N. Sobratee¹, R. Mohee² and M.F.B. Driver²
ABSTRACT

The study serves to demonstrate the capacity of the composting process in transforming poultry litter into a safe product capable of replenishing the organic matter content of soils. The overall aim was to apply four measurable approaches to evaluate composting-driven stabilisation. Total coliforms (TC), fecal coliforms (FC), Escherichia coli (EC) and fecal enterococci (FE) were systematically enumerated during a 110-day experiment. First, temperature elevation and volatile solids reduction were monitored to determine decomposition rate. The microbial indicators were then characterised via their respective rate equations using the Levenberg–Marquardt algorithm. Third, an exposure assessment investigated the exposure of root crops to enteric bacterial indicators at point of harvest. Fourth, the potential for E. coli regrowth in terms of the maximum specific growth rate ($\mu_{\text{max}}$) was parameterised. Based on the results, a mathematical relationship relating composting duration, decomposition rate and $\mu_{\text{max}}$ was derived to determine the occurrence of E. coli regrowth. Thermophilic temperatures (>55°C) were maintained in the windrows for >15 days. Log10 reductions of 6.98, −8.03, −8.18 and −5.96 occurred in TC, FC, E. coli and FE concentrations, respectively. TC, FC, EC and FE levels on root crops were reduced to very low fractions of 0.190, 0.005, 1.2 × 10−3 and 1.3 × 10−4 kg−1, respectively. FE followed a first-order decay rate while the other indicators decayed under a second-order kinetics. $\mu_{\text{max}}$ decreased significantly ($P < 0.05$) from 2.18 h−1 (week 0) to 0.95 h−1 (week 15). The mathematical relationship indicated that regrowth may occur at the onset of the post-thermophilic/nascent second mesophilic phase. Two simple and low-technology strategies have been advocated to ensure the production of pathogen-free and stabilised compost: timely adjustment of moisture content during the thermophilic phase; and turning of compost piles. The research findings were disseminated to various stakeholders in the agricultural sector.

KEY WORDS: EXPOSURE ASSESSMENT, FECAL BACTERIAL INDICATORS, LOW-COST PROCESS CONTROL STRATEGIES, REGROWTH, SANITISATION

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INTRODUCTION

Composting of biodegradable agricultural residues has the potential to provide two advantages in Africa: (1) improving soil properties and crop productivity in low-input agriculture; and (2) developing compost production as a side business to empower youth and women through entrepreneurship. Two Millennium Development Goals can thus be addressed together, albeit at different levels: ensuring environmental sustainability, and eradicating extreme poverty and hunger. The aim of the study was to demonstrate the capacity of composting to transform poultry litter into a safe soil improver.

Composts are varied and complex structures. Stability and microbiological characteristics of composts vary depending on the starting material and the specific operational parameters designed and maintained during the process (Haug, 1993). Thus, although pathogen elimination by composting has been well documented (Lemunier et al., 2005; Brinton et al., 2009; Elving et al., 2009), composting regimes required to eliminate pathogen indicators and pathogens vary widely, principally due to the highly dynamic singularity of the composting system in terms of feedstock characteristics, process variables and pile management.

The project used several approaches to benchmark the sanitisation potential in poultry litter composting. The poultry sector in sub-tropical Mauritius is characterised as traditional backyard, small-scale commercial, large-scale commercial and industrial production. The country’s eco-philosophy on environmental sustainability is addressed in the Maurice Ile Durable (MID) Green Paper, such that the results obtained correspond with the current environmental policy. This research was intended to characterise the state-of-the-science for poultry litter sanitisation via composting and to synthesise related information that has multi-disciplinary impact.

The specific objectives were to:

- establish the extent of hygienisation attained in small windrows by focusing on the use of a range of fecal bacterial indicators to judge the sanitisation process outcome;
- verify the temperature dependency of composting as a microbe-driven decomposition process;
- characterise the performance of the fecal bacterial indicators via their rate respective equations;
- determine the quantitative exposure of ready-to-eat root crops to enterobacteria from the spent poultry litter compost;
- apply predictive microbiology concepts to investigate differences in E. coli growth response in broths amended with compost-substrate extracts periodically bypassed from the windrows to mimic regrowth potential;
- identify weak point(s) during the composting process derived from the decomposition rate of the compost substrate and the maximum specific growth rates of the inoculated E. coli.

METHODOLOGY

A 110-day systematic composting study examined the survival of total coliforms (TC), fecal coliforms (FC), E. coli (EC) and fecal enterococci (FE) in three experimental windrows consisting of spent poultry litter amended with sugarcane bagasse. Microbial indicators were enumerated using the three-tube most probable number technique (ISO, 1984, 1991, 1993).

Decomposition rate

Temperature and volatile solids reduction were monitored over time. The equation of Nielsen and Berthelsen (2002) was applied to determine the decomposition rate applicable for composting temperatures as detailed in Sobrateau et al. (2008).
Survival kinetics of fecal bacterial indicators

The rate order of the fecal microbial indicators was identified based on linear relationships with time. Kinetics equations that best describe the behaviour of the faecal indicators as a function of composting time were derived using the Levenberg–Marquardt algorithm in Table Curve 2D (Systat Software, CA, USA) to fit nonlinear mathematical models using the least squares procedure as applied in physical chemistry (Sobratee et al., 2008). The decay kinetics of each indicator was classified as either first or second order.

Quantitative exposure assessment

An exposure assessment based on the source–pathway–receptor approach quantified the exposure of root crops to enteric bacterial indicators at the point of harvest. The loadings of the fecal indicators during composting were calculated by running a Monte Carlo simulation exercise in MS Excel. The assumptions and boundaries used were based on the findings of Sobratee et al. (2009b).

Determination of regrowth potential

The effect was studied of the increasing age of the compost on the kinetic parameters (microbial lag time and maximum specific growth rate) of E. coli under batch culture conditions at 37°C for 5.25 h. The liquid media used consisted of temporally different compost extracts and tryptic soya broth with ampicillin (0.3 g/l). Growth was measured by viable cell counts as described by Sobratee et al. (2009a). The data were parameterised in the Microfit© model to obtain the maximum specific growth rate ($\mu_{\text{max}}$) of E. coli. $\mu_{\text{max}}$, in the present context, is interpreted as the potential of E. coli to grow in the poultry litter despite the composting environment. The E. coli strain was obtained from the National Environment Laboratories (Mauritius).

As a means to integrate the research findings, three parameters of interest to poultry litter composting were unified in a third-order polynomial equation using the Gaussian elimination procedure in the Table Curve 3D software (Systat Software, CA, USA). The explanatory variables were time of composting and decomposition rate. The response variable used was $\mu_{\text{max}}$. The equation generated was plotted and the graphical representation was used to identify trends in $\mu_{\text{max}}$ that indicate the possibility of E. coli growing in compost despite the occurrence of optimum temperatures and decomposition rates.

RESULTS

Temperature histories revealed hygienisation attainment with maximum temperature of 66.4°C. Log10 reductions of 6.98, −8.03, −8.18 and −5.96 occurred in TC, FC, EC and FE concentrations, respectively.

The structured model of Nielsen and Berthelsen (2002), based on the application of theoretical assumptions of high activation energy-induced spontaneous enzyme deactivation, indicated system progress rate and where it could be optimised (55–59°C), thus confirming the relevance of such results for practical purposes in the technical management of composting services. It also emphasised the reduction in decomposition rate beyond 55°C; this demonstrates the importance of maintaining a temperature ceiling in the compost heaps.

The rate equations showed that FE, being more resistant to heat, followed a first-order decay rate and could encompass the totality of the composting process. By contrast, TC, FC and EC decayed more rapidly than FE in the system under second-order kinetics. FE is recommended as an indicator of process performance, whereas EC is more relevant than the others to assess end product quality.

The exposure assessment showed that TC, FC, EC and FE levels on root crops were reduced to very low levels of 0.190, 0.005, 1.2 × 10$^{-3}$ and 1.3 × 10$^{-4}$ kg$^{-1}$, respectively.
The final experiment in this research benchmarked the role of the temporally different compost extracts, representing increasingly non-host environments, in suppressing the growth of seeded *E. coli*. The experiment indirectly identified the possibility of fecal bacterial regrowth. The most significant outcome pertains to the increase in lag time from 0.75 ± 0.30 h (week 0 extract) to 1.78 ± 0.18 h (week 15 extract) and decreasing $\mu_{\text{max}}$ from 2.18 ± 0.29 h$^{-1}$ (week 0) extract to 0.95 ± 0.12 h$^{-1}$ (week 15 extract) in the matured compost extract, indicating the inability of the inoculated fecal bacteria to thrive in the mature stabilised compost microcosm.

**DISCUSSION AND CONCLUSION**

In light of these findings, the results of the decomposition parameters and maximum specific growth rates of inoculated bacteria were synthesised in Table Curve 3D to identify susceptibly weak points, in terms of sanitisation status, during the composting process. The trivariate relationship (Figure 1) showed that regrowth may be triggered at the onset of the post-thermophilic/nascent second mesophilic phase.

Simple process control strategies to mitigate this effect include moisture adjustment to prevent drying off during the thermophilic phase, and turning of compost piles to expose all feedstock to composting temperatures and aeration. Such a finding is of primary importance for hygienic process control monitoring in the context of best management practices to produce a safe and valuable conditioner to improve soil fertility.

**COMMUNICATION STRATEGY AND IMPACT**

A combination of tools and methods have been used to disseminate the research output and share the project lessons in various forums. Two oral presentations were delivered during the Research Week organised by the University of Mauritius in 2008 and 2011. The events provided a platform for interaction between industry and agriculture professionals. The findings were communicated to a wider audience which included key players in the local agricultural scene, agro-entrepreneurs and members of the public at the World Food Day celebrations in October 2010. The event was held in the context of ensuring food security and the theme was ‘United Against Hunger’. A simple poster was displayed to aid the understanding of the general public.

The current research has resulted in four peer-reviewed articles in two high-impact journals (Mohee *et al.*, 2008; Sobratee *et al.*, 2008, 2009a,b) plus two book chapters (Mohee *et al.*, 2009a,b), all of which received high rankings on BioMedLib, and will create networking opportunities for enhanced capacity-building and sharing of research outcomes. The entire research output formed part of a PhD thesis which was endorsed by the Department of Agricultural and Production & Systems, Faculty of Agriculture, University of Mauritius in August 2011.

Potential impacts involve prospects to influence policy decisions by providing structures to encourage composting in the MID context, as a practice that can address waste management issues, climate change adaptation and ensure food security via soil fertility improvement. The research findings provide the scientific understanding to review relevant legislative framework on health and safety issues associated with composting waste materials of fecal origin. Training programmes can be devised in collaboration with extension services and/or private compost producers to encourage training of personnel in the compost production supply chain. Additionally, the research outputs can be used to improve testing services and compost specification development to update current
standards for validating sanitisation during process control and for end-product quality characterisation.

On another level, the findings enable policy-makers to advocate for mass education on the environmental benefits of composting biodegradable agricultural residues and to promote the decentralisation of compost production towards local communities with a view to empowering women and youth. Based on the findings of the study, community outreach tools, such as a ‘train the trainers’ manual on low-cost process control strategies to obtain pathogen free compost, can be developed to facilitate and disseminate the implementation of safe compost production as an innovative rural entrepreneurship option.

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REFERENCES


INTEGRATED CONTROL OF HEMI-PARASITIC RICE WEED
(RHAMPHICARPA FISTULOSA) IN BENIN

S.H.N. Zossou*
ABSTRACT
The weed *Rhamphicarpa fistulosa* (Hochst.) Benth. is a hydromorphic zones species of tropical Africa. It is a wide-spread wetland species, both in crops and in natural vegetation, throughout Western, Central, Eastern and Southern Africa. It causes yield losses in lowland rice production. The objective of this study was to improve rice production in the inland valleys of Benin. Prospection, survey and experimentation were conducted to determine the extent of the damage caused by *Rhamphicarpa* spp. and also to evaluate farmers’ perceptions in the integrated control of this rice pest in lowland rice production in Benin. The results showed that the distribution of *Rhamphicarpa* increased between 1998 and 2010. It was established that 36% of visited inland valleys were infested in 2010. Farmers in infested inland valleys were very familiar with *R. fistulosa* and estimated its impact on rice production to be between 62 and 100% of yield loss. The study also showed that NERICA-L-32 and Gambiaka were the most tolerant and resistant rice varieties, respectively, to *R. fistulosa*. These results were communicated to rice production stakeholders through experimentation in rural areas by using the farmer field school (FFS) approach. Exchange visits have also been organised between farmers of infested inland valleys and those of non-infested inland valleys. Communicating our results had a significant positive impact on the lowland rice production system in infested inland valleys.

KEY WORDS: FERTILISER, LOWLAND, MANAGEMENT, NERICA, PARASITE, RHAMPHICARPA, YIELD
INTRODUCTION

The annual facultative hemiparasitic weed *Rhamphicarpa fistulosa* (Hochst.) Benth. is a hydromorphic zones species of tropical Africa and is considered to be a widespread wetland species, both in crops and in natural vegetation, throughout Western, Central, Eastern and Southern Africa (Muller, 2007). Besides Benin (Gbèhounou and Assigbé, 2003), and other West African countries such as Senegal, Burkina Faso, Mali (Ouédraogo et al., 1999), Guinea and Sierra Leone (Cissé et al., 1996), *R. fistulosa* has also been observed in Uganda (Jackson and Gartlan, 1965), the Democratic Republic of Congo and Congo-Kinshasa (Staner, 1938) and Zimbabwe (Johnson et al., 1998).

*Rhamphicarpa* can cause significant yield reductions in rice, millet, sorghum and maize (Cissé et al., 1996). It parasitises the host through a haustorium bridging parasite and host root xylem, and is not dependent on the presence of a host to complete the life cycle. The parasite derives a clear reproduction advantage from parasitising a suitable host plant (Ouédraogo et al., 1999). Despite its widespread distribution and the yield losses it causes in lowland rice production, very little research has been undertaken on *R. fistulosa*. Few control options are known or available to small-scale, resource-poor farmers in the inland valleys of Benin (Gbèhounou and Assigbé, 2003). *Rhamphicarpa* distribution in the rainfed, lowland rice-growing area of Benin was evaluated for the first time in 1998 by Gbèhounou and Assigbé (2003). *Rhamphicarpa* distribution in the rainfed, lowland rice-growing area of Benin was evaluated for the first time in 1998 by Gbèhounou and Assigbé (2003). Analysis of these data showed that there were some gaps which offered a unique opportunity for investigation. Hence there is a clear need for an analysis of the problem, as well as research on effective and simple integrated control options.

The general study objective was to contribute to food security. The specific objectives were to improve rice production in inland valleys and to improve the income of lowland rice producers in Benin.

METHODOLOGY

Inland valleys survey

Inland valleys grown with rice were first surveyed for the presence of *R. fistulosa* during the 1998 cropping season. In order to fully appreciate the spread and the scale of damage caused by *R. fistulosa*, in 2007 surveys were carried out in 21 inland valleys located in eight districts: Dassa and Glazoué in Central Benin, and Ouaké, Boukoumbé, Malanville, Gogounou, Kandi and Karimama in North Benin. For confirmation, in 2008 all inland valleys were revisited with a random sample of an additional 10 inland valleys in districts of Dassa (1), Glazoué (1), Banté (1) Boukoumbé (2), Matéri (1), Kandi (2), Ouaké (1) and Banikoara (1). In 2010, the additional 10 inland valleys of 2008 were revisited with an additional eight inland valleys in the districts of Boukoumbé (2), Tanguíëta (2) Adjohoun (2) and Bonou (2).

With the technical assistance of extension officers, all of the farmers in these inland valleys were interviewed about the presence of *R. fistulosa* in their fields. This was followed by field visits to confirm the farmers’ responses. *Rhamphicarpa* was detected everywhere within the inland valleys; it was abundant and never limited to just a few plants. The surveyed areas were selected based on the size and representativeness of rainfed, lowland rice-growing areas in Benin.

Farmers’ perceptions of *Rhamphicarpa* infestation

To fully appreciate farmers’ perceptions of the damage wrought by *R. fistulosa*, a semi-structured survey was conducted in the Dassa (Loulé 1, Loulé 2 and Gankpétin inland valleys) and Glazoué districts (Sokpona inland valley) with 120 farmers in 2007. Three inland valleys (Loulé 1, Loulé 2 and Sokpona) were selected, as *Rhamphicarpa* had been detected there and reported on previously. One inland valley with no prior report of *Rhamphicarpa*
presence identified by Gbèhounou and Assigbé since 1998 was Gankpé tin. The questions related to knowledge of Rhamphicarpa by farmers, when it was first detected and its origin in fields, yield losses, strategies adopted by farmers to manage the infestation, its local name, rice cultivars, and their seed sources.

**Pot experiments**
On-station experiments were carried out in pots in order to evaluate the potential role of some varieties of NERICA (New Rice for Africa) and other rice varieties grown in the lowlands, combined with the use of mineral fertiliser, in controlling *R. fistulosa*.

**Rice cultivars**
Seven varieties of rice were used: NERICA-L-20, 32, 39, 43; IR64 and TOG5681 (respectively Asiatic and African parents of NERICA), and Gambiaka. The choice of rice cultivars was based on their strong weed competitive check (NERICA-L-20, 32, 43 and TOG5681); their weak competitive check (NERICA-L-39 and IR64) (Rodenburg et al., 2009); and their characteristic as cultivars most used by farmers for Gambiaka (Becker and Diallo, 1996). The parasitic weed plant used was *R. fistulosa*; its seeds were collected from Sokponta infested inland valley in the district of Glazoué.

**Experimental design**
The experimental design was a split-split plot with six replications. The varieties and control (no host) constitute the main factor. The subfactors were infestation (with two levels, 0 and 5 mg of viable seeds of *R. fistulosa*) and fertilisation (with three levels, 0 kg/ha of NPK and 0 kg/ha of urea; 100 kg/ha of NPK (15 15 15) and 37.5 kg/ha of urea; 200 kg/ha of NPK (15 15 15) and 75 kg/ha of urea).

**Observations**
The parameters measured on rice were tiller number, height at 75 days after sowing, date of flowering at 50%, leaf and stem dry weight at harvest, root dry weight at harvest, yield, and kernel weight of 1,000 seeds. The parameters measured on *R. fistulosa* at harvest were aboveground number, total number of capsules, leaf and stem dry weight, and root dry weight.

**Data analysis**
Qualitative and quantitative analyses of the survey data were performed using Sphinx version 4.5 software. Data gathered from the geographical positioning system were projected onto a map using ArcView GIS 3.2 Software. All the data collected from the pot experiments were processed in Excel in Windows XP and analysed (ANOVA and linear regression) in SAS version 9.1.

**RESULTS**

*Rhamphicarpa* distribution and farmers’ views of impact
The results of the survey are summarised in Map 1. The survey in 2007 and 2008 found that nine out of the 31 prospected inland valleys were infested by *R. fistulosa*. The infested inland valleys represent 29% of the total. In 2010, new infested areas (four infested inland valleys) had been found. In conclusion, the percentage of infested areas in 2010 was found to be 36%.

Of the 120 farmers surveyed, 90 were in the district of Dassa (Loulè 1, Loulè 2 and Gankpé tin) and 30 in the district of Glazoué (Sokponta village). Of the 90 rice producers surveyed in infested inland valleys, 97% had *R. fistulosa* in their fields and 57% recalled the parasite first appearing between 1990 and 1994. The remaining 30 farmers located in the non-infested area (Gankpé tin) were not familiar with and had not heard of the parasite. The origin of the infestation was not clearly identified. Everywhere, farmers who had *Rhamphicarpa* in their fields referred to it in the local language using words whose meanings translate to killing and death. Rice producers estimated yield losses caused...
by *Rhamphicarpa* to be between 62 and 100%. The rice variety commonly used by farmers was Gambiaka. Seventy percent of farmers procured rice seeds from the market. Plate 1 shows different infested lowland rice fields.

**Effects of mineral fertilisers and rice cultivars on *Rhamphicarpa* biology**

Analysis of variance showed that fertilisation induced very highly significant effects ($P < 0.001$) on the emergence date of *R. fistulosa* and its aboveground number. Rice varieties, and the interaction between fertilisation and varieties, did not have a significant effect on the aboveground number of *R. fistulosa* ($P > 0.05$). The supply of 200 kg/ha (NPK) and 75 kg/ha of urea fertiliser mostly reduced the *Rhamphicarpa* aboveground number (Figure 1).

Rice varieties had significant effects ($P < 0.01$) on the reproduction of *R. fistulosa*, unlike fertilisation. The interaction between fertilisation and varieties did not have a significant effect ($P > 0.05$).

Fertilisation, varieties, and the interaction between fertilisation and varieties had a highly significant impact ($P < 0.001$) on leaves and stem dry weight of *R. fistulosa*. The results showed that NERICA-L-32
mostly reduced *Rhamphicarpa* aboveground dry weight, followed by IR64 and TOG5681.

**Effects of infestation and fertiliser on rice varieties**

Infestation by *Rhamphicarpa* had a significant ($P < 0.01$) effect on rice grain yields (Figure 2) and highly significant ($P < 0.001$) effects on tiller number, stem and leaf dry biomass production, but not on kernel weight and plant height. Across parasite-free and parasite-infested conditions, the range of varieties differed significantly ($P < 0.001$) in rice grain yield, 1,000-kernel dry weight, tiller number, height, leaf and stem dry weight.

The application of mineral fertiliser had significant ($P < 0.001$) positive effects on rice grain yield, tiller number, plant height, leaf and stem dry weight, but not on kernel weight. Significant infestation × cultivar interaction effects were observed on rice grain yields ($P < 0.05$), 1,000-kernel weight ($P < 0.01$), leaf and stem dry weight ($P < 0.001$). The interaction between *Rhamphicarpa* infestation and fertiliser was highly significant for tiller number only ($P < 0.001$).

*Rhamphicarpa*-inflicted yield losses of NERICA-L -32 and -39 were not significantly different from their parents, IR64 and TOG5681.

**DISCUSSION AND CONCLUSION**

**Distribution and farmers’ analysis of *Rhamphicarpa* infestation**

The current study showed that the incidence of *Rhamphicarpa* as a weed of lowland rice has risen (36% of visited inland valleys in 2010 were infested). *Rhamphicarpa* also occurs in natural vegetation (Gbêhounou and Assigbé, 2003). Interviews with rice farmers in the current study indicated that the majority (70%) of the seed originated from the local markets. Such informal seed systems are common in African countries, but lack the institutional oversight and quality control important to prevent spread of diseases and pests through seeds. The results also confirmed that *Rhamphicarpa* is a serious local constraint to rainfed rice production in Benin as a result of its high yield losses (60 to 100%), as farmers estimated. This was confirmed by the pot experiments with the most popular cultivar, Gambiaka.

**Host effects**

*Rhamphicarpa* fistulosa infestation significantly reduced rice grain yield and rice straw biomass. This was similar to previously reported effects of *Striga* (*S. asiatica* and *S. hermonthica*) on rice
FIGURE 1: EFFECT OF FERTILISER–HOST INTERACTION ON *RHAMPHICARPA* ABOVEGROUND NUMBER

![Graph showing the effect of fertiliser-host interaction on *Rhamphicarpa* aboveground number.]

- **No fertiliser**
- **(100; 37.5) kg/ha (Urea; NPK)**
- **(200; 75) kg/ha (Urea; NPK)**

**Rhamphicarpa** above ground number – with host
**Rhamphicarpa** above ground number – no host

FIGURE 2: EFFECT OF *RHAMPHICARPA FISTULOSA* INFESTATION ON YIELDS ACROSS HOSTS

![Bar chart showing the effect of *Rhamphicarpa fistulosa* infestation on rice yields across different hosts.]

- **Gambiaka**
- **IR64**
- **NERICA-L-20**
- **NERICA-L-32**
- **NERICA-L-39**
- **NERICA-L-43**
- **TDG5861**

**Rice grain yields**

- **Non-infested**
- **Infested**
(Johnson et al., 1997). Resistant and tolerant crop genotypes have lower parasitic infestation levels and fewer parasite-inflicted biomass or yield losses unless they are exposed to high levels of infestation (Rodenburg et al., 2005).

Ouédraogo et al. (1999) indicated that parasitising *Rhamphicarpa* plants accumulate more biomass than plants that grow without a host. This study confirmed their results and also showed the difference between cultivars in the amount of *Rhamphicarpa* biomass they support. *Rhamphicarpa* infection rate, which could be used to select resistant genotypes, could therefore be based on aboveground biomass dry weights. The most resistant cultivars were Gambiaka, followed in decreasing order by TOG5681, IR64 and NERICA-L-32. The remaining three NERICA-L cultivars (-20, -39 and -43) supported significantly higher aboveground biomass dry weight of *Rhamphicarpa* and could therefore be considered susceptible.

Alternatively, tolerance could be assessed by considering the relative grain yield loss. NERICA-L-32 and NERICA-L-39 are the most tolerant varieties. With reference to the agronomic characteristics of NERICA-L-32 and NERRICA-L-39, NERICA-L-32 was the most tolerant variety in the range of NERICA cultivars, and IR64 was the most tolerant variety among the local cultivars.

**Mineral fertiliser and host effects**

The application of fertiliser significantly reduced *Rhamphicarpa* plant numbers and biomass, and confirms the negative effects of *Rhamphicarpa* infestation on host performance. A previous study found that fertiliser application controls parasitic weeds of the genus Striga (Yoneyama et al., 2007).

Host presence across varieties had a significant effect on *Rhamphicarpa* biomass. *Rhamphicarpa fistulosa* is a new rice pest that merits the attention of the international scientific community. This strategy, which encompasses both the variety and the application of mineral fertiliser, may be the only way at present to control the parasite effect on lowland rice cultivation in the infested area in Benin. Therefore it is necessary to evaluate the damage caused by the parasite in other infested African countries, to study the biology and ecology of the parasite, and to research integrated strategies adopted in other countries.

**COMMUNICATION STRATEGY AND IMPACT**

The results of our study were communicated to rice production stakeholders through experimentation in the rural area using the farmer field school (FFS) approach. Pictures illustrating the important steps in the experiments have been projected for farmers in selected rural areas of lowland rice production. These projections were followed by explanations and discussions between participants. Exchange visits have been organised between farmers of inland valleys and those of non-infested inland valleys; farmers who were selected to participate in the farmer field school shared their experiences and knowledge of *R. fistulosa* infestation. Communicating our results had a significantly positive impact on the lowland rice production system in infested inland valleys.

**ACKNOWLEDGEMENTS**

We wish to thank Brice Sinsin, Adam Ahanchede, Gualbert Gbékounou, Jone Rodenburg and Paul Kiepe for their scientific support, contributions and comments during the field research. We are grateful for the financial support of the Centre Régional de Recherche et d’Éducation pour un Développement Intégré and the Inland Valleys Consortium.

**REFERENCES**


YOUNG PROFESSIONALS IN SCIENCE
BRUCELLOSIS IN BREEDING FEMALES OF CATTLE, CAMEL AND GOAT UNDER PASTORAL MANAGEMENT IN BORANA, ETHIOPIA

B. Megersa¹,³, F. Abunna², A. Regassa¹, D. Biffa⁴, J. Godfroid⁴ and E. Skjerve⁴
ABSTRACT

In developing countries, the impact of brucellosis on the economy and public health remains of particular concern. The disease poses a barrier to trade in animals and animal products and could seriously impair livelihoods of rural livestock owners in general, and pastoral societies in particular. The objective of the study was to determine to what extent *Brucella* infection is a contributing cause of abortion among breeding females of cattle, camels and goats in Borana, Ethiopia. A breeding female subpopulation of 283 cattle, 756 camels and 757 goats were used in this study. Serum samples were serially tested using the rose bengal test and the complement fixation test. The study showed that anti-*Brucella* antibodies were prevalent in 10.6% (95% confidence interval (CI) 7.4, 14.9), 2.2% (95% CI 1.4, 3.7), and 1.9% (95% CI 1.1, 3.2) of cattle, camels and goats, respectively. Abortion was more commonly reported in camels (23.4%) than cattle (13.8%) and goats (12.4%). *Brucella* infections contributed significantly to abortion in cattle (odds ratio (OR) = 4.7; 95% CI 2.0, 10.8) and goats (OR = 6.9; 95% CI 2.2, 21.7), but not in camels. The number of young produced by breeding females was apparently reduced in seropositive groups. Keeping more than two animal species at household level was found to be the risk factor for cattle (OR = 3.1; 95% CI 1.2, 7.9) and camel (OR = 5.3; 95% CI 1.2–23.5) seropositivity to *Brucella* infection when compared with animals from households that kept only two animal species. This may imply the possibility of cross-species transmission of *Brucella* infection under such mixed herding. The wet season (OR = 4.8; 95% CI 1.3, 18.1) was found to be associated with seropositivity in goats, linked to a coincidence of increased deliveries in flocks with possible excretion of *Brucella* organisms. The results showed that *Brucella* infection is the likely cause of abortion in cattle and goats, while other causes largely outweigh brucellosis as a cause of abortion in camels in Borana.

KEY WORDS: EPIDEMIOLOGY, PUBLIC HEALTH, RISK FACTORS, RUMINANTS, SEROLOGY

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INTRODUCTION

The economic and public health impact of brucellosis remains of particular concern in developing countries such as Ethiopia (WHO, 2006). The disease poses a barrier to trade in animals and animal products, creates public health hazards and is an impediment to free animal movement. It could seriously impair socio-economic development for livestock owners, who represent a vulnerable sector in rural populations in general and pastoral societies in particular (Benkirane, 2006). Brucellosis remains endemic and continues to be a major public and animal health issue in many developing regions of the world, including Ethiopia. The disease can generally cause significant loss of productivity through abortion, prolonged calving interval, low herd fertility and comparatively low milk production in different ruminants (Radostits et al., 2000; Wernery and Kaaden, 2002). Evidence of Brucella infections has been serologically demonstrated by several researchers in sera of animals in Ethiopia. Seroprevalence has been predominantly reported in cattle (Berhe et al., 2007; Kebede et al., 2008; Mekonnen et al., 2010) while the status of the disease in camels (Teshome et al., 2003; Megersa et al., 2005) and goats (Teshale et al., 2006; Ashenafi et al., 2007) has not been well documented. More importantly, the significance of animal brucellosis in causing abortion and reproductive loss in different livestock species has not been substantially concluded. Therefore the objective of this study was to determine the role of Brucella infection in causing abortion and its contribution to reproductive losses in breeding females of cattle, camels and goats in Borana, Ethiopia.

MATERIALS AND METHODS

A repeated cross-sectional study was carried out on brucellosis cows, camels and goats from December 2007 to October 2008 in Yabello, a district located at 4°53’24”N, 38°04’48”E in Borana, Southern Ethiopia. Sixteen villages were selected based on random sampling. At least two to three villages per pastoral association (PA, the smallest administrative unit) were included in the study, and restrictions on the selections were imposed, based on the accessibility of the villages by vehicle or the proximity to roads and the presence of the three ruminant species. Seroprevalence reports of brucellosis in cattle (Berhe et al., 2007) camels (Teshome et al., 2003; Megersa et al., 2005) and goats (Teshale et al., 2006; Ashenafi et al., 2007) were considered to estimate the expected mean prevalence of 5% among the three ruminants. Based on this assumption, Epicalc 2000 (version 1.02) was used to calculate the sample size for each ruminant species (on the basis of a further assumption of 7% null hypothesis, 95% CI 0.05 precision level and 80% case detection power of the test). Accordingly, a total of 283 cows, 757 camels and 756 goats primiparous and above were subsampled and analysed from the data generated for the sero-epidemiological study of brucellosis.

For ease of restraining, the preferred sample collection time was early in the morning, before the animals were taken out to graze. Blood samples of 10 ml were aseptically collected using plain tubes from local cattle and camels, and about 5 ml from goats through jugular venipuncture. Animals were blood sampled during the dry (December 2007 to January 2008) and rainy seasons (April to May 2008) to determine seasonal effects on the occurrence of brucellosis. Serum samples were separated within 12 h of collection and transported to the laboratory in an icebox, where they were stored at −20°C until testing. Information on potential risk factors such as environment, animal factors and husbandry practices was provided on a standard form during blood sampling. In addition, a questionnaire survey was administered to individual livestock owners to gather information on herd or flock management, composition, herd movement and type of water point used. Serum samples were serially tested using the rose bengal test (RBT) using RBT antigen as a presumptive test, and using the complement fixation test (CFT) as the confirmatory test at the National Veterinary Institute (NVI), Debre Zeit,
Ethiopia. Anti-Brucella species antibody detections by RBT and CFT were performed according to the OIE (2004) procedure. An animal was considered positive if it tested seropositive on both RBT and CFT serial interpretation. All the necessary statistical analysis was performed using STATA version 10.0 for windows (Stata Corp., 2001). Association of abortion as well as exposure variables with Brucella seropositivity was assessed using logistic regressions. The mean number of calves or kids (live births) per breeding female was compared between seropositive and seronegative groups.

**RESULTS**

Seropositive reactors were more frequently detected in cattle than in camels and goats, with 10.6, 2.2 and 1.9%, respectively. Table 1 displays brucellosis seropositivity, history of one or more abortions among the three animal species, and association of abortion with seropositivity. Abortion was more commonly reported in camels than in cattle and goats. About 23.4% of dromedary females had a history of one or more abortions, compared with 13.8 and 12.4% in cattle and goats, respectively. Abortion was significantly associated with Brucella seropositivity in cattle (odds ratio (OR) = 4.7) and goats (OR = 6.9) but not in camels (OR = 1.4). There was a significant association between old age and abortion in camels (OR = 4.6, 95% CI = 2.3, 8.1) and cattle (OR = 2.04, 95% CI = 1.1, 16.8), but abortion was higher among younger goats.

The mean ages of breeding females and number of young animals produced by females together with their brucellosis status are shown in Table 2. The average ages of subsampled females were 8.1 (range 4 to 16), 10.2 (range 5 to 22) and 3.1 years (range 2 to 9) for cattle, camels and goats, respectively. It appears that the number of young animals produced per breeding female was slightly reduced in seropositive groups. It is worth noting that the number of kids produced per goat per parity was regarded as single birth due to incomplete information on multiple births.

Results of the associations of potential risk factors with seropositivity to Brucella infections among breeding females based on multivariable logistic regression analysis are shown in Table 3. The exposure variable identified for cattle was keeping more than two livestock species (OR = 3.1) compared with keeping two species at household level. Similarly, the same scenario as in cattle was also observed for camels, with increased risk of seropositivity in camels kept alongside other animal species (OR = 5.3). In goats, the wet season

<table>
<thead>
<tr>
<th>Animal species</th>
<th>Brucellosis Status</th>
<th>Number</th>
<th>Abortion Number (%)</th>
<th>OR (95% CI)</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Negative</td>
<td>253</td>
<td>28 (11.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>30</td>
<td>11 (36.7)</td>
<td>4.7 (2.0, 10.8)</td>
<td>&lt;0.000</td>
</tr>
<tr>
<td>Camel</td>
<td>Negative</td>
<td>739</td>
<td>172 (23.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>17</td>
<td>5 (29.4)</td>
<td>1.4 (0.5, 4.1)</td>
<td>0.501</td>
</tr>
<tr>
<td>Goat</td>
<td>Negative</td>
<td>744</td>
<td>62 (8.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>13</td>
<td>5 (38.5)</td>
<td>6.9 (2.2, 21.7)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
TABLE 2: MEAN (95% CI) AGE AND NUMBER OF YOUNG ANIMALS (YA) PRODUCED BY BREEDING FEMALES OF CATTLE, CAMELS AND GOATS

<table>
<thead>
<tr>
<th>Animal species</th>
<th>Brucellosis</th>
<th>No.</th>
<th>Mean age ± SE</th>
<th>Mean YA ± SE</th>
<th>Mean YA ± SE (adjusted for age)</th>
<th>Difference in YA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Negative</td>
<td>253</td>
<td>8.0 ± 0.2</td>
<td>3.8 ± 0.1</td>
<td>3.9 ± 0.1</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>30</td>
<td>8.3 ± 0.4</td>
<td>3.4 ± 0.2</td>
<td>3.4 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>Camel</td>
<td>Negative</td>
<td>739</td>
<td>10.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>17</td>
<td>10.4 ± 1.0</td>
<td>3.1 ± 0.4</td>
<td>3.1 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>Goat</td>
<td>Negative</td>
<td>743</td>
<td>3.1 ± 0.1</td>
<td>2.5 ± 0.1</td>
<td>2.9 ± 0.1</td>
<td>16.0</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>14</td>
<td>4.1 ± 0.6</td>
<td>2.5 ± 0.5</td>
<td>2.5 ± 0.5</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3: MULTIVARIABLE ANALYSIS OF POTENTIAL RISK FACTORS FOR SEROPOSITIVITY TO BRUCELLA INFECTIONS IN THE BREEDING FEMALES OF CATTLE, CAMELS AND GOATS

<table>
<thead>
<tr>
<th>Species</th>
<th>Variables</th>
<th>Levels</th>
<th>No.</th>
<th>Prevalence (%)</th>
<th>OR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>Age category</td>
<td>Younger</td>
<td>61</td>
<td>1.6</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>175</td>
<td>14.9</td>
<td>9.9 (1.3, 74.7)</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Older</td>
<td>47</td>
<td>6.4</td>
<td>3.8 (0.4, 38.0)</td>
<td>0.257</td>
</tr>
<tr>
<td></td>
<td>Species composition*</td>
<td>2 species</td>
<td>119</td>
<td>5</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2 species</td>
<td>164</td>
<td>14.6</td>
<td>3.1 (1.2, 7.9)</td>
<td>0.019</td>
</tr>
<tr>
<td>Camel</td>
<td>Species composition</td>
<td>2 species</td>
<td>324</td>
<td>0.6</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2 species</td>
<td>432</td>
<td>3.5</td>
<td>5.3 (1.2, 23.5)</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Season</td>
<td>Dry</td>
<td>499</td>
<td>1.6</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>257</td>
<td>3.5</td>
<td>1.9 (0.7, 4.9)</td>
<td>0.209</td>
</tr>
<tr>
<td>Goat</td>
<td>Season</td>
<td>Dry</td>
<td>551</td>
<td>0.7</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>206</td>
<td>4.4</td>
<td>4.8 (1.3, 18.1)</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>Age category</td>
<td>Younger</td>
<td>191</td>
<td>2.1</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>526</td>
<td>1.0</td>
<td>0.4 (0.1, 1.4)</td>
<td>0.149</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Older</td>
<td>40</td>
<td>10.0</td>
<td>1.9 (0.4, 9.2)</td>
<td>0.434</td>
</tr>
</tbody>
</table>

*Household-level livestock species composition (presence of cattle, camels, goats or sheep) ranged from two to four animal species.
(OR = 4.8) was found to be associated with seropositivity to *Brucella* infections. The wet season is probably linked to coincidence of increased deliveries in flocks with excretion of *Brucella* organisms, which is the actual risk factor for infection.

**DISCUSSION AND CONCLUSION**

Seropositivity to *Brucella* infection was significantly higher in cattle (10.6%) compared with camels (2.2%) and goats (1.9%), which is consistent with the serosurvey findings of brucellosis in different ruminant species sharing the same ecosystem in Chad (Schelling et al., 2003). Cadmus et al. (2006) also reported higher seroprevalence to *Brucella* species from Nigerian cattle than goats, while seroprevalence was higher in Sudanese cattle and camels compared with sheep and goats (Mokhtar et al., 2007). Conversely, records of higher seroprevalence were documented in camels and goats in the Middle East areas (Abbas and Agab, 2002; Al-Majali, 2005; Al-Majali et al., 2008; Dawood, 2008). In classical brucellosis epidemiology (i.e. *Brucella abortus* in cattle, *Brucella melitensis* in sheep and goats, and *Brucella suis* in pigs) where control measures are not in place, a state of being endemic is reached in the maintenance host species which is characterised by a high seroprevalence at both herd and individual animal levels. Animals are infected early in their life, and females are likely to abort at their first pregnancy. In the Middle East, *B. melitensis* is endemic in small ruminants, and seropositivity is detected in the vast majority of flocks, with individual prevalence reaching 27.7% (Al-Majali, 2005). In Denmark, *Brucella suis* biovar 2 has been isolated in cattle and was linked to its presence in the hare (*Lepus europaeus*) reservoir (Andersen and Pedersen, 1995). These studies suggest that infection with *Brucella* spp. in a non-preferential host is not sustainable, and a state of being endemic has not been reached. Similarly, the occurrence of *B. melitensis* or *B. abortus* in camels was found to be linked to their presence in their livestock reservoir, i.e. small ruminants and cattle, respectively (Abbas and Agab, 2002; Al-Majali et al., 2008; Dawood, 2008). Accordingly, higher brucellosis seroprevalence in cattle than in camels and goats in the present study confirmed a spillover of infection from cattle to the latter species. Cattle, camels and goats, and to some extent sheep, are the principal livestock species that are kept in Borana lowland. Herding of these animals together, which is customary among the traditional pastoral population, is one of the putative factors that encourages transmission of the *Brucella* infection. Keeping more animal species at household level may increase animal density and the chances of contact between animals, thus facilitating exposure to infectious agents and increasing the risk of infection. Likewise, mixed herding was reported by different authors to be a risk factor for *Brucella* transmission between different animal species (Al-Majali et al., 2008; Musa et al., 2008). Musa and his co-authors (2008) reported higher seroprevalence of brucellosis in camels kept with cattle, sheep and goats in Sudan. The authors subsequently isolated both *B. melitensis* and *B. abortus* (*B. melitensis* biovar 3, *B. abortus* biovar 6) from camels in the area. This substantiated the existence of cross-species transmission of *Brucella* infection under such composite holdings. The wet season is linked to increased deliveries with excretion of *Brucella* organisms that could facilitate transmission and exposure to the pathogen. The most common clinical manifestation of brucellosis in natural hosts is reproductive loss resulting from abortion, birth of weak offspring, or infertility. In particular, abortion, stillbirth or a weak, non-viable calf is the hallmark of brucellosis (Olsen and Tatum, 2010). Abortion in farm animals (Kabagambe et al., 2001; Schelling et al., 2003; Muma et al., 2007; Musa et al. 2008) represents the leading complaint attributed to *Brucella* infections. In the present study,
seropositive cattle (OR = 4.7) and goats (OR = 6.9) were much more likely to have had an abortion in previous years compared with non-reactors. This is comparable with the findings of Kabagambe et al. (2001) and Schelling et al. (2003) from Chad, who reported that Brucella seropositive animals were three to five times more likely to have had an abortion compared with seronegative groups. Association of seropositivity with abortion was not observed in camels, unlike other study findings, which documented the contribution of Brucella infections to camel abortion (Musa et al., 2008). Known causes of abortion in camels are many and involve a wide range of etiologic agents, both specific and non-specific. A thorough literature review by Tibary et al. (2006) demonstrated that abortion rates due to infectious diseases vary from 10% to more than 70% in some areas, and a wide range of infectious causes of abortion were identified. Thus results from this study confirmed that brucellosis is the likely cause of abortion in cattle and goats, while other causes largely outweigh brucellosis as a cause of abortion in camels in Borana. The incidence of abortion and number of young animals produced per breeding female have been regarded as reasonable indicators for productivity in livestock (McDermott et al., 1987). Consequent to abortion, the number of young animals and total milk production are the two most important factors affected (Olsen and Tatum, 2010). In the present study, an attempt was made to generate data on the reproductive history profile of breeding females to examine the role of Brucella infection in reducing the number of young animals produced. The mean number of young animals produced was slightly reduced in seropositive groups. In goats, however, the mean number of kids produced by both positive and negative groups is similar, which is attributable to a higher mean age in the positive group than in the negative group. It is important to note that information based on a cross-sectional study which has poor causal inference ability may not provide a quantitative impact estimate and may have limitations, but that this is the only information available for a pastoral production system where more extensive studies are not feasible.

In conclusion, the study showed that antibodies to Brucella organisms were prevalent in breeding females, and the contribution of Brucella infection to abortion was observed in cattle and goats. Although based on crude estimates using cross-sectional data, an apparent reduction in the percentage of calves and kids produced by seropositive females was indicated. Animal brucellosis impacts significantly on livestock productivity and poses a zoonotic risk to the pastoral households. Therefore further investigation into human brucellosis and identification of Brucella species or biotypes causing brucellosis is essential in order to design effective control programmes.

COMMUNICATION STRATEGY AND IMPACT

Information, education and messaging on the distribution and transmission of the disease was communicated to the pastoral community, administrative structures and schools, as well as to community and religious/traditional leaders at church/mosque/social gatherings. We have utilised pastoral community committees, networks of extension workers/development agents and community animal health workers. Feedback from the pastoral community has revealed that pastoralists have been sufficiently informed of the transmission and impact of the disease and that they have started to manage their livestock in line with the recommendations put forward as a result of the study findings. In general, awareness has been created among pastoralists with regard to the handling of animals and animal byproducts. The livelihood of the pastoralists has also improved, and they are playing their own role in helping the country to generate increased revenue from
exporting healthy animals and animal products. Work is ongoing in collaboration with Tufts University to persuade the Government of Ethiopia to incorporate the issues of pastoralists into the curricula of selected universities (departments of sociology, natural resources and range sciences, and animal health and production). These are the departments that play the biggest role in addressing pastoral issues. The selected universities have participated in several workshops and training programmes organized by Tufts University with a view to incorporating pastoral affairs into their curricula.

ACKNOWLEDGEMENTS

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REFERENCES


THE IMPACT OF GLOBAL PRICE INSTABILITY ON CAMEROON CEREAL MARKETS

J.J. Ambagna¹ and G.Q. Kane²
ABSTRACT

The Cameroon economy is dependent on international food markets to feed the country’s population, but the instability of these markets creates unfavourable prices on local markets. The aim of this study was to determine the impact of the instability of international cereal prices on the Cameroon markets. Based on the estimate derived from a threshold autoregressive model, using data from the International Monetary Fund and the Cameroon National Statistics Institute, a review was undertaken of the cereal price indices for markets in Yaoundé and Douala. This made it possible to accept the hypothesis of a cointegrating relationship between price indices for cereals on the international market and the Cameroon markets. In the specific case of Yaoundé, the asymmetric transmission hypothesis was adopted to show that the cereal price index tends to return more quickly to its equilibrium level when cereal prices fall on the international market. Conversely, if a shock drives cereal prices up on the international market, the cereal price index is less flexible and so does not return to its equilibrium level, possibly leading to food insecurity for households and their status as net purchasers of food products.

KEY WORDS: ASYMMETRIC TRANSMISSION, COINTEGRATING RELATIONSHIP, FOOD INSECURITY, INSTABILITY, MODEL

AFFILIATIONS

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2 University of Yaoundé II, Faculty of Economic Sciences and Management (FSEG), Yaoundé, Cameroon.
INTRODUCTION

The liberalisation of agricultural trade in 1994 triggered an upsurge in the volume of food products imported into Cameroon, thus increasing the economy’s dependence on cereal imports. Most studies point to comparative advantages being available as a result of opening up agricultural trade (Nash and Mitchell, 2005; Maros and Will, 2008) but one significant development is often overlooked: the impact of global food price instability on national markets.

The international food markets are highly unstable. A country that is heavily dependent on these markets is therefore vulnerable to price instability on the national markets. Several factors account for spatial price transmission. This applies to the market power of certain firms or certain commercial intermediaries, the costs of transactions, information and risk asymmetries, intervention policies and consumer food preferences. The literature on agricultural price transmission is dominated by the debate on asymmetric price transmission. Two variants in asymmetric price transmission are singled out: positive asymmetric transmission (price increases are passed on faster than price reductions) and negative asymmetric transmission. The basic theory that asymmetric price transmission is the rule rather than the exception is put forward by Peltzman (2000) in a study that covered 282 products, including 120 types of farm produce. However, the methodological problems involved with the empirical tests may account for this finding, because they lead to the systematic rejection of the zero hypothesis of price transmission symmetry (Gauthier and Zapata, 2001). If such a hypothesis were invariably verified this would lead to a shortcoming in the economic hypotheses, as asymmetric transmission has always been regarded as an exceptional case. The hypothesis would also imply consumers failing to benefit from a price cut and producers from a price increase, such that these two groups would suffer from deteriorating economic welfare simultaneously as a result of price instability. The only groups that would stand to gain from the price instability would be, for example, the intermediaries.

Even if the price transmission asymmetry hypothesis is validated, the meaning of this asymmetry is still in question. Some studies show that price increases are passed on faster than price reductions (Hahn, 1990; Bernard and Willett, 1996). Conversely, other researchers concluded that the reverse is true (Ward, 1982; Punyawadde et al., 1991). However, Ward (1982) showed that oligopolies may be reluctant to lose their market power, but that they pass on price reductions faster than price increases (negative asymmetric transmission). In the light of the threshold autoregressive (TAR) model, Ntsama (2011) accepts the asymmetric transmission hypothesis for Cameroon tomato market pairs. Accordingly, traders are apparently faster to pass on tomato price increases than reductions. The asymmetrical reactions to price shocks are reported to be attributed in this case to the transaction costs, imperfect information, the market power of certain operators and, more importantly, the fact that tomatoes are not easily storable and even prone to perishing quickly.

Another often cited reason for asymmetric price transmission in developing countries is the information asymmetry between the ‘centre’ and the ‘periphery’ (Meyer and Cramon-Taubadel, 2004). Prices at the ‘centre’ in fact respond less to price changes at the ‘periphery’, whereas prices at the ‘periphery’ respond faster to those at the ‘centre’.

The aim of this study was to determine the impact of the instability of international cereal prices on cereal markets in Yaoundé and Douala, Cameroon.
METHODOLOGY

Data collection

The price series were collected on a monthly basis for the 1994–2010 period and covered three cereals: rice, wheat and maize. The cereal prices were denominated in CFA francs per kilogram. They were derived from the monthly Laspeyres cereal price indices on the international market and the Yaoundé and Douala markets, with the base being set as January 1994. The world price index (WPI) for cereals on the world market was derived from cereal price data issued by the International Monetary Fund (IMF). The cereal price indices in Yaoundé (YPI) and Douala (DPI) were derived from the price series gathered by the Cameroon National Statistical Institute (NSI).

Econometric model

A cointegrating relationship standard test was performed to ascertain if there is any long-term relationship between the price indices. The next step was to estimate an asymmetric error correction model, specified with a view to analysing the nonlinearity of the cointegrating relationship between the price indices.

The hypothesis of a cointegrating relationship between the price indices was tested using the standard Engle and Granger procedures (1987) (Table 1). If the residual is stationary, the price indices are cointegrated, but the residual cannot be stationary owing to the continuing shocks of technological progress or demand, or intervention policy shocks. Hence the difficulty in concluding that the prices are cointegrated, even though they may be.

Analysis of an asymmetric cointegrating relationship calls for a cointegrating relationship with break test to be performed in advance to determine endogenously a break date in the long-term relationship. The transmission asymmetry is then described via threshold models. The error correction term is described via a single threshold autoregressive (TAR) model. The asymmetric cointegrating relationship hypothesis is tested on the basis of the Enders and Granger procedures (1998). The cointegrating relationship test is based on the asymmetry hypothesis, whereby:

\[ \Delta \varepsilon_t = I_1 \rho_1 \varepsilon_{t-1} + (1-I_1) \rho_2 \varepsilon_{t-1} + \sum_{k=1}^{\infty} \varphi_k \Delta \varepsilon_{t-k} + \nu_t \]

When the coefficients 1 and 2 are negative, the cointegrating relationship between the price hypothesis is accepted. Two tests are performed: a $t$-max to test the hypothesis according to which these two coefficients are negative, and an $F$-test to test the hypothesis according to which these two coefficients are non-zero. When the test detects the presence of asymmetry in the cointegrating relationship between the prices, it is then possible to estimate an error correction model where the price adjustment speed depends on the type of imbalance.

\[ \Delta P^d_t = \eta + I_1 \lambda^- \varepsilon_{t-1} + (1-I_1) \lambda^- \varepsilon_{t-1} + \sum_{k=0}^{l} \alpha_k \Delta P^w_{t-k} + \sum_{k=1}^{m} \beta_k \Delta P^d_{t-k} + \nu_t \]

NOTES

1. The choice of three cereals is based on the percentage they represent of food imports: 60% on average.
2. This choice is fully justified by the availability of the data and the adjacency of the two port cities to which the imported products are transported.
RESULTS

Cereal price trends on the world and local markets showed some similarities, but domestic market cereal prices were constantly lower than international prices. The most significant peak is seen in 2008, particularly with the food crises that affected most African countries. Figure 1 shows the cereal trends on domestic and world markets.

The hypothesis concerning the stationary nature of the residuals is accepted for the Yaoundé and Douala markets. A 1% variation in the price index for cereals on the international markets results in a price index variation of 0.94 and 0.7% on the Yaoundé and Douala markets, respectively. The conclusion was that the price indices for cereals on the international market and the domestic market were cointegrated. The symmetric error correction model may be specified. The findings are reported in Table 2.

### TABLE 1: ENGLE–GRANGER TEST (STANDARD COINTEGRATING RELATIONSHIP TEST)

<table>
<thead>
<tr>
<th>Series</th>
<th>Coefficient</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaoundé</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>90.63767***</td>
<td>14.9</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.94713***</td>
<td>14.46</td>
</tr>
<tr>
<td>Douala</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>126.2845***</td>
<td>21.17</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.70591***</td>
<td>10.98</td>
</tr>
</tbody>
</table>

### FIGURE 1: CEREAL PRICE TRENDS ON THE WORLD AND LOCAL MARKETS (CFA FRANC/kg)

[Graph showing cereal price trends]
The symmetric error correction model is valid because the spring-back effect $\lambda$ is negative and significant. The price indices for cereals on the Yaoundé and Douala markets adjust to the price index for cereals on the international market. When the adjustment is symmetric, domestic prices match international ones at the rate of 0.069 in Yaoundé and 0.1709 in Douala. This disparity may be attributed to the distance between the city of Yaoundé and Douala port. The asymmetric price transmission hypothesis was verified on the basis of the Enders and Granger test (1998) (Table 3).

The tabulated $t$-max statistic shows that the coefficients $\rho_1$ and $\rho_2$ are significantly negative at the 5% threshold on the two markets. Similarly, the $F$-test also revealed that these two coefficients were significantly non-zero for the two markets. The cointegrating relationship hypothesis was confirmed on the two markets. However, the Wald test makes it possible to reject the hypothesis of equality of the two coefficients uniquely on the Yaoundé markets: the price transmission was asymmetric. An asymmetric error correction model may therefore be specified. Conversely, in the case of the Douala markets, the asymmetric cointegrating relationship hypothesis was rejected. The price transmission is symmetric. Rising and falling prices were passed through at the same rate. The asymmetric error correction model was therefore not specified in this case.

### Table 2: Standard Error Correction Model

<table>
<thead>
<tr>
<th>Series</th>
<th>Coefficient</th>
<th>$t$-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaoundé</td>
<td>$\lambda$</td>
<td>$-0.069^{***}$</td>
</tr>
<tr>
<td></td>
<td>$\alpha_0$</td>
<td>$-0.076$</td>
</tr>
<tr>
<td></td>
<td>$\alpha_1$</td>
<td>$-0.206^{**}$</td>
</tr>
<tr>
<td>Douala</td>
<td>$\lambda$</td>
<td>$-0.1709^{***}$</td>
</tr>
<tr>
<td></td>
<td>$\alpha_0$</td>
<td>$0.0616$</td>
</tr>
<tr>
<td></td>
<td>$\alpha_1$</td>
<td>$0.0938$</td>
</tr>
</tbody>
</table>

### Table 3: Estimate of the TAR Model

<table>
<thead>
<tr>
<th>Series</th>
<th>Coefficient</th>
<th>$t$-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaoundé</td>
<td>$\varrho_1$</td>
<td>$-0.181$</td>
</tr>
<tr>
<td></td>
<td>$\varrho_2$</td>
<td>$-0.068$</td>
</tr>
<tr>
<td></td>
<td>$\varrho_1 = \varrho_2$, Wald = 3.6825, Prob = 0.05642, $F = 7.1222$</td>
<td></td>
</tr>
<tr>
<td>Douala</td>
<td>$\varrho_1$</td>
<td>$-0.251$</td>
</tr>
<tr>
<td></td>
<td>$\varrho_2$</td>
<td>$-0.206$</td>
</tr>
<tr>
<td></td>
<td>$\varrho_1 = \varrho_2$, Wald = 0.340, Prob = 0.5602, $F = 17.98$</td>
<td></td>
</tr>
</tbody>
</table>
When prices on the Yaoundé markets were below their equilibrium level (upward price shock), the pass-through rate was 0.03; otherwise the rate was 0.133 (Table 4). Price movements were therefore rigid downwards, but flexible upwards. The return to equilibrium was therefore faster when the price index for cereals on the local market was lower than its equilibrium level.

**DISCUSSION AND CONCLUSION**

The outcomes confirmed the asymmetric transmission of prices. Higher cereal prices on global markets are reflected more quickly than reductions on the Yaoundé markets. Variations in international cereal prices that passed through to the Cameroon markets resulted in an increase in food prices. Price instability resulted in the instability of purchasing power (if incomes fail to adjust), which adversely affected the availability of food products, to the detriment of both consumers and producers. The Temple and Dury (2003) analysis confirmed this adverse side-effect of price instability on food security in Cameroon. However, while price instability may be endogenous to local markets, as revealed in the analysis, this study showed that the instability may also be imported as a result of tariff cuts, which distort prices of agricultural commodities traded in international markets. Economies able to absorb the price shocks could derive real benefit from opening up markets, but this does not apply to ‘small economies’ such as Cameroon. Accordingly, food security has to form part of the general growth and agricultural development policies in developing countries that are uncompetitive on the international markets. Hence the need to decouple Cameroon’s urban markets from the highly unstable international markets. This can be achieved through the direct intervention of the public authorities in the short and medium term in order to stabilise locally produced food, or by boosting national food supply in the long term.

**COMMUNICATION STRATEGY AND IMPACT**

The paper was presented during several symposiums (five social science research seminars in Dijon on 8 and 9 December 2011 and an international symposium organised by Senegal’s national science and technology agency in Dakar on 2 November 2012). Several conferences are scheduled to be held in various universities, with invitations being sent to policymakers from the Ministries of Agriculture and Rural Development. The impact of the study involves making the authorities aware of the need to steer food policy in another direction in the long term, and revitalising the agricultural sector by alerting stakeholders and policymakers to the need to boost national food production.
ACKNOWLEDGEMENTS

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REFERENCES


IMPROVING AQUACULTURE PRODUCTION IN THE KOU VALLEY, BURKINA FASO

O.T. Amoussou¹, I.A.K. Youssao¹ and A. Toguyén²
ABSTRACT

This study is part of a search for alternatives to diversify fishing activities in the Kou Valley Lake to curb the overexploitation of fisheries resources. The objective of the study was to: (1) inventory the fish diversity; (2) identify the fish population management and exploitation system; and (3) determine the growth performance of Oreochromis niloticus farmed in cages and fish ponds. To this end, catches were sampled in the light of small-scale and experimental fisheries activities. A total of 30 species were surveyed and divided into 14 families. The diversity index was 0.94. The fishing gear most often used were the cast net and gill net, accounting for 40 and 32.73%, respectively, of all fishing activities. The gear and size category breakdown of the fish caught showed that small fish are the most exploited. The three processing systems that female fish wholesalers applied were smoking, frying and drying. In short, fisheries resources were being overexploited. Fish cage culture is apparently the most suitable for diversifying aquaculture activities and, by the same token, boosting the incomes of lakeside residents. These findings were presented to the fisheries industry stakeholders, whereupon recommendations were made for their inclusion in their rules of procedure with a view to safeguarding the future of their activities.

KEY WORDS: DIVERSIFY, DIVERSITY INDEX, MANAGEMENT, OVEREXPLOITATION

AFFILIATIONS

1 University of Abomey-Calavi (UAC), Cotonou, Benin.
2 International Centre for Research and Development on Stockbreeding in Sub-humid areas (CIRDES), Bobo-Dioulasso, Burkina Faso.
INTRODUCTION

Overall, fisheries catches have declined sharply in West Africa since the early 1990s. This is attributable to increased fishing intensity and steady growth in the fishing industry. Overexploitation is the primary reason for the general changes affecting the bulk of the aquatic ecosystems (Lalèyè et al., 2004; Ndiaye et al., 2010). Other factors, such as pollution, the destruction of habitats and the introduction of new species, have led to the degradation of the ecosystems (Ndiaye et al., 2010). Climate change also poses a serious threat to the operation of the aquatic ecosystems and their continuing biodiversity (Villanueva, 2004). Against this background, aquaculture becomes the sole alternative for boosting fish stocks in the Sahel region.

The aim of this study was to contribute to the development of a high-performance production system in order to boost aquaculture production in the urban fringe of Bobo-Dioulasso on a sustainable basis. More specifically, this research seeks to: (1) inventory fish diversity in the Kou Valley Lake; (2) identify the lake’s fish population management and exploitation system; and (3) determine the growth performance of Oreochromis niloticus farmed in cages and fish ponds.

MATERIALS AND METHODS

Study framework

The study was undertaken in Bama village (latitude west: 11°22’ longitude north: 04°22’ altitude: 300 m), 30 km to the south-west of the town of Bobo-Dioulasso, from March 2010 to August 2011. The sub-Sudan type of climate alternates between a rainy season (May to October) and a dry one (November to April). The average annual rainfall varies between 654.3 and 1.191 mm with an average of 922.26 mm and 76.5 days of rain. In the case of the comparatively high air temperatures the minimum monthly average is 20.28°C, while the maximum is 33.92°C. The bush and tree savannah vegetation predominantly comprises herbaceous plants clumped together as floating islands, and these create obstacles to the deployment of certain kinds of fishing equipment, such as gill nets, in the lake.

Data collection

Catches were sampled in the light of small-scale and experimental fisheries activities. The fish population of the lake and its management and exploitation system were identified. The growth performance of Oreochromis niloticus was assessed in two cages (0.86 m³) and one fish pond (5.71 m³). The biological material consisted of young fish with an average weight of 4 ± 1.86 g. The stocking densities were 99 fish/m³ for the cages and 5 fish/m³ for the fish pond. The fish were fed with commercial pellet feed titrated at 30% of protein, containing the following ingredients: soya, rice bran, spent grains, fish meal, shellfish, premix, binder and salt. The daily ration was dispensed twice daily at 8 and 16 h. The 10% total live weight ratio was applied during the experiment (Arrignon, 1993). Body weight development and survival control were measured every 15 days on 38.55% of the population reared (i.e. performed solely on the fish in the cages). When the experiment was completed, all the fish were weighed. Various zootechnical performance parameters were calculated (Khwuanjai and Pornchai, 1997).

Statistical analyses

The SAS (1996) generalised linear models were used to analyse variance. The F-test was performed to identify the implication of each variable factor and the averages were estimated and compared two at a time using the t-test. The correlation between the growth parameters was calculated using the SAS Proc corr procedure.
RESULTS

Inventory of the fish fauna in the lake

The survey results showed 30 species, divided into 14 families (see Annex). The most represented families in terms of the number of species were Mormyridae and Cichlidae each with six species. The values referring to the specific contribution (SC) and the specific frequency (SF) for each of the listed species shows that *Clarias gariepinus* is the most abundant with an SC of 9.97%, followed by *Protopterus annectens*, *Tilapia zillii* and *Oreochromis niloticus* with SCs of 9.66, 9.03 and 8.72%, respectively. There were no significant ($P > 0.05$) differences between these SCs. The diversity index was 0.94 following completion of the inventory, confirming the lake’s great species richness.

Fish fauna management and exploitation system

Mindful of the time allocated to fisheries activities, three types of fishermen were identified: professional (78.57%), semi-professional (17.86%) and amateur (3.57%).

There were four main items of fishing equipment: cast nets (40%), gill nets (32.73%), long lines (20%) and pots (7.27%). The values of the catch per unit effort (CPUE) and the values of the monthly fishing effort (E) are shown in the charts below.
effort (E) showed large variations between the equipment and the fishing months (Figure 1).

The daily production was 1,375.35 g or 328.74 g in the case of cast nets, 116.43 g for pots, 415.18 g for gill nets and 515 g for long lines.

The size category breakdown showed that most of the fish were caught with gill nets (44.3%) and pots (44.86%). Long lines (45.45%) fell into the second category (10–20 cm) and cast nets (32.69%) the third category (20–30 cm) (Figure 2). Three processing techniques were used: smoking, frying and drying. Fresh fish were generally sold by weight. In the case of species such as tilapias (Oreochromis niloticus, *Tilapia zillii, Sarotherodon galilaeus*), catfish (*Clarias gariepinus*), horsefish (*Gymnarchus niloticus*) and Nile perch (*Lates niloticus*), the prices were CFA F 500, 750, 1,250 and 1,500 per kg, respectively.

**Assessment of Oreochromis niloticus growth performances**

The survival rate was 75.29% in cage 1, 81.18% in cage 2 and 97.04% in the fish pond. The nutritive quotient was 2.72 for cage 1, 0.97 for cage 2 and 7.37 for the fish pond. The net biomass was 702, 1,553 and 1,176.5 g, respectively, for cage 1, cage 2

**TABLE 1: ZOO TECHNICAL PARAMETERS FOR OREOCHROMIS NILOTICUS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cage 1</th>
<th></th>
<th>Cage 2</th>
<th></th>
<th>Hole</th>
<th></th>
<th>Significance test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>SE</td>
<td>Average</td>
<td>SE</td>
<td>Average</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Standard length</td>
<td>8.84a</td>
<td>2.58</td>
<td>8.78a</td>
<td>0.93</td>
<td>8.42a</td>
<td>1.20</td>
<td>NS</td>
</tr>
<tr>
<td>Final weight</td>
<td>37.43a</td>
<td>2.47</td>
<td>31.25b</td>
<td>1.50</td>
<td>29.79b</td>
<td>1.54</td>
<td>*</td>
</tr>
<tr>
<td>Weight increase</td>
<td>33.43a</td>
<td>2.47</td>
<td>27.28b</td>
<td>1.50</td>
<td>25.79b</td>
<td>1.54</td>
<td>*</td>
</tr>
<tr>
<td>Weight increase/day</td>
<td>0.88a</td>
<td>0.07</td>
<td>0.72b</td>
<td>0.04</td>
<td>0.67b</td>
<td>0.04</td>
<td>*</td>
</tr>
<tr>
<td>Specific growth rate</td>
<td>5.50a</td>
<td>0.20</td>
<td>5.35a</td>
<td>0.12</td>
<td>5.13a</td>
<td>0.12</td>
<td>NS</td>
</tr>
</tbody>
</table>

SE, standard error; *, P < 0.05; NS, not significant; averages from the same line followed by the same letter are not significantly different at the 5% threshold.

**TABLE 2: CORRELATIONS BETWEEN THE VARIOUS GROWTH PARAMETERS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Standard length</th>
<th>Final weight</th>
<th>Weight increase</th>
<th>Weight increase/day</th>
<th>Specific growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard length</td>
<td>1</td>
<td>0.60***</td>
<td>0.60***</td>
<td>0.60***</td>
<td>0.58***</td>
</tr>
<tr>
<td>Final weight</td>
<td>1</td>
<td>0.99***</td>
<td>0.99***</td>
<td>0.96***</td>
<td></td>
</tr>
<tr>
<td>Weight increase</td>
<td>1</td>
<td>0.99***</td>
<td></td>
<td>0.96***</td>
<td></td>
</tr>
<tr>
<td>Weight increase/day</td>
<td>1</td>
<td>0.99***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific growth rate</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

***, P < 0.001.
and the fish pond. The biomass per square metre was 536.25 g/m² for cage 1; 1,455.94 g/m² for cage 2; and 1,229.97 g/m² for the fish pond. The growth parameter data are given in Table 1. The various growth parameters (Table 2) correlated very significantly ($P < 0.001$).

**DISCUSSION AND CONCLUSION**

When the inventory was completed, four new species (*Schilbe mystus*, *Synodontis eupterus*, *Micralestes comoensis* and *Petrocephalus pellegrini*) never previously surveyed had been discovered. However, eight species (*Hyperopisus bebe*, *Mormyrops anguilloides*, *Mormyrus rume*, *Barbus alabes*, *Siluranodon auritus*, *Synodontis membranaceus*, *Synodontis schall* and *Malapterurus electricus*), which were likely to be encountered (Sanon, 1995), were not found. This could be because of runoff and migratory movements. During one period of the year, a species may be present and even in abundant quantities, while the species may apparently be absent in another period (Lalèyè *et al.*, 2004).

A size category breakdown showed that most fish were small, possibly owing to the types of equipment used. A study conducted on reservoirs in Burkina Faso showed that large-mesh gill nets produce very low yields, whereas small-mesh nets measuring between 10 and 15 mm were more effective (Baijot *et al.*, 1994).

The growth performance variations observed between cage 1, cage 2 and the fish pond may be attributable to the fish levels effect (Bamba *et al.*, 2008). The average daily growth rates were higher than those obtained in the Ivory Coast (Bamba *et al.*, 2008): 0.88 g/day for cage 1, 0.72 g/day for cage 2 and 0.67 g/day for the fish hole with the feed titrated at 30% of protein. However, depending on the stock used, its feed and breeding conditions, the individual daily growth rate of the tilapia may be 2 to 4 g/day (Lazard, 2009). The survival rates recorded (75.29% for cage 1, 81.18% for cage 2, 97.04% for the fish pond) were considered to be appropriate. These reported findings (growth and survival) confirmed the good quality of the water in which the fish are kept and the nutritional value of the commercial feed used.

The Kou Valley Lake has a species richness equal to a total of 30 species with a diversity index (0.94) close to unity, confirming a great diversity of species for the lake. Distinctive features of the fisheries resources being overexploited are the presence of small fish in most catches, a high number of people fishing on the lake, a lengthy fishing period and the deployment of equipment and nets with small meshes. Subject to the requirement for a subsequent assessment of the yields for each breeding system, cage rearing was apparently the most suitable system for the diversification of aquaculture activities and, by the same token, for boosting the incomes of the lakeside residents.

**COMMUNICATION STRATEGY AND IMPACT**

The direct beneficiaries of the study’s findings are fishermen (72 people), farmers/fish farmers (eight people), female fish wholesalers and fishing supplies traders (53 people) in the Kou Valley. The indirect beneficiaries are the entire working population (men and women) of the Valley (over 500 people). The study findings were presented to fisheries industry stakeholders, whereupon the stakeholders made recommendations for their inclusion in their rules of procedure with a view to safeguarding the future of their activities. The fisheries industry stakeholders were provided with training on the theme of technological breakthroughs. Two scientific reports drawn up when the study was completed were made available to various policymakers (Directorate for Fisheries and the French-speaking University Agency). A poster was produced and presented during a seminar.
ACKNOWLEDGEMENTS

This study was completed under the mobility grant awarded by the French-speaking University Agency (AUF) via the ‘Integration of Young People’ project.

REFERENCES


### ANNEX: TAXONOMIC LIST OF FISH SPECIES IDENTIFIED IN THE LAKE

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Size (cm)</th>
<th>SF</th>
<th>SC</th>
<th>K</th>
<th>b</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protopterida</td>
<td>Protopterus annectens annectens (Owen, 1839)</td>
<td>34.67 ± 0.75</td>
<td>31</td>
<td>9.66</td>
<td>0.57</td>
<td>1.71</td>
<td>0.41</td>
</tr>
<tr>
<td>Polypterida</td>
<td>Polypterus bichir Geoffroy Saint-Hilaire, 1802</td>
<td>34.30 ± 0.83</td>
<td>5</td>
<td>1.56</td>
<td>0.77</td>
<td>2.73</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Polypterus endlicheri endlicheri Heckel, 1849</td>
<td>39.50 ± 0.42</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Polypterus senegalus senegalus Cuvier, 1829</td>
<td>20.39 ± 0.55</td>
<td>16</td>
<td>4.98</td>
<td>0.76</td>
<td>2.01</td>
<td>0.67</td>
</tr>
<tr>
<td>Osteoglossida</td>
<td>Heterotris niloticus Cuvier, 1829</td>
<td>43.27 ± 25.35</td>
<td>22</td>
<td>6.85</td>
<td>0.91</td>
<td>2.72</td>
<td>0.97</td>
</tr>
<tr>
<td>Mormyridae</td>
<td>Brevimyrus niger (Günther, 1866)</td>
<td>13.63 ± 0.95</td>
<td>7</td>
<td>2.18</td>
<td>1.32</td>
<td>2.84</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Marcusenius abadii (Boulenger, 1901)</td>
<td>13.90 ± 0.27</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Petrocephalus bovei Valenciennes, 1846</td>
<td>06.50 ± 0.71</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Pollimyrus isidori Valenciennes, 1846</td>
<td>08.63 ± 0.50</td>
<td>3</td>
<td>0.93</td>
<td>1.57</td>
<td>2.70</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Petrocephalus pellegrini Poll, 1941*</td>
<td>07.60 ± 0.85</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Marcusenius senegalensis Steindachner, 1870*</td>
<td>14.15 ± 0.49</td>
<td>2</td>
<td>0.62</td>
<td>0.47</td>
<td>0.85</td>
<td>1.00</td>
</tr>
<tr>
<td>Gymnarchidae</td>
<td>Gymnarchus niloticus Cuvier, 1829</td>
<td>57.63 ± 29.20</td>
<td>21</td>
<td>6.54</td>
<td>0.30</td>
<td>2.70</td>
<td>0.84</td>
</tr>
<tr>
<td>Alestidae</td>
<td>Alestes baremoze (Joannis, 1835)*</td>
<td>07.95 ± 0.34</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Brycinus nurse (Rüppell, 1832)</td>
<td>14.10 ± 0.80</td>
<td>5</td>
<td>1.56</td>
<td>2.58</td>
<td>1.01</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Micalestes comoroensis Poll and Roman, 1967*</td>
<td>05.82 ± 0.76</td>
<td>6</td>
<td>1.87</td>
<td>1.54</td>
<td>2.14</td>
<td>0.60</td>
</tr>
<tr>
<td>Cyprinidae</td>
<td>Barbus macrops Boulenger, 1911</td>
<td>06.66 ± 0.83</td>
<td>10</td>
<td>3.12</td>
<td>1.7</td>
<td>3.28</td>
<td>0.75</td>
</tr>
<tr>
<td>Claroteidae</td>
<td>Auchenoglanis occidentalis Valenciennes, 1840</td>
<td>11.90 ± 0.56</td>
<td>2</td>
<td>0.62</td>
<td>0.87</td>
<td>1.51</td>
<td>1.00</td>
</tr>
<tr>
<td>Schilbeidae</td>
<td>Schilbe mystus Linnaeus, 1758*</td>
<td>13.20 ± 0.47</td>
<td>7</td>
<td>2.18</td>
<td>1.41</td>
<td>3.60</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Schilbe intermedius Rüppell, 1832</td>
<td>11.41 ± 0.56</td>
<td>9</td>
<td>2.80</td>
<td>1.24</td>
<td>3.09</td>
<td>0.97</td>
</tr>
<tr>
<td>Claridae</td>
<td>Clarias (Clarias) galpinus Burchell, 1822</td>
<td>23.44 ± 10.35</td>
<td>32</td>
<td>9.97</td>
<td>1.03</td>
<td>2.79</td>
<td>0.83</td>
</tr>
<tr>
<td>Mochokidae</td>
<td>Synodontis eupetens Boulenger, 1901*</td>
<td>10.05 ± 0.19</td>
<td>13</td>
<td>4.05</td>
<td>3.24</td>
<td>3.51</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Synodontis schall Bloch et Schneider, 1801</td>
<td>09.10 ± 0.15</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Channidae</td>
<td>Parachanna obscura Günther, 1861</td>
<td>20.14 ± 0.60</td>
<td>14</td>
<td>4.36</td>
<td>1.11</td>
<td>2.67</td>
<td>0.73</td>
</tr>
<tr>
<td>Cichlidae</td>
<td>Chromidotilapia guntheri Sauvage, 1882*</td>
<td>09.40 ± 0.01</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Hemichromis bimaculatus Gill, 1862</td>
<td>06.71 ± 0.01</td>
<td>14</td>
<td>4.36</td>
<td>2.50</td>
<td>1.16</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Hemichromis fasciatus Peters, 1852</td>
<td>10.92 ± 0.36</td>
<td>16</td>
<td>4.98</td>
<td>2.62</td>
<td>2.44</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Oreochromis niloticus Linnaeus, 1758</td>
<td>13.71 ± 0.43</td>
<td>28</td>
<td>8.72</td>
<td>3.85</td>
<td>2.90</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>Sarotherodon galilaeus Linnaeus, 1758</td>
<td>11.11 ± 0.28</td>
<td>14</td>
<td>4.36</td>
<td>3.67</td>
<td>2.51</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Tilapia zillii Gervais, 1848</td>
<td>09.58 ± 0.28</td>
<td>29</td>
<td>9.03</td>
<td>3.07</td>
<td>3.19</td>
<td>0.87</td>
</tr>
<tr>
<td>Anabantidae</td>
<td>Ctenopoma kingsleyae Günther, 1896</td>
<td>11.33 ± 0.25</td>
<td>4</td>
<td>1.25</td>
<td>2.39</td>
<td>1.70</td>
<td>0.49</td>
</tr>
</tbody>
</table>

*Species not previously reported in the Kou Valley’s Lake; –, species not caught more than once.

K, condition factor; b, allometry factor; R², coefficient of determination.
INTEGRATED USE OF LIQUID ORGANIC MANURE AND PHOSPHORUS FERTILISER: EFFECT OF SEQUENCE OF APPLICATION ON MAIZE YIELD AND P UPTAKE IN TROPICAL SOILS

J.O. Azeez, T.O. Ibijola, M.T. Adetunji and A.A. Oyekanmi*
ABSTRACT

Bulkiness associated with the application of solid poultry manure necessitated seeking alternative methods of application. The study evaluated the effect of the integrated use of poultry manure extract (tea) and the sequence of phosphorus (P) application on soil P sorption, P uptake and maize yield, in acid alkaline and neutral tropical soils. Chemical characterisation of the tea, stability and soil P sorption was performed using standard procedures. The treatments were: simultaneous addition of P and tea (PT); P before tea (PBT); tea before P (TBP); and control (no amendments). Their effects were evaluated on P uptake and maize yield using completely randomised and randomised complete block designs in greenhouse and field, respectively. Phosphorus was applied as super phosphate at 0.134 g P pot⁻¹ of 5 kg soil and 4.5 g P plant⁻¹ and tea at 50 ml pot⁻¹ and 3.5 ml plant⁻¹ in greenhouse and field, respectively. Results showed that tea contained 400 mg N, 155.80 mg K, and 10.48 mg P l⁻¹ and the nutrients were at their highest level 2 weeks after preparation. Soil P sorption conformed to the Freundlich model. The lowest P sorption efficiency (37.19%) and the highest phosphate requirement (12.51 mg P kg⁻¹) were recorded in acid soil. Integrated use of the tea and P fertiliser increased maize yield both in the greenhouse and the field. TBP, PT and PBT treatments produced a 14, 12 and 10% increase in maize grain yield, respectively, over the control. Maize P uptake was increased in treatment PBT in the greenhouse and in the field. It was concluded that integrated use of the tea and P fertiliser had a positive and complementary effect on maize yield, irrespective of the sequence of application. The technology has the potential to boost farmers’ agricultural productivity and the prospects for its uptake are promising.

KEY WORDS: EFFICIENCY, GREENHOUSE, FIELD, NUTRIENT MANAGEMENT, POULTRY MANURE TEA, PHOSPHORUS SORPTION

AFFILIATIONS

* Federal University of Agriculture, Abeokuta, Nigeria.
INTRODUCTION

Nigerian and many tropical soils suffer from poor fertility and are susceptible to erosion (Ojeniyi, 1995). One of the most popular ways of solving fertility problems in these soils is by fallowing for 3–5 years to replenish lost nutrients and organic matter. However, anthropogenic and other socio-economic pressures have resulted in reduced fallow periods, leading to continuous cultivation and consequent nutrient depletion (Aduayi et al., 2002). Application of fertilisers to solve soil fertility problems is an age-long practice in sub-Saharan Africa. However, before the advent of inorganic fertilisers, compost and farmyard manure constituted the major external inputs of nutrients to crops. The introduction of intensive production systems and high-yielding crop varieties with high nutrient demands resulted in increased need for organic fertilisers, which could not be supplied in sufficient quantities. In cases where they are available, transportation problems, manure bulkiness and labour cost limit their use (Agyenim et al., 2006).

Most manure sourced from farms in sub-Saharan Africa is nutrient-poor, particularly that sourced from under-fed animals, and this has necessitated the application of large quantities of manure to satisfy the nutrient demands of crops. The problem, however, could be solved by supplementing manure application with inorganic fertilisers. Alternatively, the problem of manure bulkiness could be solved by extracting the nutrient in soluble form before application to soils. Very recently, a new fertiliser technology has been designed to process organic materials into liquid forms such as poultry manure tea (extract from poultry manure) and plant tonic (extract from plant biomass) in order to ease the decomposition process and enhance the release of nutrients for plant use. Some researchers have reported that this technology is a rich source of nutrients, simple to prepare and sustainable (Moyin-Jesu and Akinwale, 2002).

Management practices aimed at increasing phosphorus availability in weathered soils of sub-Saharan Africa are important. This is because of the need to prevent P fixation in soils. The application of combined organic–inorganic inputs has been widely reported in literature as a means of increasing P availability in weathered soils (Mnkeni and Mackenzie, 1985; Mkhabela and Waman, 2005). However, most farmers apply both manure and fertilisers in sequence according to the availability of the materials, applying manure and P fertilisers in the same field either at the same time or one after the other, depending on what is available at the time of land preparation. The effect of this practice (sequence) on P solubility and availability has not been extensively studied, particularly for soils used for maize production. There is also little information on the use of liquid organic fertiliser and its effect on soil P characteristics and uptake by maize.

Hence the objectives of this study were: (1) to characterise poultry manure tea and evaluate its nutrient stability; (2) to determine the effect of poultry manure tea on soil properties and P sorption characteristics; and (3) to quantify the effect of the poultry manure tea and P fertiliser application sequence on P uptake and maize yield. The nutrient uptake must be analysed before determining the yield, and not vice versa.

METHODOLOGY

Materials, soil sampling and analyses

Surface soil samples (0–20 cm depth) were collected to represent acidic, neutral and alkaline soils. The soil samples were air-dried for 48 h and sieved through a 2-mm-diameter sieve in preparation for the laboratory studies and greenhouse experiment. The chemical characteristics of the soils were analysed using standard methods (IITA, 1979; Kalra and Maynard, 1991). A prominent local maize variety (Oori) used by
farmers in the study area was the test crop for the trial. The types of fertiliser used were single superphosphate (18% P₂O₅), urea (46% N) and muriate of potash (60% K₂O).

Preparation of poultry manure and manure tea

Poultry manure free of litter from a battery-caged laying hen was obtained from the university’s poultry farm. The poultry manure tea was prepared as follows: the poultry manure was sun-dried (7% moisture) and 10 kg was weighed into a burlap bag containing a stone weighing about 5 kg to prevent floating. The bag was tied shut and immersed into a 50-litre container, which was stirred every 3 days for 2 weeks. After the extraction process, the extract was diluted with water at a ratio of 1:5. The poultry manure and tea prepared were analysed for total N, P, K, organic matter and pH using standard methods (Page et al., 1982).

Manure stability and sorption studies

The stability of the poultry manure tea was evaluated as a completely randomised design (CRD) trial, by storing 1 l of the tea at room temperature in a container for 2 months with two replications. The tea was analysed for N, P, K, and C using the above-mentioned procedures at weekly intervals. A control was also performed by adding a few drops of formalin in order to suppress microbial activities (Hartono et al., 2005). The effect of the time of application of the manure tea in relation to P fertiliser on P sorption was evaluated using the procedures of Agbenin and Igboke (2006). Treatments were: simultaneous addition of P and tea (PT), P before tea (PBT), and tea before P (TBP).

Greenhouse experiment

For each of the three soil types, soil samples were dispensed into pots at 5 kg soil per pot. The treatments were PT, PBT, TBP and control. All treatments were replicated four times. The experimental design was CRD. Poultry manure tea was applied at the rate of 50 ml per pot (Moyin-Jesu and Akinwale, 2002) and P fertiliser was applied at 60 kg P₂O₅ ha⁻¹; therefore 0.134 g P₂O₅ was added to each pot. In treatments where tea or P fertiliser were applied in sequence, there was a 1-week interval in between applications. Basal urea and muriate of potash were applied to all pots 2 weeks after planting at 120 kg N and 60 kg K₂O ha⁻¹, respectively. Three maize (Zea mays) seeds were planted per pot; seedlings were thinned to one stand per pot 2 weeks after emergence. Data were collected on maize dry matter yield and P uptake after 8 weeks.

Field evaluation

The field experiment was conducted at the University of Agriculture, Abeokuta (latitude 7.13°N, longitude 3.28°E, south-west Nigeria) between September and December 2010. The experimental site was tilled conventionally and the design was a randomised complete block. The treatments were same as for the greenhouse study. Poultry manure tea was applied at 3.4 l plot⁻¹ (size 6 by 3 m) (Moyin-Jesu and Akinwale, 2002), and P fertiliser was applied at the rate of 108 g P₂O₅ plot⁻¹. All agronomic practices were as reported for the greenhouse study. The maize planting distance was 25 by 75 cm (population of 53,333/ha). Data were collected on maize dry matter yield, grain yield and P uptake using standard procedures (Page et al., 1982).

Statistical analyses

Data obtained were subjected to analysis of variance (ANOVA), correlation and regression analyses using the statistical analysis system (SAS Institute, 1990). Significant treatment means were separated using the Duncan multiple range test (DMRT) at 5% probability.
RESULTS

It was observed that the soils had a low to medium nutrient content (organic carbon, nitrogen, phosphorus and potassium), and poultry manure tea was rich in nutrients but very low in phosphorus (Table 1).

It was observed that the N content of the manure tea was statistically similar from week 1 to 6. The highest amount of P and K was observed at the second week of incubation (Table 2).

Soil P sorption revealed that the Freundlich model was best suited to the soil data under investigation using the coefficient of determination $R^2$ as an index of discrimination (Table 3). The dry matter yield of maize (Table 4) for the greenhouse trial showed that the sequential addition of poultry manure tea and P fertiliser did not impact significantly on the dry matter yield (DMY) of the maize; however, the control had the lowest values. In the field, grain yield was highest (2.75 t ha$^{-1}$) in TBP plots, followed by PT and PBT, while the lowest yield was obtained in the control. There was also no significant difference in DMY across treatments. The treatment effect was not significant on P uptake.

Generally, manure tea increased maize dry matter and grain yield. The lowest amount of soil alkalinity was observed across the soil types in PT (51.25 mg kg$^{-1}$). There was also a positive and significant correlation ($r = 0.62; P < 0.01$) between P uptake and dry matter yield. The stepwise regression between P uptake and other soil and

<table>
<thead>
<tr>
<th>TABLE 1: PROPERTIES OF THE SOILS, MANURE AND MANURE TEA USED FOR THE EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil properties</strong></td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>pH</td>
</tr>
<tr>
<td>Organic carbon (g kg$^{-1}$)</td>
</tr>
<tr>
<td>Nitrogen (g kg$^{-1}$)</td>
</tr>
<tr>
<td>Phosphorus (mg kg$^{-1}$)</td>
</tr>
<tr>
<td>K (cmol kg$^{-1}$)</td>
</tr>
</tbody>
</table>

Soil A = neutral soil, Soil B = acid soil, Soil C = alkaline soil; Tea = poultry manure tea.

<table>
<thead>
<tr>
<th>TABLE 2: EFFECT OF INCUBATION PERIOD ON THE NUTRIENT CONTENT OF THE TEA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nutrient</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>N%</td>
</tr>
<tr>
<td>P (mg kg$^{-1}$)</td>
</tr>
<tr>
<td>K (mg kg$^{-1}$)</td>
</tr>
</tbody>
</table>

Mean values with the same letters across the row are not statistically different at $P = 0.05$. 
agronomic parameters indicates that the clay content of the soil and the DMY are the two most important parameters that contributed to maize P uptake (P uptake = 7.83 – 0.26 clay + 0.47 dry matter yield, $R^2 = 0.64; P < 0.01$).

**DISCUSSION AND CONCLUSION**

The soils’ low fertility indicated the need for fertilisation. They were, however, adequate for the study. The need for supplemental P fertiliser to enhance P availability and reduce low P fixation was reflected in the properties of the poultry manure tea. The organic carbon of the manure was relatively higher compared with other nutrient content; this is in line with the observation of Azeez and Van Averbeke (2010). Conformity of soil sorption with the Freundlich model has also been reported by Dubes and Becquer (2001). The sorption data implied that the affinity of the soil for the adsorbate was lower than the aqueous solution concentration of the adsorbate, implying minimal P fixation (Essington, 2004).

**TABLE 3: COEFFICIENT OF DETERMINATION ($R^2$) VALUE OF FREUNDLICH AND LANGMUIR ISOTHERM MODELS**

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Coefficient of determination ($R^2$)</th>
<th>Langmuir model</th>
<th>Acid</th>
<th>Alkaline</th>
<th>Neutral</th>
<th>Freundlich model</th>
<th>Acid</th>
<th>Alkaline</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBT</td>
<td>0.028</td>
<td>0.025</td>
<td>0.003</td>
<td></td>
<td></td>
<td>0.313</td>
<td>0.663</td>
<td>0.752</td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>0.018</td>
<td>0.096</td>
<td>0.000</td>
<td></td>
<td></td>
<td>0.784</td>
<td>0.910</td>
<td>0.875</td>
<td></td>
</tr>
<tr>
<td>TBP</td>
<td>0.049</td>
<td>0.064</td>
<td>0.003</td>
<td></td>
<td></td>
<td>0.858</td>
<td>0.902</td>
<td>0.895</td>
<td></td>
</tr>
</tbody>
</table>

*PBT, application of P fertiliser before poultry manure tea; PT, simultaneous application of poultry manure tea and P fertiliser; TBP, application of poultry manure tea before P fertiliser.

**TABLE 4: EFFECT OF SEQUENTIAL ADDITION OF POULTRY MANURE TEA AND P- FERTILISER ON DRY MATTER YIELD (g pot–1) AND PHOSPHORUS UPTAKE BY MAIZE (mg kg–1) IN THE GREENHOUSE**

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Neutral soil</th>
<th>Alkaline soil</th>
<th>Acid soil</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DMY (g pot–1)</td>
<td>P uptake (mg kg–1)</td>
<td>DMY (g pot–1)</td>
<td>P uptake (mg kg–1)</td>
</tr>
<tr>
<td>TBP</td>
<td>8.17</td>
<td>4.94</td>
<td>7.15</td>
<td>7.41</td>
</tr>
<tr>
<td>PBT</td>
<td>7.05</td>
<td>12.7</td>
<td>5.32</td>
<td>3.05</td>
</tr>
<tr>
<td>PT</td>
<td>8.55</td>
<td>4.63</td>
<td>4.67</td>
<td>2.87</td>
</tr>
<tr>
<td>CNT</td>
<td>6.43</td>
<td>3.15</td>
<td>5.50</td>
<td>2.65</td>
</tr>
</tbody>
</table>

*ns ns ns ns ns ns ns ns

TBP, application of P fertiliser before poultry manure tea; PT, simultaneous application of poultry manure tea and P fertiliser; CNT, control. † GNY, grain yield.
The increase in maize dry matter yield (in the greenhouse) with the application of poultry manure tea and P fertiliser over the control implies that the treatments improved the nutrient content of the soils and its availability to maize. A similar increase in yield and nutrient uptake following application of a humic substance combined with mineral fertiliser had also been previously reported (Pinton et al., 1999). The soil aluminium content also implied that there was a reduction in P fixation when P was applied simultaneously with poultry manure tea. It also suggests that there was a possible complexation of Al with organic acid. The correlation indicated that an increase in dry matter yield led to a proportional increase in P uptake, while soil clay was inversely correlated to P uptake. It is concluded that poultry manure tea could be applied simultaneously with P fertiliser to enhance P availability and reduce phosphorus sorption. The combined application of poultry manure tea and P fertiliser is recommended because of their complementary and synergistic effects in improving dry matter and grain yield.

COMMUNICATION STRATEGY AND IMPACT

The findings have been accepted for publication by two journals: Journal of Plant Nutrition (‘Effect of the sequential application of liquid organic manure and phosphorus on maize agronomic traits and P uptake in some tropical soils’, doi: 10.1080/01904167.2014.881860), and Communications in Soil Science and Plant Analysis.

During the course of the trial, trips were undertaken by farmers and some university researchers. The technology was deemed to have high potential to boost farmers’ agricultural productivity, and the prospects for its uptake are promising.

REFERENCES


HOW IMPROVED ZAÏ TECHNIQUES AFFECT SORGHUM PRODUCTION IN THE SAHELIAN AREA OF BURKINA FASO

P. Bayen and A. Thiombiano*
ABSTRACT

The issue of soil degradation represents a major challenge in Sub-Saharan Africa. The need to remediate degraded soils to a level of functionality is crucial for the local communities in areas affected by desertification, and will help in the fight against famine and poverty. The aim was to demonstrate that a combination of water management with organic materials and the zaï technique can result in better crop yields from degraded soils. To this end, a randomised Fisher block design was used to test the germination capacity and sorghum yields from degraded soils to assess the size of the holes and the quality of the soil organic matter. Based on the various treatments, this design comprises 32 plots accounting for eight factorial treatments (2 × 4) in four replications. The outcomes showed that the hole sizes and type of enrichment material had a significant ($P < 0.001$) impact on sorghum germination and yields. The grain yields varied from 383.10 ± 32.13 kg/ha in the large zaï holes + compost manure, to 5.77 ± 1.90 kg/ha in the small zaï holes without compost manure. The zaï technique with large holes combined with compost manure can therefore allow for crops to be grown sustainably on degraded land in the Sahelian area.

KEY WORDS: CROP YIELDS, DEGRADED SOILS, REMEDIATION, SOIL IMPROVER

AFFILIATIONS

* Laboratory of Plant Biology and Ecology, University of Ouagadougou, Ouagadougou, Burkina Faso.
INTRODUCTION

Drought is one of the key factors hampering agricultural and forestry production in arid and semi-arid areas of West Africa (Van Keulen and Breman, 1990). The growing population has accelerated the pace at which natural resources have been exhausted in these areas over the past few decades, resulting in a gradual loss of vegetation and the physical, biological and chemical degradation of the soils.

In Yatenga province, in the northern region of Burkina Faso, the unstable weather conditions, anthropogenic pressure and the seriously degraded soil condition no longer allow a balance to be maintained between human use of natural resources and their temporal and spatial regeneration. The areas of bare soil that have appeared are continuing to spread. These are called ‘zippélés’ in Mooré (one of the main languages in Burkina Faso).

Against a background of the continuing disappearance of arable land, the remediation of these degraded soils is regarded as a key instrument for reducing poverty, as this would boost the incomes of rural families who are heavily reliant on arable land. A wealth of research on degraded land has been conducted in the Northern region of Burkina Faso (Kaboré, 1995; Zougmoré et al., 1999; Sawadogo et al., 2008) to investigate various soil management factors, such as productivity, organic manure and phosphate fertilisation, including conservation, as remedial measures for these degraded soils.

In order to identify solutions that are accessible for farmers, a study was conducted to determine ways of improving the zaï technique, which involves growing crops in holes thereby concentrating runoff water and organic materials in a micro-basin (Roose et al., 1993). Local technology such as zaï has the advantage of being easy for small producers to adopt, while offering a better agronomic performance.

The general objective of this study was to evaluate how zaï holes and organic manure influence the agricultural productivity of degraded soils. The specific objectives were to determine how the hole sizes affect the water-collection capacity in the zaï technique, and the impact of organic manure on sorghum yields.

MATERIALS AND METHODS

Experimental design

The experiment design comprised four completely randomised Fisher blocks (21 × 47 m) involving eight factorial treatments (2 × 4) and four replications representing a total of 32 elementary plots (8 × 8 m) (Figure 1). The consecutive blocks or plots were separated by a 5-m alley. The treatments in elementary plots of each block were distributed at random by combining the hole sizes and the organic manure. There were two types of zaï hole: large holes 35 cm in diameter and 20 cm deep, and small holes 25 cm in diameter and 12 cm deep (standard holes). Each plot comprised 49 holes spaced at 1-m intervals in relation to their centre, totalling 7,656 holes/hectare.

Four different types of soil organic manures were applied:
- Zc: zaï + 460 g compost
- Zc + g: zaï + 230 g compost + 20 g grass
- Zg: zaï + 40 g grass
- Za: zaï alone without soil organic manure.

Experimental material

The crop used was sorghum (Sorghum bicolor (L.) Moench), the improved variety Sariaso 11 (synonyms: CEF 382/2-1-1). The potential yields were estimated at 3–4 t/ha. The fertilising substrates deployed in zaï holes were compost and straw obtained from Loudetia togoensis, a grass widely distributed throughout the national territory. The characteristics of the organic substrates used are shown in Table 1.
TABLE I: CHARACTERISTICS OF THE ORGANIC SUBSTRATES USED IN THE TREATMENTS

<table>
<thead>
<tr>
<th>Organic substrates</th>
<th>Carbon (%)</th>
<th>Nitrogen (%)</th>
<th>Phosphorous ($P_2O_5$) (%)</th>
<th>Potassium ($K_2O$) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>25.75</td>
<td>1.21</td>
<td>0.29</td>
<td>0.85</td>
</tr>
<tr>
<td>Grass</td>
<td>93.5</td>
<td>0.29</td>
<td>0.65</td>
<td>1.41</td>
</tr>
</tbody>
</table>

FIGURE 1: EXPERIMENTAL DESIGN
Data collection

Three days after sowing, the number of grains that germinated was counted for each hole in order to calculate the germination capacity. At the end of the growing cycle, the aboveground biomass (straw) and the weight of the panicles were measured on site. Samples (leaves, stems, panicles) were collected, then weighed to assess the aboveground biomass (straw) and the weight of the panicles when wet and when dry after oven-drying at 80°C for 96 h.

Data processing and analyses

The germination capacity, aboveground biomass and plot yields were calculated according to the following formulas:

\[
\text{Percentage germination} = \frac{\text{Number of germinated seeds}}{\text{Number of seeds sown}} \times 100
\]

\[
\text{Seed yields (kg/ha)} = \frac{\text{Weight of seeds per plot}}{\text{Area of plot (ha)}}
\]

The variable soil organic manures and hole sizes were processed as fixed categorical factors, while the block factor was processed as a randomised factor. All the statistical analyses were undertaken using the R statistical software (R Development Core Team, 2010).

RESULTS

How the treatments affect sorghum germination

The germination capacity of sorghum seeds varied significantly according to the hole size \(F_{[1;1138]} = 6.12; P = 0.013\) and the soil improver \(F_{[3;1138]} = 41.26; P < 0.001\). Interaction between these two factors also had a significant effect \(F_{[3;1138]} = 3.70; P < 0.011\). The large and small zaï holes alone and zaï + compost had the highest germination capacities, with 53.98 to 62.08% and 51.94 to 58.33%, respectively (Figure 2). The small zaï holes + grass + compost and the small zaï holes + grass yielded the lowest germination capacities (31.11 and 27.97%).

TO THE TREATMENTS

How the treatments affect straw and sorghum grain yields

The productivity of the aboveground biomass of sorghum plants varied considerably according to the soil organic manure \(F_{[3;20]} = 42.82; P < 0.001\). The highest straw production was found in holes treated with compost (947 kg/ha), followed by those treated with compost + grass (509 kg/ha). The amount of aboveground biomass produced in the zaï holes + compost was four to ten times higher than the amount achieved in zaï holes alone (control) and zaï + grass (Figure 3). Sorghum grain yields varied considerably according to the soil organic manure \(F_{[3;20]} = 69.92; P < 0.001\) and hole size \(F_{[1;20]} = 6.23; P = 0.02\). The grain yields varied from 383.10 ± 32.13 kg/ha in large zaï holes + compost to 5.77 ± 1.90 kg/ha in small zaï holes alone (Figure 4). The zaï + grass treatments had slightly lower yields compared with those of zaï treatment alone (24.56 kg/ha vs 29.07 kg/ha).

DISCUSSION

How the treatments affect germination capacity

Bare soils (zippelés) are generally characterized by their impermeability. The surface-sealing film that forms on these soils results in poor water infiltration and ventilation of the horizontal layers. Digging holes eliminates the surface-sealing crust and restores the soil water infiltration and aeration. The water retained in the holes allows for infiltration, thus boosting the soil moisture that is so important for germination. The germination capacity varied according to the sizes of the holes. The capacity was higher in the large holes, apart from the large holes enriched with
FIGURE 2: GERMINATION CAPACITY OF SORGHUM GRAINS ACCORDING TO THE TREATMENTS

FIGURE 3: ABOVEGROUND BIOMASS OF SORGHUM ACCORDING TO THE TREATMENTS
How the treatments affect sorghum yields

The yields represent the material expression of the sorghum’s uptake of water and minerals (Sangaré, 2002). This is the most prominent parameter for expressing the performance of the production techniques (Sangaré, 2002). The production of aboveground biomass (straw) and grains varied considerably according to the soil organic manure applied. To this end, the production of straw and grains was significant in zaï treatments with compost followed by zaï treatments involving half compost and half grass. Low production levels for straw and grains were reported in zaï treatments involving grass and those for zaï alone. Digging holes helped the water to percolate through the soil more easily and produce a better water supply so as to take advantage of the mineral reserves in the zippélé (bare soil) and provide opportunities for harvesting. This outcome showed the relevance of the zaï technique as an effective water and soil conservation structure for runoff management (Kaboré, 1995). Just making more water available by
breaking the soil’s surface crust does not appear to lead to increased sorghum production. This means the degradation of the test site is not just physical, and that water scarcity is not the only factor to blame for the low level of productivity. The elimination of the physical constraint may improve the water conditions, but it exposes other key constraints related to the soil’s chemical and biological deficiency. Maximising the use of rainwater is not much of an advantage unless the soil’s nutrient deficiency is corrected (Roose, 1994).

The study found that straw and grain yields significantly increased with the addition of compost. Incorporating grass only in the holes produces yields similar to those achieved with zaï without soil organic manure. Straw buried in holes did not decompose to make the minerals available to the plants. Research by Zougmoré et al. (1999) showed that by helping the straw to decompose, the microorganisms use minerals such as nitrogen, possibly leading to a temporary immobilisation or a nitrogen deficiency in the soil, thus restricting crop development and production. When the same soil organic manure was used, the straw and grain yields varied according to the sizes of the holes, being higher in the large holes than in the small ones. This outcome is due to the large holes collecting more runoff water than the small ones owing to their width, and retaining soil moisture for a longer period of time owing to their depth.

CONCLUSION

Growing sorghum with the zaï technique has shown the extent to which the system can restore the production of a degraded soil. The remediation process first of all necessitates helping the water to percolate more effectively through the soil, and then having more organic (compost) and/or mineral nutrients available. This study also showed that zaï technique-based sorghum production yields depended primarily on the size of the holes and the quality and quantity of soil organic manure. In order to get the most from the zaï technique, wider and deeper holes need to be dug and a large quantity of good quality compost has to be provided. The zaï system can effectively restore the productivity of barren land when combined with the addition of the organic and/or mineral fertilisers required for crop development.

COMMUNICATION STRATEGIES AND IMPACT

A thesis for the Diploma of Advanced Studies, ‘How soil remediation affects plant productivity: the case of improved zaï techniques in Yatenga’, has been deposited with the library of the University of Ouagadougou Life and Earth Sciences Training and Research Unit. Presentations have been made at the final workshop of BIOTA (Biodiversity Monitoring Transect Analysis), Ouagadougou, 25–27 January 2010; the celebrations for the Burkina Faso National Independent Holiday, 11 December 2009, Yatenga; Open Houses on activities involved in doctoral research projects at the University of Ouagadougou, 7–12 February 2011, Ouagadougou. One online publication has been produced (Bayen et al., 2011).

ACKNOWLEDGEMENTS

We wish to thank the BIOTA West (Biodiversity Monitoring Transect Analysis) project, which provided all the funding for this study.

REFERENCES


USE OF A SOLAR WATER HEATER IN TRADITIONAL BEER PROCESSING TO REDUCE ENVIRONMENTAL DEGRADATION IN RURAL BURKINA FASO

W.F. Compaore¹,², K. Koudougou¹, A.H Yonli² and T. Daho²
ABSTRACT

The traditional beer-processing sector is experiencing rapid growth in rural areas. Traditional beer processing involves a series of steps: acquiring raw materials, malting, brewing, packing and sales. An environmental impact study carried out via a life-cycle analysis (LCA) produced a global warming potential (GWP) of 21.56 g CO₂ eq per functional unit (FU), which is equal to 1 l traditional beer, 3.33 l water/FU, 0.15 kg of solid waste/FU versus 1.84 l liquid waste/FU. The brewing subsystem accounted for 99.44% of the GWP, 59.70 of water consumption, 64.52 of solid waste, and 40% of liquid waste. The deployment of a solar water heater (SWH) would provide savings equal to 11% of the wood requirements and 18% of the water requirements, plus a 10% reduction in the workload. Based on the firewood savings, the payment of CFA F200 into a local fund run by a producers’ association will provide for the replacement of defective equipment. The cost of the SWH is a drawback, involving CFA F25.85/kg wood compared with CFA F5.00/kg previously. Cheaper SWHs have been suggested for a positive return on investment during the lifetime of the equipment.

KEY WORDS: HEATER, IMPACT, LIFE CYCLE ANALYSIS, SAVINGS

AFFILIATIONS

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2 Institute of the Environment and Sustainable Development (IGEDD), Laboratoire de physique chimie de l’environnement (LPCE)/Université de Ouagadougou, 03 BP 7021 Ouagadougou 03, Burkina Faso.
INTRODUCTION

Developing countries are experiencing unprecedented population growth coupled with sluggish economic growth focused almost entirely in the urban environment. The rural areas are not standing still. In order to improve their quality of life, rural communities have boosted their income-generating activities. Most of these activities involve processing farm and fishery products. In Burkina Faso, the processing of traditional beer is an income-generating activity carried out entirely by women in rural areas. The processing activity lasts several days, alternating with firewood-based heating and concentration (Belliard, 2001; Palé et al., 2010). The processing makes use of environmental resources and generates waste, residues and/or by-products.

Renewable energy equipment is apparently one solution to lessen the environmental impact (EI) (Koroneos et al., 2005). The theory is that the use of water pre-heated in solar water heaters in traditional beer processing will require less firewood and reduce the filtering stages, thereby boosting the benefits and incomes for women in rural areas.

The objectives of this study were to determine the EI of beer processing in rural areas, to deploy solar water heaters in traditional beer processing in order to curb the environmental damage, and to make an economic assessment of the viability. Thought has been given to the question of improving the traditional beer production process and boosting its profitability in order to strengthen the capacity of women in rural areas.

The goal is to ensure sustainable development in rural areas of Burkina Faso while guaranteeing the compatibility of development, the environmental factor and social welfare.

METHODOLOGY

The approach adopted was based on an EI study of traditional beer processing followed by the deployment of a solar water heater (SWH), and an economic study in production environments in rural areas in Burkina Faso.

Field of study

The study was conducted in the central plateau region from August 2011 to January 2012, when the data were collected.

Assessment of the environmental impact of beer

The EI assessment was made in the light of a life-cycle analysis (LCA) according to ISO 14040/14044 (2006; see Remy and Siemers, 2011) and the calculations undertaken using the software CMLCA 5.1.

The aims of the LCA were to gain a preliminary understanding of the resources used, the energy consumed and the environmental footprint of traditional beer processing in rural areas; to identify the stages where the relevant emissions and resources can be curbed; to guide the process for operating the SWH; and to help to develop strategic planning and act as a decision-making tool in future policies.

The item under consideration was traditional beer and the study system was the processing activity (Figure 1). The functional unit (FU) under consideration was 1 l of traditional beer. Against the background of the consumption of resources and emissions, five relevant impact categories were singled out (Table 1). Data gathering on the life-cycle inventory led to the creation of a flowchart for traditional beer processing (Figure 2). The processing unit is a three-stone stove enclosed by a wall (Figure 3).
Operation of the solar water heater

Burkina Faso enjoys sunlight equal to over 5 kWh/m² a day (Royer et al., 1998).

The SWH referred to in this study was a tank sensor solar water heater (Schneider and Guissou, 1999). The absorber is made from black sheet metal. Black matt paint is used for the absorbing coating. The absorber has a surface area measuring 1.80 m². The storage system is a sheet metal tank painted black. The water is poured directly into the tank. The back of the absorber is insulated with glass wool and the tank has a layer of insulation. The SWH holds 140 l water (Figure 4).

The SWH was manufactured on the basis of the EI findings and in accordance with the hot water requirements. It was placed in a traditional beer processing unit. The savings in terms of firewood, water, time and profit were calculated. The amount of wood saved relative to the cost of the SWH was also estimated and compared with the price of the wood prior to deployment of the SWH. The return on investment was also estimated. Several scenarios were scrutinised for a positive return on investment.
FIGURE 2: QUANTIFICATION OF INPUTS AND OUTPUTS FOR A SINGLE PREPARATION

- Grains 42 kg
- Mucilage 3 kg
- Wood 400 kg
- Water 500 L
- Super Petrol 1 L
- Oil Lamp 0.2 L
- Diesel Oil 0.1 L
- Straw 3 kg
- Yeast 1 kg

Processing/manufacture of beer: Dolo

- Gas emission from burning wood:
  - CO₂ = 600 000 g
  - CH₄ = 1500 g
  - N₂O = 64 g

- Solid waste can be used for animals: 70 kg
- Solid waste 23 kg
- Gas emission from fuel: CO₂ = 3234 g
- Wastewater: 205 L

Traditional beer: 150 L

FIGURE 3: BEER PROCESSING UNIT

FIGURE 4: SOLAR WATER HEATER UNDER CONSIDERATION
RESULTS

Environmental impact of traditional beer

The traditional beer processing contribution to GWP is 21.56 g CO₂ eq/FU; 3.33 l water/FU; 0.15 kg of solid waste/FU; 1.84 l liquid waste/FU. The LCA shows that the brewing subsystem accounts for 99.44% of the GWP, 59.70% of water consumption, 64.52% of solid waste and 99.51% of the wood requirement (Figure 5).

The solar water heater

Reduction of environmental impact

Using hot water for brewing during the soaking process reduces the cooking time, thus cutting wood consumption by up to 8%. Using hot water during filtering reduces the filtering time, concentrates the juices and reduces wood consumption by 3%, or a total of 11%. Using hot water for filtering and cleaning reduces water consumption by 18%. The carbon intensity falls from 102.4 to 80.38 g CO₂/MJ.

Cost-effective solar water heater

With a purchase price of CFA F400,000 (€610) and three production cycles a month, the SWH can save 1,584 kg of wood a year, or 15.9 t, over its 10-year lifespan. Moreover, the equipment purchase cost relative to the amount of wood saved over its lifespan is CFA F25.25/kg of wood compared with CFA F5.00/kg (400 kg of wood at CFA F2,000).

Sustainability

The project’s sustainability needs to be ensured by replacing the defective SWH, extending the project to other women producers, and ensuring a positive return on investment during its lifetime. In order to avoid reducing the net profit, CFA F200, calculated on the basis of the amount of wood saved with the market price of wood being CFA F5.0/kg, had to be paid after each production cycle into a local fund representing the collective producers’ organisation (Figure 6). The price of the solar water heater used, equal to CFA F400,000, will under no circumstances generate a positive return on investment, so the SWH has to cost between CFA F72,000 and 192,000 depending on whether what is involved is single use, dual use, triple use, or if the number of production cycles is increased (Table 2).
FIGURE 6: INTEGRATED SUSTAINABILITY DIAGRAM

1. Raising awareness about the equipment, specific training on the income-generating activity EI

2. Local team for follow-up management, first level maintenance, replacement

3. Manufacturing and distribution of equipment, financial support of investors, government, NGO

4. 200 Francs deposit per production cycle for payback, replacement and maintenance

5. Fund managed by producers’ association with the support of the local authority

6. Replacement and maintenance, possibility of initiating other project (solar panels)

TABLE 2: SAVINGS FOR SUSTAINABLE DEPLOYMENT OF SOLAR WATER HEATERS

<table>
<thead>
<tr>
<th>Number of production cycles per month</th>
<th>Wood savings/lifetime (kg)</th>
<th>Sum to be paid/production</th>
<th>Return on investment/lifetime</th>
<th>Investment return rate/CFA F400,000</th>
<th>Suggested price</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>15,840</td>
<td>200</td>
<td>72,000</td>
<td>72,000</td>
<td>72,000</td>
</tr>
<tr>
<td>4</td>
<td>21,120</td>
<td>200</td>
<td>96,000</td>
<td>96,000</td>
<td>96,000</td>
</tr>
<tr>
<td>6</td>
<td>31,680</td>
<td>200</td>
<td>144,000</td>
<td>144,000</td>
<td>144,000</td>
</tr>
<tr>
<td>8</td>
<td>42,240</td>
<td>200</td>
<td>192,000 (−12%)</td>
<td>192,000</td>
<td>192,000</td>
</tr>
</tbody>
</table>
DISCUSSION AND CONCLUSION

In the light of the LCA, traditional beer processing is acknowledged to contribute to global warming, deplete the available biomass, consume water and create waste. The brewing subsystem is the main contributor to the types of impact selected (Figure 5).

The study made it possible to parameterise criteria for the deployment of SWH in the main income-generating activities in rural areas and the Sahelian area in Burkina Faso, to propose an approach to sustainability in the case of its use (negative return on investment period) with the SWH being operated. The study provided a method of identifying and reducing the EI of traditional beer processing in rural areas and estimating its contribution to deforestation and greenhouse gas emissions (197,483.16 t C eq).

The research was used to revise traditional beer processing activity by easing the workload (10% reduction in workload), boosting its profitability by using less firewood (11%) and water (18%), educating the locals on the issues involved, and creating an action plan to cover the whole of the territory.

The study has produced a number of potential benefits, including a reduction in the EI of traditional beer processing by using less firewood (up to 15.9 t per SWH/per producer over a 10-year period. 18% or 75 l less water will be needed per process, which works out at 11,700 l a year/producer, in a time of water shortages caused by climate change. This will ease the pressure on the reservoirs and water pumps in the villages. A higher income for women equal to CFA F1,200 per production cycle, or CFA F187,200 annually, was realised. Other advantages include the cost-efficient use of farm and fisheries products as a result of encouraging local processing and their enhancement (higher value-adding opportunities), and a better ability to contend with the bad weather conditions related to climate change in Africa.

The outcomes could include a reduction in greenhouse gas emissions due to the deployment of SWH, protecting forests and CO₂ fixation, as a result of which the project could be funded by carbon credits. Solutions to the fairly high cost of the equipment could include an adjustment of the SWH and the collective organisation of the women producers. A suitable policy has to be adopted in order to reduce and plan for an increase in the environmental impact of income-generating activities in rural areas.

COMMUNICATION STRATEGY AND IMPACT

Strategies for reporting the findings involved sharing information with the rural communities and decision-makers. Awareness-raising was achieved through focus group discussions, cinema evenings and door-to-door surveys. The study will be presented at the university, distributed to students during the graduating class, and deposited in the institute’s library. Findings will be posted on the World Water Forum website (solutionsforwater.org).

ACKNOWLEDGEMENTS

We wish to thank the traditional beer producers, the research team from the Department of Food Quality Control and Applied Nutrition, and Christian Remy from the Berlin Centre of Competence for Water. We would also like to thank the Islamic Development Bank and the African Wildlife Foundation for their financial support.

REFERENCES


EFFECT OF FREEZING ON NUTRITIONAL VALUES OF SIX ORPHAN CROPS IN GHANA

K.J. Taah¹, G.C. van der Puije¹ and E.A. Gyamera²
ABSTRACT

Food insecurity and malnutrition continue to affect many Ghanaians. The government supports research in crop improvement through the Savannah Agriculture Research Institute, Tamale and Crop Research Institute, Kumasi, in Ghana. The ease with which most orphan crops grow in the wild and their highly developed local adaptability make them ideal crops for attention under changing climate conditions of rising temperatures and erratic rainfall. The objectives of the study were to determine the nutritional values of six orphan crops: *Amaranthus cruentus* (aleefu), *Vernonia amygdalina* (bitter leaf), *Corchorus olitorius* (bush okra), *Solanum macrocarpon* (ntropo), *Tetrapleura tetraptera* (prekese) and *Hibiscus cannabinus* (kenaf) by assessing the nutrient content [crude protein (% CP), % ash and moisture content (% MC)] on sun-dried frozen and non-frozen samples. For the non-frozen samples, bitter leaf recorded the highest % CP while prekese recorded the least % CP. Bush okra recorded the highest % ash, with kenaf recording the least % ash. Percentage moisture content was highest in prekese and lowest in ntropo. Freezing had no significant effect on the % CP values of the crops analysed; however, freezing resulted in significant losses in the % ash values of aleefu, kenaf and ntropo. The promotion and consumption of orphan crops could contribute to the mitigation of food insecurity and malnutrition and increase access to locally available nutrient-rich diversified food sources.

KEY WORDS: FOOD INSECURITY, MALNUTRITION, ORPHAN CROPS, PROXIMATE ANALYSIS

AFFILIATIONS

1 University of Cape Coast, Ghana.
2 c/o Mr Michael Kofi Andoh, National Insurance Commission, Accra, Ghana.
INTRODUCTION

Unstable domestic production, high food prices and levels of unemployment continue to threaten food security in Ghana. Almost three in 10 Ghanaians are chronically malnourished (FAO, 2009). Many farming households in Ghana do not have adequate food throughout the year. Each year, in the Kassena-Nankana district of Northern Ghana, from January to June, many households barely have adequate food to feed their families (Niagia, 2002). As part of measures to mitigate food insecurity and malnutrition, the government supports research in crop improvement and also receives donated food aid. Maize, cassava and cocoa receive much scientific attention in Ghana’s crop research programmes.

Crops such as bitter leaf (Vernonia amygdalina), velvet tamarind (Dialium spp.), waterleaf (Talinum triangulare) and earth nut (Voandzeia subterranea) scarcely receive any scientific or policy attention despite their resilience in adverse weather conditions and increased tolerance to pests and diseases. These crops have become orphaned due to neglect by the scientific community and policymakers, though they are better able to mitigate food insecurity and malnutrition in many low-income Ghanaian households. In many rural communities in Ghana, orphan crops play an essential role in the livelihood of the inhabitants. The Food and Agriculture Sector Development Policy (FASDEP) and the Growth and Poverty Reduction Strategy Phase II (GPRS II) seem to promote research in exotic vegetables and soybean over most orphan crops.

The objective of the research was to determine the nutritional significance and the effects of freezing on the nutritional composition of six orphan crops in Ghana. The results were used to raise awareness of the nutritional value and the need to promote research on orphan crops in Ghana to enhance their wider use in mitigating food insecurity and malnutrition in Ghana.

METHODOLOGY

Sources, types of plant samples and preparation for laboratory analysis

Fresh leaves of ntropo (Solanum macrocarpon), aleefu (Amaranthus cruentus), bitter leaf (Vernonia amygdalina), bush okra (Corchorus olitorius), kenaf (Hibiscus cannabinus) and dried prekese (Tetrapleura tetraptera) were collected, cleaned, washed and chopped into pieces (Figure 1). Each plant sample was divided into two portions, bagged and labelled as frozen or non-frozen. Samples labeled frozen were frozen in a freezer compartment of a regular household refrigerator for over a 24-h period before being solar-dried. Samples that were labelled non-frozen were solar-dried without freezing. All samples were reduced to a powder and kept in a sealed container for proximate composition analysis.

Determination of dry matter and moisture by cold weight method

The percentage of laboratory dry matter and moisture were determined after samples were oven-dried at 105°C overnight. The following equations were used in the determination of laboratory dry matter (LDM) and moisture:

\[
\% \text{ LDM} = \left( \frac{\text{weight of fresh solar dried sample} - \text{weight of oven-dried sample}}{\text{weight of fresh sample}} \right) \times 100
\]

\[
\% \text{ laboratory moisture} = 100 - \% \text{ LDM}
\]

Total ash determination

Total ash was determined after samples were ashed in a muffle furnace set at a temperature of 550°C overnight. The formula for determining % ash is:

\[
\% \text{ ash} = \left( \frac{\text{weight of ash/weight of fresh solar dried sample}}{\text{LDM}} \right) \times 100
\]
Crude protein determination

The samples were digested, distilled and titrated against M/140 HCl solution. Boric acid was used as an indicator. A sample blank was analysed following a similar protocol. The formula used to calculate % crude protein (% CP) is:

\[
% \text{ CP} = \frac{[\text{sample titre (cm}^3) - \text{blank titre (cm}^3) \times \text{solution volume} \times 6.25]}{[10^2 \text{ aliquot} \times \text{sample weight (g)}]}
\]

(Source: Allen et al., 1974.)

Percentage ash content

All the samples had high levels of ash, which indicates the dietary mineral value of the orphan crops. Figure 3 shows the percentage ash values of aleefu, kenaf, bitter leaf, bush okra and ntropo. Though bush okra recorded the highest % ash content, it was not significantly higher than that of ntropo. Kenaf recorded the lowest % ash content, but this was not significantly different from those of aleefu and bitter leaf.

Percentage moisture content of solar-dried orphan crops

Ntropo recorded the lowest moisture content; however, it was not significantly different from that recorded by aleefu and bush okra. Prekese recorded the highest moisture. The moisture content of prekese was significantly higher than that of ntropo but not significantly different from that of bitter leaf and kenaf (Figure 4).

Comparisons of nutritional values of selected orphan and major vegetables

Aleefu, bush okra, kenaf and bitter leaf were richer in protein than cabbage and carrot (Figure 5).

FIGURE 1: (A) CORCHORUS OLITORIUS (BUSH OKRA); (B) AMARANTHUS CRUENTUS (ALEEFU); (C) TETRAPLEURA TETRAPTERA (PREKESE); (D) SOLANUM MACROCARPON (NTROPO); (E) VERNONIA AMYGDALINA (BITTER LEAF); (F) HIBISCUS CANNABINUS (KENAF)
FIGURE 2: PERCENTAGE PROTEIN LEVELS IN FIVE NON-FROZEN SOLAR-DRIED ORPHAN CROPS

![Bar chart showing percentage protein levels in five non-frozen solar-dried orphan crops.]

FIGURE 3: PERCENTAGE ASH CONTENT OF FIVE NON-FROZEN SOLAR-DRIED ORPHAN CROPS

![Bar chart showing percentage ash content in five non-frozen solar-dried orphan crops.]

**EFFECT OF FREEZING ON NUTRITIONAL VALUES OF SIX ORPHAN CROPS IN GHANA**

[Further content or data can be added as necessary.]
EFFECT OF FREEZING ON NUTRITIONAL VALUES OF SIX ORPHAN CROPS IN GHANA

FIGURE 4: PERCENTAGE DRY MATTER AND MOISTURE CONTENT OF SIX NON-FROZEN SOLAR-DRIED ORPHAN CROPS

FIGURE 5: COMPARISONS OF % CP OF REGULARLY USED VEGETABLES AND ORPHAN CROPS
Effect of freezing on nutritional composition of selected orphan crops

Freezing and mineral content of samples
Freezing resulted in significant losses in the ash values of some of the orphan crops analysed. Figure 6 shows the results of the effect of freezing on the % ash content of the analysed samples. All five frozen samples analysed for ash recorded lower ash values than their non-frozen counterparts; the reduction in ash values was significantly different only in aleefu, kenaf and ntropo, while that in bitter leaf and bush okra was not significantly different.

Effect of freezing on crude protein
Freezing did not result in any significant increase or reduction in the % CP content of any of the samples analysed.

Freezing and moisture content
Although freezing resulted in a significant increase in the moisture content of ntropo and aleefu, it did not have any significant impact on the moisture content of bush okra, kenaf, bitter leaf or prekese (Figure 7).

DISCUSSION AND CONCLUSION
All six orphan crops analysed could be of great value in improving nutrition and mitigating food insecurity in Ghana. Bitter leaf is almost twice as rich in crude protein as cabbage (Brassica oleracea var. capitata) (Mosha and Gaga, 1999), an exotic leafy vegetable which is more common as food in Ghana. Bitter leaves could provide an affordable means of combating widespread protein deficiency, especially in poorer communities of Ghana. Promoting this leafy orphan crop could help diversify Ghana’s food base while supplying the much needed protein which is essential in the alleviation of malnutrition. Bush okra, a mucilaginous orphan leafy vegetable, is also highly rich in minerals and could effectively be used in the eradication of hidden hunger in Ghana.

Bitter leaf, though highly rich in protein, has a bitter taste, which may prevent people from appreciating this nutritious orphan leafy vegetable. The bitter taste, which may be due to the expression of certain genes, could be improved through methods such as mutation breeding. Reducing the bitterness of bitter leaf, without compromising its nutritional value, would be an ideal approach to encourage its use as a vegetable. Alternatively, improving the processing of bitter leaf could also reduce the bitterness associated with this orphan crop.

Except for bitter leaf and bush okra, which did not record major reductions in mineral content, aleefu, ntropo and kenaf showed high losses in mineral content after freezing. Freezing, though an easy and ideal method for preserving fresh foods, could compromise the nutritional value of certain foods. Dietary minerals of some orphan crops could be reduced after freezing; this could be due to the effect of freezing and thawing of the frozen food item. As water freezes, its volume increases, which tends to shatter plant cells. For as long as the plant material remains frozen, the nutrients remain intact. However, when the plant materials thaw, nutrients in the plant materials are leached and lost from ruptured cells. It has been reported that freezing reduces calcium content by 5%, potassium by 10% and copper by 10% in frozen food (Anon., 2012). The insignificant reduction in ash values of bitter leaf and bush okra may suggest that these orphan crops are more resistant to freezing injury. Freezing, however, did not result in any significant reduction in crude protein; this may be due to the chemical properties of proteins.

Selected orphan crops available in Ghana offer great potential because of the high levels of crude protein and minerals (ash content), and could be used to mitigate malnutrition and food insecurity, especially in poorer communities. Policymakers should encourage further research on these crops.
**FIGURE 6: EFFECT OF FREEZING ON % ASH CONTENT OF FIVE SOLAR-DRIED ORPHAN CROPS**

- **'Aleefu' Kenaf**
- **Bush okra**
- **Kenaf**
- **'Ntropo' Bitter leaf**

<table>
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<tr>
<th>Orphan leafy vegetables</th>
<th>Non-frozen</th>
<th>Frozen</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Aleefu' Kenaf</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Bush okra</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>Kenaf</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>'Ntropo' Bitter leaf</td>
<td>20</td>
<td>23</td>
</tr>
</tbody>
</table>

**FIGURE 7: EFFECT OF FREEZING ON MOISTURE CONTENT OF SIX SOLAR-DRIED ORPHAN CROPS**

- **'Aleefu'**
- **Bush okra**
- **Kenaf**
- **'Ntropo'**
- **Bitter leaf**
- **'Prekese'**

<table>
<thead>
<tr>
<th>Orphan crops</th>
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<tbody>
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<td>'Aleefu'</td>
<td>5</td>
<td>8</td>
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<tr>
<td>Bush okra</td>
<td>10</td>
<td>12</td>
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<td>Kenaf</td>
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<td>18</td>
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<td>'Ntropo'</td>
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<tr>
<td>Bitter leaf</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>'Prekese'</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>
COMMUNICATION STRATEGY AND IMPACT

This research has created awareness of the nutritional significance of Ghana’s orphan crops among a section of students and lecturers at the University of Cape Coast and the Graduate School of Nuclear and Allied Sciences, University of Ghana. This will help widen the patronage of these orphan crops by the public, hence creating higher demand, and may encourage the government and policymakers to support research on orphan crop improvement in Ghana. The research was presented to a selection of lecturers and students in the School of Agriculture, University of Cape Coast, for a BSc award in 2010. An abstract was accepted by the organisers of ‘Crops For The Future: Beyond Food Security’– 2nd International Symposium on Underutilized Crop Species, although I was unable to attend in person.

ACKNOWLEDGEMENTS

I greatly appreciate the supervision of Dr Kingsley Taah and Mr Osei.

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EFFECT OF PALM FRONDS AND COW DUNG BIOCHAR AND ITS BLENDS ON SOIL PROPERTIES

M.O. Ekebafe, P.O. Oviasogie and N.O. Asueni*
ABSTRACT

Biochar is a carbon-rich product obtained when biomass such as wood, manure or leaves is heated in a closed vessel with little or no air. It is an appropriate tool for sequestering carbon dioxide in soils for a lengthy period in order to mitigate global warming. The study objective was to determine the effects of biochar and its blends on soil properties. The palm fronds and cow dung biochar produced at 300°C for 3 h were characterised in terms of pH, attrition, porosity, bulk density, ash content, conductivity, surface charge, nutrient value, percentage yield and surface area. Soil samples were prepared and analysed for physico-chemical properties. The growth, soil physico-chemical properties and water-retaining capacity of the biochar–soil mixture samples in which sprouted oil palm seedlets had been planted were measured as a function of biochar type and loading (0, 10.0, 20.0, 30.0 and 40.0 t ha⁻¹). There was good improvement in the soil water-retaining capacity, at 20–35% more with 40 t ha⁻¹ dry biochar application than the control. The results of the soil-biochar analysis on the growth of the oil palm measured at a biweekly interval for 2 months showed that there was a significant ($P < 0.05$) increase in the biometrics data compared with the control. The physico-chemical properties of the biochar–soil mixture samples showed significant ($P < 0.05$) improvement.

**KEY WORDS:** AMENDMENT, BIOMASS, CARBON DIOXIDE, PRODUCTIVITY, WATER-RETAINING CAPACITY

AFFILIATIONS

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INTRODUCTION

Food insecurity encompasses food scarcity as well as the inability to purchase food, a poverty-related issue. Although food insecurity occurs throughout the developing world, it is most acute in sub-Saharan Africa, where the attainment of food security is intrinsically linked with reversing agricultural stagnation, safeguarding the natural resource base, and reducing population growth rates (FAO, 1996). For some time, the research community has recognised low soil fertility, particularly nitrogen and phosphorus deficiencies, as one of the major biophysical constraints affecting oil palm plantations due to continuous soil-fertility depletion. The urgent need to address these threats creates a growing demand for solutions that can be implemented now or in the near future. These solutions should be implemented both locally by individuals and by the government in order to have an impact nationally. One such approach is the use of biochar (Lehmann et al., 2003). Biochar has unique properties that make it a valuable soil amendment to sustainably increase health and productivity. Even though biochar has been the subject of scientific investigation for 10 years, efforts have been isolated or regionally focused (Glaser et al., 2001).

The objective of the research was to evaluate the effect of palm frond and cow dung biochars and blends on soil water-retaining capacity, soil physico-chemical properties and the growth performance of the oil palm seedlets, under varying loading concentrations.

METHODOLOGY

Materials

Fronds of the African oil palm tree (*Elaeis guineensis*) and the dung of domesticated cow (*Bos taurus*) were obtained from the premises of the Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Nigeria. The sprouted oil palm seedlets and the soil were also from NIFOR.

Preparation of biochar

The palm fronds were separated from the palm stalk and cut down for ease of handling and processing, while the cow dung was dried at 75°C for 3 h before use for further analysis. Two samples of 4.0 kg from each organic source were pyrolysed at 300°C for 3 h. The biochar obtained was then milled to fine powder using a mechanical grinder, and sieved through a mesh size of 150 µm. The biochar particles that passed through the screen were collected, characterised and used for further analysis.

Characterisation of biochars and soil samples

The biochars were characterised as follows: percentage yield (dry weight basis) on pyrolysis was obtained from the weight difference pre- and post-pyrolysis; ash content was determined using the method described in ASTM D1762-84 (1983; see www.astm.org); the bulk density was determined using the method described by Ahmedna et al. (2000); the pH was determined using the ASTM D1512 (1983) method; the method used to measure the surface area was iodine adsorption (Ishak and Baker, 1995); and the conductivity of the biochar was determined using a conductivity meter. Attrition was determined using the method described by Marshal et al. (1996); and porosity was determined using the method described in ASTM D1584 (1983). Calcium and magnesium concentrations were determined by EDTA titration, while the sodium and potassium concentrations were determined by flame photometry (Model 410, Sherwood, UK) and the nutrient values were determined using AOAC standard methods (www.aoac.org).

Soil samples from surface to a depth of 30 cm were collected using an auger and prepared for further analysis. All the reagents used for analysis were of analytical grade and were used without further purification.
The soil samples were analysed as follows: bulk density was measured by the core method, (Grossman and Ranches, 2002) and soil pH was measured using a 1:1 soil–water ratio (Hendershot et al., 1993). Soil organic carbon was estimated by combustion at 840°C (Wang and Anderson, 1998) while total nitrogen was obtained using the micro-Kjeldahl method. Cation exchange capacity (CEC) was measured using ammonium acetate leaching at pH 7.0 (Rhoades, 1982). Available phosphorus was determined using the Olsen method (Emteryd, 1989).

### Experimental design and method

Measured quantities of each of the biochar samples (palm frond and cow dung: 0, 10.0, 20.0, 30.0 and 40.0 t ha⁻¹, dry biochar), were designated as W₀–W₄. Blends of both biochars in ratio 1:1 were thoroughly mixed with uniform quantities of soil, placed in polythene containers. Sprouted seedlets of the oil palm were planted in the centre of each pot. The soil was irrigated to field capacity and the volume of water required to saturate the soil was recorded. The experiment was conducted in a greenhouse which consisted in total of 13 treatments [4 palm frond biochar (PFB) and 4 cow dung biochar (CDB) concentrations; 1 control, 4 biochar blends (BB)] laid out in a complete randomised design in three replications. Measurements of plant height, leaf area, pigment values, relative water content (RWC) and root-to-shoot ratio were taken at 2-week intervals after planting for 8 weeks. The water-retaining capacity was evaluated as weight of water retained by treatment = weight of water treatment minus weight of water in control.

### Statistical analysis

The results presented are the mean values ± standard errors obtained from at least three replicates. Significant differences between the treated and control plants were determined using the ANOVA F-test ($P < 0.05$). Statistical analyses were conducted using the statistical software package Genstat 12.

### RESULTS

#### Growth performance of oil palm seedlets

The results of the physico-chemical properties of the biochar and experimental soil have been presented previously (Ekebafe, 2011).

### DISCUSSION AND CONCLUSION

The greater the surface area, the more effective the biochar in affecting soil properties (although the nature of the surfaces plays an equally important role). Biochar macropores are also relevant to the movement of roots through soil; they store water and provide habitats for a vast array of soil microbes (Brady and Weil, 2002).

Two factors, feedstock and pyrolysis conditions, control the amount and distribution of mineral matter in biochar (Glaser et al., 2001). Results given in Table 1 show that the amount of water used increases significantly ($P < 0.05$) with the amount of amendments. This is to be expected, since the more biochar is added, the more water the soil uses because of the ability of the biochar to absorb water (Glaser et al., 2001). However, these results (Table 1) show that subsequent addition of water in later weeks significantly decreases ($P < 0.05$) from the initial amount of water absorbed due to the ability of the biochar to store water for plant use. This translates to more water for the plant, particularly considering the arid condition of the soil in sub-Saharan Africa. The initial water demand of the soil–BB was higher by 19.1% when compared with the soil PFB and CDB treatments.

Results given in Table 2 summarise the effect of the biochars on the growth performance of the oil palm sprouted seedlets. These show a significant growth performance expressed in terms of the height, root/shoot ratio, leaf area, relative water capacity of leaves, and pigment values. However, the blend had
a significant effect on growth compared with that of the control and other treatments over the period. This can probably be attributed to the high nutritive value of the blend over the others, which has a significant effect on the properties of soil supporting the oil palm (Lehmann et al., 2003).

Tables 3 and 4 summarise the effect of the biochars on soil properties supporting the oil palm for a 2-month period. The results showed a significant improvement ($P < 0.05$) on the soil cation-exchange capacity, total organic carbon, and available phosphorus and nitrogen, leading to a significant

<table>
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<td>375c</td>
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<td>275a</td>
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<td>86.6</td>
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<td>SEM</td>
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<td>39.76</td>
<td>31.57</td>
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</tr>
<tr>
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<td>27.10</td>
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<td>CV (%)</td>
<td>27.68</td>
<td>22.00</td>
<td>24.08</td>
<td>28.12</td>
</tr>
</tbody>
</table>

CV, coefficient of variation; SEM, standard error of the mean; LSD, least square difference. Different letters in columns indicate significant differences between treatments at $P < 0.05$. 

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EFFECT OF PALM FRONDS AND COW DUNG BIOCHAR AND ITS BLENDS ON SOIL PROPERTIES
The results show the immediate positive effect of the biochars on the properties of the soil, the water-retaining capacity of soil and the growth rate of the seedlets over a period of 2 months, which corroborate the earlier assertion of Liang et al. (2006).
The results showed that biochar prepared from cow dung and palm fronds influenced the growth rate of the sprouted seedlets more as blends. The results indicated that the ability of the soil to retain water improved with the introduction of the biochar. The results further demonstrated that the biochar blend formulation should be recommended because it influenced the physico-chemical properties of soil supporting the oil palm and the growth rate of the sprouted seedlets better than the individual biochars and the control by 28%. This increase in plant growth and soil improvement will no doubt contribute to boosting yield and productivity, which would also help to address the challenges of feeding a growing population in the continent. However, more research needs to be carried out to determine the best quality of biochar and its output in view of the influence of pyrolysis time, temperature and mode of application.

COMMUNICATION STRATEGY AND IMPACT

The research was communicated at the 33rd International conference of the Chemical Society of Nigeria, Ogun 2010, 18–22 September 2010 and the 36th Annual Conference of the Soil Science Society of Nigeria, Nsukka, 12–16 March 2012. The work generated considerable interest among researchers, being a relatively new concept to them, and because it provides an avenue to reducing waste biomass constituting environmental pollution and its utilisation performance in agriculture. The research has also featured in a peer-reviewed journal (Ekebafe, 2011). The impact of the research work on community farmers has been impressive so far.

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URBAN FARMING AND ACCESS TO WATER IN A CHANGING CLIMATE: THE CASE OF MARKET GARDENING IN COTONOU

B.J. Foé Éloundou¹,², A. Hounkpatin³, B. Fayomi¹,², Z.S. Bachirou¹,³, M. Hountondji¹ and B. Cissé⁴
ABSTRACT

Market gardening accounts for 25% of all the vegetables consumed in Cotonou, but the sector is affected by the impact of climate hazards on water availability. The aim of this research was to learn how climate change affects access to water in the market gardening sector in Cotonou. From an ecosystem perspective, this case study was based on a sociological review of the perceptions through action research conducted among two groups of market gardeners. All interviewees acknowledged that the weather had changed, as well as various effects related to water access: (1) the constant drying out of water points; (2) increased evapotranspiration from soils; and (3) flooding caused by rainfall within a very short period. Apart from the physical effort involved, watering has to be undertaken on a daily basis involving from two to four sessions within an 8-h period. The main options pinpointed were: aircraft dispersion-based irrigation to replace watering by hand, and the continuous use of compost to boost the moisture and water-retaining capacity of soils. However, to achieve a sustainable level of production given growing urban demand, other factors need to be improved: (1) increasing access to land and financial resources to make it easier to obtain and deploy irrigation and drainage systems; (2) enhancing the value chain for marketing gardeners’ products; and (3) the most effective use of ICT for sharing information and knowledge about climate risks.

KEY WORDS: CITY, POPULATION, PRODUCTION, VEGETABLES

AFFILIATIONS

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INTRODUCTION

United Nations figures show that the level of urbanisation rose from 30 to 50% between 1950 and 2007 and is set to reach 60% in 2030 (UN, 2007). The fastest rate of urban growth is found in Africa: an average rate of 4.3% for a population expected to comprise over 1.5 billion inhabitants by 2050 (Véron, 2007). This urban population growth results in increased demand, particularly for nutritional foods. The structural adjustment plans in place from 1990–2000 triggered an economic crisis, weakening purchasing power for urban households and creating a boom in the informal local economy, involving new sectors such as urban farming (Coussy and Vallin, 1996; Chaléard and Dubresson, 1999).

Vegetable farming in Cotonou is a commercial enterprise; the first site was launched in the Houéyiho district in 1970 (Brock and Foeken, 2006). In the wake of the economic crisis of the 1990s, the system became widespread, with replications at several sites, creating an extensive fresh vegetable production network (Agossou et al., 2001; Kakai et al. 2010; Lee-Smith, 2010). This comprises 25% of all household vegetable consumption in Cotonou, with the remainder being brought in from rural areas as well as from Burkina-Faso and Nigeria (Temple and Moustier, 2004; IAGU, 2011).

Market gardening also creates employment opportunities for young people migrating from the countryside. Urban farming and market gardening have to contend with the impact of climate change, and the availability of and access to water (Mendelsohn et al., 2000; GIEC, 2007, Morton, 2007; Hertel and Rosch, 2010). Rising temperatures, erratic rainfall, the appearance of drought pockets and flooding are just some of the climate risks affecting the availability and management of water resources. The broad aim of this research was to evaluate the effect of climate change on the availability of water for the market gardening sector in the city of Cotonou. The specific objectives were (1) to identify how climate risks affect the availability of and access to water in the market gardening sector and schemes rolled out by producers to contend with the new ecosystem; and (2) to provide information on the initiatives required to maximise the efficient and effective control and management of water resources for market gardening.

METHODOLOGY

The research was undertaken between January and June 2011 in Cotonou. Within the context of an ecosystem, the study was divided into complementary phases: (1) the research phase, based on identifying and assessing climate risk-driven changes affecting the availability of and access to water for market gardening; and (2) an information- and knowledge-sharing scheme to boost the capacities of market gardeners. The research component was based on a study conducted among two groups of market gardeners (Houéyiho and Enagnon) located in the 12th and 4th districts, respectively. Samples of 75 market gardeners were selected at random from the two sites. The data-gathering phase involved direct observations and semi-structured interviews.

The direct observations involved an average of two weekly visits to each site, or a total of four visits a week for both of them. The key observation factors were the water access systems and the various changes affecting day-to-day activities, particularly watering, that had a direct bearing on variations in water availability. Two variables were considered during each visit: (1) the daily frequency of the watering sessions; and (2) the daily duration of the watering process. The interviews were conducted in French or the local language, Fon, depending on the interviewee’s preference. This helped to identify individual and collective perceptions within the market gardening community as regards climate change. Special attention was paid to the changes market gardeners perceived in the water access process, and the various individual and collective measures taken to address the situation.
The quantitative data provided by the observations were entered into an Excel spreadsheet to enable descriptive statistical analysis as a result of computing an (average) position indicator. The pre-recorded interviews were transcribed to enable content analysis and to identify relevant similarities and differences between the stakeholders’ discourses and field observations. The action component was based on information- and knowledge-sharing about climate change (causes, manifestations and consequences), emphasising the potential effects on water resource availability and reporting the adaptations highlighted in certain cases.

Two operational techniques were adopted: radio programmes and community workshops. The radio programmes were hosted by scientists and social stakeholders. They were produced in French and translated into Fon. For the two weekly programmes (one live and the second rebroadcast), the format for each programme was 30 minutes divided into three sections: (1) Stakeholders have their say: a 5-minute spot, this involved seeking the opinions of target groups about the theme of the week; (2) Science has its say: the guest of the day (academic or technician) had 10 minutes in which to communicate scientific or technological information on the theme of the day; (3) What can be learned?: in this section the permanent guest linked the ideas of scientists and stakeholders and the key underlying issues and potential conclusions. A telephone line was set up to invite listeners’ reactions. The community workshops addressed the same themes as the radio programmes, making it possible to amplify and fine-tune the exchange of information and experiences within the target groups.

**RESULTS**

By the end of the 6-month project implementation process, 80 field observation visits had been made to the two sites and 75 market gardeners had taken part in the interviews (Table 1). Fifteen radio programmes were made, involving 30 broadcasts (15 live and 15 rebroadcasts), and 10 community workshops were organised.

**Effects of climate risks on market gardening**

Ninety per cent of the market gardeners interviewed felt that the weather had changed, with the impact being felt in their everyday lives. The first factor to be mentioned by the market gardeners was the heat. This perception may be valid, given the overall increases in temperatures worldwide (IPCC, 2012). References were also made to irregular rainfall leading to pockets of drought or flooding. The climate change created new spatio-temporal water availability patterns, which market gardeners were struggling to come to terms with. These risks did not

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**TABLE 1: BREAKDOWN OF INTERVIEWEES BY GENDER AND AGE GROUP**

<table>
<thead>
<tr>
<th>Site</th>
<th>Gender</th>
<th>Age range</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Under 30</td>
<td>Over 30</td>
</tr>
<tr>
<td>Site 1</td>
<td>20</td>
<td>22</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Site 2</td>
<td>25</td>
<td>18</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>30</td>
<td>40</td>
<td>35</td>
</tr>
</tbody>
</table>

*Source: Clim-info project, JVE-Benin, 2011.*
lead to a water crisis, but the interviews highlighted the problems market gardeners had in controlling and gaining access to sufficient quantities of water in good time. The water supply at the Enagnon site, for example, was based on wells built within these holdings. The open, shallow wells were exposed to the sun, so the water was constantly evaporating and drying up more often. The sunshine was also conducive to evapotranspiration affecting the surface areas being cultivated. This, combined with the poor water-retaining capacity of the sandy soils in Cotonou, meant less water being available not only in the wells, but also in the soils.

Certain jobs, such as watering by hand, had to be done more often and were more physically demanding and time-consuming. At the Enagnon site, for example, the average daily watering frequency was two to four tries a day depending on the intensity of the sunshine and the amount of water available in the wells. This variable watering would take up to 8 h a day. Market gardening was destabilised by obstacles such as having access to land and inputs and pollution (Nouatin and Bachabi, 2010). When deciding on the types of vegetables to grow and in what quantity, market gardeners had to factor in the water requirements for participating crops, namely more work, irregular production, price instability and lower income, and the work involved during watering. So market gardeners constantly had to contend with the risk of flooding. Apart from the annual cyclical circumstances resulting from the city’s geographical location (Ailo, 2010; Wallez, 2010), the flooding caused by heavy rainfall during a comparatively short period increased waterlogging. This had several implications, and though varying from one producer to another, four effects stood out more than the others for the market gardeners (Table 2).

**Options and constraints in adopting the most effective water control approach**

Women and young market gardeners were particularly vulnerable to this new ecosystem, where an irregular water supply interacts with the degraded quality of soil on the surface areas being cultivated. Other intermittent or periodical activities were necessary to enable these groups to supplement their incomes, as they were failing to keep pace with the ever-increasing daily requirements. Four types of conflicting activities were identified: (1) small local shops selling basic goods (sugar, milk, coffee, cooking oil, firewood, etc.) and run by women; (2) zemidjan motorcycle taxi transport, a business strictly for men; (3) the selling of smuggled petrol; and (4) fishing on Lake Nokoé or the Benin sea coast. In the case of market gardening, these four sectors shared the same labour on a daily basis or periodically. Consequently, it was difficult to make a precise assessment of the incomes derived solely from market gardening and to discover how they varied according to the water access constraints.

<table>
<thead>
<tr>
<th>Effects</th>
<th>More work</th>
<th>Irregular production</th>
<th>Price instability for market gardening enterprises</th>
<th>Lower income for market gardeners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual/75</td>
<td>68</td>
<td>53</td>
<td>38</td>
<td>73</td>
</tr>
<tr>
<td>Percentage</td>
<td>90</td>
<td>70</td>
<td>51</td>
<td>97</td>
</tr>
</tbody>
</table>

Source: Clim-info project, JVE, Benin, 2011.
The need to lessen the labour intensity associated with watering led to the creation of an aircraft dispersal irrigation system using motor pumps at certain specific sites, such as the Houéyiho site, as an alternative to the manual watering system applied at roughly 90% of market gardening sites in Cotonou (Deguenon, 2008). This disparity was explained by (1) the cost of buying, operating and maintaining the equipment required for the system; and (2) the risks the market gardeners had to contend with of being relocated/evicted (Assogba, 2003). Aside from official sites, such as the Houéyiho site, market gardeners occupied land belonging to the state, companies or even private individuals. In the absence of any farming contract, the individuals involved in market gardening were under constant threat of eviction, which prevented some market gardeners from establishing a permanent irrigation system. The alternative to an irrigation system was to hire more people to do the watering, but this option drove up the production costs. Twenty per cent of market gardeners reported having received a loan from a financial institution at least once, while others started their business using their own funds and help from others. In addition to the bureaucratic and administrative burdens, interest rates could be as high as 24%, restricting market gardeners’ capacity to repay the loans granted (Tokannou and Quenum, 2007).

In addition to irrigation, the market gardeners sought to improve the soil quality so as to boost the water- and moisture-retaining capacity. Two techniques were singled out: mulching and the use of compost. Roughly 80% of the market gardeners interviewed said that they applied one or the other option on their holdings. The yields provided by the sandy, low-nutrient soils were boosted by mixing dried grass with the thin layer of topsoil during the soil preparation stage. Known as planches, the mounds or ridges formed on the soils were next covered with a layer of compost or chick manure (James et al., 2010). As well as its fertilising capacity, the compost increased the moisture and water-retaining capacity of the soils (Matondo and Miambi, 1990; Kakaï et al., 2010). However, not all market gardeners agreed on the use of compost being appropriate and, in particular, whether it could increase production enough to satisfy the increasing demands of urban households. This is why some of them would add low-impact chemical fertilisers to help the soils recover the nutrients lost through over-exploitation and sometimes reduce the problems caused by pests (Assogba-Komlan et al., 2007).

**DISCUSSION AND CONCLUSION**

The market gardening sector covered roughly 25% of all vegetables consumed by Cotonou households, contributing to diversity for the consumers to maintain their nutritional balance. Climate risks represented a new challenge for market gardeners in addition to the structural, organisational and financial woes they face. Irrigation and composting were some of the options proposed to curb the physical and temporary water access constraints and improve soil quality. The growing urban demand indicated that simultaneous interventions were required, such as access to land, credit and inputs, the professionalisation of producers and the enhancement of the market gardening production value chain, with the focus on processing and marketing. The limitations of this study suggest the need to make a more detailed analysis of the correlations between variations in water availability and changes to market gardening production and socio-economic determinants, such as the number of jobs and incomes. Maximising the effectiveness and efficiency of the new information- and knowledge-sharing process is also possible, using information and communication technologies, such as community radio stations, television and mobile phones, which are available to urban producers. These gadgets made it easier to be one step ahead in planning and managing climate effects and risks. There has to be a constant complementary relationship between science,
technology and the media, with the focus on boosting the skills of the stakeholders and professionals in the local media. Hence the challenge for the post-2015 development agenda for Africa.

COMMUNICATION STRATEGY AND IMPACT

On the basis of the clim-info project which supported this study, a series of 30 programmes were broadcast by the Océan FM (88.6 MHz) radio station serving Cotonou city and the surrounding area. The usual audience comprises roughly 300,000 people, including all sections of the population. The outcomes were also reported on the Africa-Adapt innovation fund platform (www.africa-adapt.net). The project’s operational impact was to improve local perceptions of climate change in general, particularly among the groups of market gardeners taking part in the project. The study also made it possible to gain a better understanding of the impact of climate change on market gardening, not least the various physical and temporary water access constraints.

ACKNOWLEDGEMENTS

We specifically thank the NGO Enda-TM Senegal for granting the financial resources via the Africa-Adapt innovation fund and JVE-Benin for assuming the implementation role, with technical support from COPES-AOC.

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THE EFFECT OF *OPUNTIA FICUS-INDICA* AND *LEUCAENA KX2* SUPPLEMENTATION ON THE WEIGHT GAIN OF GRAZING LAMBS

D.Y. Gebremariam*
ABSTRACT

One of the main constraints of livestock production in Eritrea is low quantity and quality feed during the dry season. An experiment was carried out to evaluate the nutritive value of cactus (Opuntia ficus-indica) and Leucaena KX2 and to study the effect of supplementing these feeds on weight change of grazing lambs during the dry season. Twenty-four fat-tailed grazing lambs were supplemented with four levels (on fresh basis) of cactus (C) and Leucaena KX2 (L):

- treatment 1 (T1) = no supplement;
- treatment 2 (T2) = 350 g C + 117 g L;
- treatment 3 (T3) = 700 g C + 198 g L;
- treatment 4 (T4) = 1,050 g C + 292 g L.

Chemical analysis of C and L showed that, except in ash, L was higher than C in crude protein (27.29 vs 1.35%), crude fibre (CF) (18.57 vs 10.61%) and metabolisable energy (ME) (12.28 vs 11.39 MJ/kg DM). The ash content of C (19.42%) was, however, higher than that of L (10.21%). Lambs in T3 and T4 had significantly higher ($P = 0.05$) weight gains than those in T1 and T2. It was concluded that supplementing small quantities of cactus and Leucaena KX2 to sheep in the dry season saves the animals from weight loss and subsequent death. The project would have a potential impact in rural communities in terms of feed and food security and environmental wellbeing.

KEY WORDS: CLADODES, DRY SEASON, FAT-TAILED, FRESH, LEAVES, SPINY
INTRODUCTION

More than 80% of the Eritrean population lives in rural areas integrating crop and livestock production as a means of livelihood. However, as in other parts of arid/semi-arid regions, Eritrean livestock production frequently faces shortage of feed. Especially in the highlands, productivity of the rangelands is very low and their size is shrinking due to crop encroachment and frequent drought. The only feed resources available in the dry season are crop residues. Conventional supplements such as concentrates are unaffordable by subsistence farmers and are rarely available. Therefore many animals lose weight and even die during the dry months of the year, thus further increasing the poverty level of rural communities.

Research or development activities that focus on at least maintaining the body weight of animals during the critical dry season, and thereby avoiding poor animal performance and/or death, would greatly improve livelihoods of rural communities. The challenge therefore is to identify feed resources that are cheaper, drought-resistant, locally available, and can support ruminants in the dry season. In dry areas such as Eritrea, cactus (Opuntia) and Leucaena are among the attractive nonconventional alternative dry-season feed resources that should be studied.

The cactus is found in the highlands and eastern escarpment; however, it has not been adequately tested to date as a potentially valuable feed (Kayouli et al., 2006). The fact that cactus is a drought-resistant plant makes it an attractive fodder option in the Eritrean rangelands (especially in the highlands and arid lowlands), which are characterised by shallow soils. Given that more than 50% of the total land area of Eritrea is rangelands, the potential of cactus as an alternative feed is huge. Cactus varieties are either spiny or non-spiny; spineless varieties are easier to use and handle as animal feed and fruit for human consumption (Candelario, 2004).

Leucaena is one of the most nutritious tropical forages fed to ruminants and is highly digestible (Preston and Leng, 1987). It has excellent potential for use in both the Central Highlands Zones and in valley beds of the Western Lowlands of Eritrea, in areas with 600 mm and above of rainfall (Kayouli et al., 2006). Moreover, once established, it is drought-resistant, which makes it also suitable in areas with less rainfall. The Leucaena plantation at the National Agricultural Research Institute (NARI) is hybrid KX2.

The rumen micro-organisms require energy and protein sources in forms they can use for better fermentative functions, hence the combination of cactus (energy) and Leucaena (protein).

This study had two objectives: evaluation of (1) cactus and Leucaena as alternative feeds, and (2) their supplementary effects on the weight gain of grazing lambs in dry seasons.

METHODOLOGY

The study was carried out at the livestock farm of the NARI headquarters in Eritrea, during the dry months of March to June 2009, over a period of 118 days. Twenty-four fat-tailed highland lambs, 3–6 months old and weighing 20 ± 4.95 kg, were used in the experiment. Lambs were dewormed using Ivermectin and adapted to the feeds over a 2-week period before they were randomly allocated to four treatment (T) groups of three animals replicated twice. During the experiment, all lambs grazed for 7 h daily in the rangeland around the institute. The supplements in each treatment were: T1 = none; T2 = 350 g cactus and 117 g Leucaena KX2; T3 = 700 g cactus and 198 g Leucaena KX2, T4 = 1050 g cactus and 292 g Leucaena KX2.

Spiny cactus cladodes, obtained from wild plantations within the livestock farm, were used in the experiment. After removing the spines manually, fresh cladodes were chopped and supplemented to lambs twice a day (morning and evening), before and after grazing.
Leucaena KX2 leaves were also obtained daily from a plantation within NARI’s Halhale station. The variety used was kx2 hybrid. Twigs measuring less than a pencil size were cut daily and supplemented fresh to the lambs twice a day (morning and afternoon), before and after grazing. An analysis for chemical composition of cactus and Leucaena was carried out at the National Animal Feed Laboratory, Ministry of Agriculture. The technique used was proximate analysis according to the procedures of AOAC (1984).

Data on the supplementary feed intake and live weight of lambs were recorded daily and biweekly, respectively. A randomised complete block design (RCBD) was used in the experiment and the data were analysed using the analysis of variance procedures of the GenStat (2005) statistical software. Differences between groups were evaluated by t-test.

<p>| TABLE 1: PROXIMATE ANALYSIS OF THE DIFFERENT FEEDS INVOLVED IN THE EXPERIMENT |</p>
<table>
<thead>
<tr>
<th>Feeds examined</th>
<th>DM (%)</th>
<th>Ash (%)</th>
<th>CP (%)</th>
<th>CF (%)</th>
<th>EE (%)</th>
<th>ME (MJ/kg DM)</th>
<th>DCP</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leucaena leaves</td>
<td>35.00</td>
<td>10.21</td>
<td>27.29</td>
<td>18.57</td>
<td>0.50</td>
<td>12.28</td>
<td>19.72</td>
<td>69.22</td>
</tr>
<tr>
<td>Cactus cladodes</td>
<td>11.00</td>
<td>19.42</td>
<td>1.35</td>
<td>10.61</td>
<td>0.20</td>
<td>11.39</td>
<td>1.07</td>
<td>63.87</td>
</tr>
</tbody>
</table>

<p>| TABLE 2: MEAN VALUES FOR LIVE WEIGHT (LW) GAIN, FEED INTAKE AND FEED CONVERSION OF LAMBS |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Grazing and:</th>
<th>No supplement</th>
<th>350 g cactus + 117 g Leucaena</th>
<th>700 g cactus + 198 g Leucaena</th>
<th>1,050 g cactus + 292 g Leucaena</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial LW (kg)</td>
<td>20.1</td>
<td>20.0</td>
<td>20.0</td>
<td>20.4</td>
<td></td>
</tr>
<tr>
<td>Final LW (kg)</td>
<td>18.0</td>
<td>19.9</td>
<td>21.1</td>
<td>22.4</td>
<td></td>
</tr>
<tr>
<td>LW change (g/day)</td>
<td>–17.65 ± 9.06a</td>
<td>–0.71 ± 19.40a</td>
<td>9.18 ± 14.03b</td>
<td>16.95 ± 7.09b</td>
<td></td>
</tr>
<tr>
<td>Feed intake (DM) (g/head/day)</td>
<td>0</td>
<td>52</td>
<td>104</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Cactus</td>
<td>0</td>
<td>44</td>
<td>75</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Leucaena KX2</td>
<td>0</td>
<td>96</td>
<td>179</td>
<td>266</td>
<td></td>
</tr>
<tr>
<td>Total supp. DM</td>
<td>0</td>
<td>96</td>
<td>179</td>
<td>266</td>
<td></td>
</tr>
<tr>
<td>Consumption index*</td>
<td>0 ± 0a</td>
<td>495.6 ± 52.4b</td>
<td>893.6 ± 85.9c</td>
<td>1263.1 ± 87.9d</td>
<td></td>
</tr>
<tr>
<td>Conversion†</td>
<td>–</td>
<td>–137</td>
<td>20</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

* g DM/100 kg LW/day; † g DM intake/g gain in LW; along rows, values with different letters significantly differ from each other (P < 0.05).
RESULTS

The values of the chemical analysis of feeds involved in this experiment are shown in Table 1. *Leucaena* KX2 was higher than cactus in all aspects of feed quality except ash; the metabolisable energy content of both supplements is virtually identical.

Table 2 shows the values of live weight change, dry matter (DM) feed intake and feed conversion efficiency of lambs. Used fresh, supplementing grazing lambs with 700 g cactus and 198 g *Leucaena* and 1050 g of cactus and 292 g *Leucaena* (T3 and T4) resulted in a significantly higher ($P = 0.05$) live weight gain compared with the nonsupplemented group (T1) and the group given the lowest level of supplement (T2).

Supplementation of only 350 g cactus and 117 g *Leucaena* to grazing lambs reduced daily weight loss from more than 17 g to less than 1 g; and doubling the cactus level to 700 g and raising *Leucaena* to 198 g promoted a weight gain of more than 9 g/day. Tripling the level of cactus to 1050 g and raising *Leucaena* to 292 g resulted in a gain of almost 17 g/day.

However, despite a notable trend, increasing the cactus supplementation level from 0 (T1) to 350 g (+117 g *Leucaena*) (T2) or from 700 g (+198 g *Leucaena*) (T3) to 1050 g (+292 g *Leucaena*) (T4) did not result in significantly higher ($P > 0.05$) live weight gain.

DISCUSSION AND CONCLUSION

The moisture, ash and crude fibre (CF) contents (89, 19.42 and 10.61%, respectively) of cactus used in this experiment tally with earlier studies (Nefzaoui, 1996–97; Tegegne, 2001; Peter, 2001). In reference to CF, Tegegne (2001) reported that the content varies with age (7.96, 8.03 and 10.72% for younger, middle-aged and old cladodes, respectively). Similar findings (8 to 15%) and (9 to 20%) were also reported by Nefzaoui (1996–97) and Patricio (2001), respectively.

The crude protein (CP) content of cactus in this study (1.35%) was very low compared with those reported by many previous studies, which were in the ranges of 3.5% (Patricio, 2001) to 9.2–13.4% (Tegegne, 2001); this is far below the limiting level for microbial growth, which is 6–7% as reported by the second author. However, (Nefzaoui, 1996–97) reported only slightly higher CP content (2–5%). But since lambs were also supplemented with *Leucaena*, which is high in CP content (27.29%), microbial growth might have not been hampered. Fortunately, the CP content of cactus can be increased using nitrogen and phosphorus fertilisers and genetic selection (Peter, 2001). The metabolisable energy (ME) content of cactus in this study (11.39 MJ/kg DM) is similar (10.88 MJ/kg) to that reported by Peter (2001), while this was a little higher (9.41 MJ/kg DM) than that reported by Patricio (2001). The ME content in this study indicates that cactus was a good source of readily available energy (Patricio, 2001; Vasta et al., 2008; Degu et al., 2009).

The variations in the nutritional quality of cactus cladodes (particularly in CF, CP and carbohydrates) have been reported to be attributable to the variety, age and part of the plant, season of the year, and soil fertility or crop management (Patricio, 2001; Peter, 2001; Tegegne, 2001). These variations may explain the low protein content in this study. Tegegne (2001) reported that as age of cladodes increased (young, middle-aged and old), CP content decreased from 13.42 to 9.15% while CF increased from 7.96 to 10.72%. The cactus used in this study was considered as a wild plant as it was not cultivated. Cladodes were harvested during the dry season and it was not possible to determine plant and/or cladode age and to carry out soil fertility analysis.

The crude fibre (18.6%) and ash (10.2%) contents of *Leucaena* were in line with the 18.4% and 7.9% values reported by Ruiz-Feria et al. (1998) while CP content (27.3%) was higher than the 22.9% value
reported by the same author. The reason for the higher CP value in this study might have been that the *Leucaena* used was hybrid KX2, a high-yielding hybrid variety. The ME content of *Leucaena* in this study was higher than that of alfalfa (10.54 MJ/kg DM) as reported by Patricio (2001) or by Peter (2001) for digestible energy (11.05 MJ/kg DM). The ME content of *Leucaena* was also slightly higher (12.28%) than that of cactus used in this study. This implies that it was a source not only of protein but also of energy to the lambs.

In this study, lambs fed higher levels of cactus and *Leucaena* gained (9 to 17 g) more weight than those given no supplements (18 g below zero) or lower levels of supplements (1 g below zero). The positive body weight gain of lambs could have been the result of the high CP content of *Leucaena* and the high non-structural carbohydrate content of cactus (which served as source of readily fermentable carbohydrates, which improve the utilisation of ammonia for microbial growth). Cactus is also rich in vitamin A, which makes it a valuable feed as it is virtually the only source of minerals and vitamin A under harsh conditions (Nefzaoui, 1996–97; Peter, 2001).

Ben Salem *et al.* (2002) reported that nitrogen supplementation of cactus-based diets with urea-treated straw or Atriplex foliage improved the nutritional value of these diets and hence sheep growth. Nefzaoui (1996–97) stated that Opuntia (a good source of energy), Atriplex (a good source of protein) and Acacia (a fibre source) are nutritionally complementary. As was the case in this study, animals obtained their fibre, energy and protein requirements from grazing (or straw supplementation), cactus and less expensive sources of protein, respectively.

In the present study, low levels of weight gain were achieved due to low levels of cactus and *Leucaena* supplementation. However, the level of weight gain achieved may be good news for livestock producers in arid and semi-arid countries who observe their animals becoming emaciated and eventually dying in drought years. Higher levels of weight gain can be achieved by increasing the supplementation levels of cactus and *Leucaena*. Degu *et al.* (2009) reported that the mean daily weight gain of sheep in many studies varied widely according to the type and level of supplementation. In a feeding study with lambs given basal diets of wheat straw, growth rates of 81 g/day were obtained by replacing costly concentrate feeds with cactus and Atriplex, which, compared with the traditional and expensive barley grains and soybean meal, can be easily made available to subsistence farmers at a low cost (Ben Salem *et al.*, 2004). Thus in arid climate rangelands the exploitation of some drought tolerant shrubs, such as cactus and *Leucaena*, represents an effective strategy for livestock feeding (Vasta *et al.*, 2008).

In conclusion, supplementing small quantities of cactus and *Leucaena* KX2 to sheep during the dry season saved the animals from weight loss or death; sheep on these diets not only maintained body weight, but also gained moderate levels of live weight, improving the livelihoods of subsistence farmers. As about half of Eritrea’s land area is rangelands, future research and development projects should focus on how cactus and *Leucaena* KX2 can be better utilised as feed, and on ways of planting them extensively in the rangelands. This would enhance the sustainability of livestock production and food security in the country.
COMMUNICATION STRATEGY AND IMPACT

The findings of this research project were presented to high-ranking policy makers, agricultural research and extension officers and staff, and other invited guests during NARI’s annual meeting. A brief presentation was also made during the national annual meeting of the Ministry of Agriculture. For further dissemination of the findings, a scientific article will be submitted to the Journal of Livestock Research for Rural Development.

The project has a potential impact in terms of feed and food security and environment. Rural communities would be motivated to grow cactus on their yards and enclosures to feed their animals and themselves (the fruit is very delicious and nutritious). They would also generate income by selling excess fruit to nearby towns. This creates employment opportunities for urban women – though, to a limited extent, this is also witnessed today. Farmers can also generate income by keeping bees and producing honey, since cactus is a good bee forage. Moreover, there would be a positive impact on the environment (more than 50% of the Eritrean territory is rangelands) as cactus conserves moisture and soil in addition to contributing organic matter to the soil as cladodes decay.

ACKNOWLEDGEMENTS

I wish to thank the following colleagues at NARI for their support: Dr T. Tesfai, Dr T. G/selassie, E. Tesfai, E. Kiflay, M. G/nigus, W. Mehari, S. Berhane, all laborers and other staff.

REFERENCES


INTRODUCTION OF HEAT-TOLERANT GENES INTO EXOTIC LAYERS FOR IMPROVED EGG PRODUCTION UNDER HOT AND HUMID ENVIRONMENTS IN GHANA

J.K. Hagan¹ and S.O. Olympio²
ABSTRACT

Exotic layer poultry breeds in Ghana do not perform to their full genetic potential due to the warm and humid environment. A breeding programme was undertaken with the aim of incorporating heat-tolerant genes of local indigenous birds into layers to make them more productive under such environments. Four groups of Lohmann Brown layers with the naked-neck and frizzle traits were generated after four successive generations of backcrossing. A total of 360 16-week-old pullets (90 from each of the four groups) were used in a completely randomised design experiment that lasted for 72 weeks. Each treatment group had three replicates, each with 30 birds. The birds were kept in partitioned, open-sided, deep-litter pens (with 30 pullets in each compartment) and fed ad libitum with layer diets containing 18% crude protein and 2800 Kcal ME/kg. Results showed that the layers with the naked-neck and frizzle traits were significantly ($P < 0.05$) superior in terms of age at sexual maturity, feed conversion ratio and egg weight compared with their sibs without these traits. Birds with a combination of the two traits laid significantly ($P < 0.05$) at higher rates than their sibs with single doses of the genes, which in turn also laid at a significantly ($P < 0.05$) higher rate than their counterparts without the traits. The results showed that incorporating the heat-tolerant genes into exotic layers made them more adaptable to hot and humid environments. This was evidenced by the increased egg production observed in the naked-neck and frizzled birds compared with their fully feathered counterparts.

KEY WORDS: ADAPTABLE, EXOTIC BREEDS, FRIZZLE, NAKED-NECK, SUPERIOR, TRAITS

AFFILIATIONS

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2 Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.
INTRODUCTION

Commercial poultry production in Ghana depends largely on exotic breeds introduced as parents or commercial hybrids. The importation of these exotic breeds limits self-dependence for poultry development and also dilutes the genetic make-up of the locally adaptable indigenous birds. In spite of the high productive performance of these exotic birds, their full genetic potential is usually not fully reached in the tropics due to the hot and humid environments. Such birds lay only between 230–270 eggs, far below the 300 or more eggs per annum attained in their countries of origin (MoFA, 2010). Garces et al. (2001) observed that high environmental temperatures limit performance of the birds under intensive production systems. To overcome the problem of reduced performance as a result of heat stress, farmers adopt methods such as the provision of fans, insulating pens, high-energy diets and feed supplementation. These are all very expensive methods of minimising the negative effect of heat stress. One cost-effective method of ameliorating the effect of heat stress on productivity is the introduction of tropically relevant heat-tolerant genes such as naked-neck (Na) and frizzle (F) into these exotic birds (Galal et al., 2007). This is because in hot and humid tropical conditions, the dissipation of body heat of birds is reduced and their feed consumption is depressed, culminating in reduction in general productivity. This, according to Galal et al. (2007), has necessitated the use of naked-neck (Na) and frizzle (F) genes in Ghana (Hagan, 2010) for exotic breed improvement programmes with respect to egg production in the tropics.

The naked-neck condition is characterised either by the complete absence of, or reduced, feathers in the neck region of chickens, which is controlled by an autosomal dominant gene (Somes, 1990). The frizzle condition, on the other hand, curls the feathers and reduces their size, thus increasing the heat conductivity of the feather coverage (Somes, 1990). These genes have been shown to reduce the insulating power of the birds’ plumage, making the birds heat-tolerant. Crossbreeding between local chickens with the heat-tolerant genes and highly productive exotic breeds would ensure the exploitation of the rusticity of the former and the increased productive performance of the latter in tropical environments. Such a programme tends to produce highly adaptable and superior birds with improved egg production characteristics.

To this end, a breed improvement and adaptation strategy was undertaken in order to increase egg production in hot and humid tropical environments in Ghana.

METHODOLOGY

Experimental population

The base populations used in this experiment were the offspring of a cross from local male lines which were heterozygous for the naked-neck (Na) and frizzle (F) genes and Lohmann Brown female lines homozygously recessive for the two genes. In order to retain the high egg production traits in the offspring, the F₁ were successively backcrossed with the Lohmann Brown, generation after generation. At the end of the fourth generation, four different combinations of genes for feather distribution and morphology constituting four genetic groups were segregated. These were: combined naked-neck frizzle (Na/naF/f), naked-neck only (Na/naf/f), frizzle only (na/naF/f) and their normally feathered (na/naf/f) sibs. These populations were maintained under some intense selection pressure for egg production. To avoid inbreeding, planned pedigree mating was practised in each generation. The egg production performance of these four genetic groups was evaluated under on-station experimental conditions.
Study site and management of experimental birds

The experiment was carried out at the Poultry Section of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. The experimental site was in the transitional forest zone between latitudes 6°35´ and 6°40´ and longitudes 1°30´ to 1°35´, with an elevation between 250 and 300 m above sea level (MoFA, 2010) and a mean annual rainfall of around 214.3 mm in June and 165.2 mm in September. The birds were kept in a partitioned, open-sided, deep-litter house constructed using sandcrete blocks, with 30 pullets in each compartment. They were housed in partitioned deep-litter pens with a stocking density of 1 bird/0.15 m². The birds were fed layer diets containing 18% crude protein and 2,800 Kcal ME/kg from the age of 18 weeks onwards. Feed and water were provided ad libitum. There were eight nests (measuring 30 × 30 × 35 cm) to each pen. Eggs were collected twice daily, at 09:00 and 15:00 GMT. The maximum and minimum daily temperatures during the study period ranged between 26.5–35.5°C and 20.1–25.3°C, respectively, while the relative humidity ranged from 55–80%. All recommended prophylactic treatments for the area were followed. All the birds were reared under the similar environmental, managerial and hygienic conditions.

Data collection and parameter estimation

Data on daily egg production were kept throughout the laying period on a pen-by-pen basis. In terms of egg production, the parameters taken were age at sexual maturity (age at first lay), rate of lay (hen/day), egg mass, egg weight, and egg internal and external characteristics. Age at sexual maturity was estimated as the age at which the birds laid their first egg. Egg mass was calculated as the product of egg weight (g) and hen/day egg production. Feed conversion ratio was calculated as the ratio of kilograms of feed intake to kilograms of egg produced. At 30 weeks of age, 15 samples of fresh eggs were collected from each of the phenotypes for internal and external egg quality tests at the Department of Physics of KNUST. Eggshell thickness, albumen height, yolk height, Haugh unit and yolk colour score were considered as determinants of egg quality and analysed and determined following the procedure of Parmar et al. (2006).

Statistical analysis

The data obtained were subjected to a one-way analysis of variance with phenotype effect using the GenStat General Linear Model procedure (Discovery Edition 4). Where significant differences were found, means were separated using the least significant difference (lsd) test at the 5% level of significance.

The linear model used for the data analysis was:

$$Y_{ij} = \mu + g_i + \varepsilon_{ij}$$

Where $Y_{ij} =$ performance of the $j$th pullet of the $i$th phenotypic group; $\mu =$ overall general mean common to all observations; $g_i =$ fixed effect due to $i$th phenotype ($i = 1, 2, 3, 4$); and $\varepsilon_{ij} =$ random error effects peculiar to each observation.

RESULTS

The egg production performances of the four phenotypes are presented in Table 1 with significant ($P < 0.05$) phenotype effects on all the parameters studied.

From the data in Table 1, the introduced heat-tolerant genes significantly ($P < 0.05$) affected the egg production performance of layers, with birds that showed the genes in the double segregation state producing more eggs at a significantly higher rate than those with a single dose of the genes, which in turn were superior to the birds that were fully feathered.
The analysis of the egg quality characteristics of the four phenotypes showed no significant ($P > 0.05$) effects on the internal and external egg characteristics studied (Table 2).

**DISCUSSION AND CONCLUSION**

The superior egg-laying performance of the layers with the double doses of the heat-tolerant genes (Table 1) confirms that these genes are associated with increased egg production in hot and humid conditions. Even though the experiment was carried out in a moderately warm environment (22.5–33.5°C), the superior performance of the naked-neck and frizzle phenotypes was still evident. These results are similar to those of Merat (1986), Yushimura *et al.* (1997), Barua *et al.* (1998) and Abdel-Rahman (2000), who all reported that the naked-neck phenotypes were superior to the normally feathered chickens in egg production and feed conversion efficiency, in a hot and humid environment.

### TABLE 1: MEAN EGG PRODUCTION PERFORMANCE OF THE NAKED-NECK, FRIZZLE AND NORMALLY FEATHERED PHENOTYPES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phenotype</th>
<th>±SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Naked-neck frizzle</td>
<td></td>
</tr>
<tr>
<td>Egg mass (g/HD)</td>
<td>50.0°</td>
<td>1.5</td>
</tr>
<tr>
<td>Feed intake (g/day)</td>
<td>115°</td>
<td>2.4</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>2.0°</td>
<td>0.04</td>
</tr>
<tr>
<td>Rate of lay hen/day (%)</td>
<td>80.7°</td>
<td>2.7</td>
</tr>
<tr>
<td>Age at 1st lay (days)</td>
<td>119.3°</td>
<td>1.9</td>
</tr>
<tr>
<td>Egg weight (g)</td>
<td>59.7°</td>
<td>2.3</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>6.4°</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Means in a row with different superscript letters are significantly different at the 5% level. HD, hen-day.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phenotype</th>
<th>±SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na/naF/f</td>
<td></td>
</tr>
<tr>
<td>Shell thickness (mm)</td>
<td>0.38</td>
<td>0.056</td>
</tr>
<tr>
<td>Yolk diameter (mm)</td>
<td>38.97</td>
<td>1.433</td>
</tr>
<tr>
<td>Yolk height (mm)</td>
<td>17.22</td>
<td>0.585</td>
</tr>
<tr>
<td>Haugh unit (%)</td>
<td>77.42</td>
<td>2.291</td>
</tr>
<tr>
<td>Albumen height (mm)</td>
<td>8.22</td>
<td>0.097</td>
</tr>
<tr>
<td>Yolk colour score</td>
<td>4.25</td>
<td>0.566</td>
</tr>
</tbody>
</table>

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**TABLE 2: INTERNAL AND EXTERNAL EGG CHARACTERISTICS OF THE FOUR PHENOTYPES**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phenotype</th>
<th>±SEM</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Na/naF/f</td>
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<td>na/naF/f</td>
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<td></td>
<td>na/naF/f</td>
<td></td>
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</tbody>
</table>

### Footnotes:

*Means in a row with different superscript letters are significantly different at the 5% level. HD, hen-day.*
environment. The birds that possessed the heat-tolerant genes laid their first egg significantly earlier than those that were homozygous recessive for the genes, even though they were all segregated from the same flock. According to Merat (1990), Horst and Mathur (1992), Haaren-Kiso et al. (1995) and Abdel-Rahman (2000), the naked-neck and frizzle genes were associated with early maturity when the birds were reared in both moderately warm to hot, humid environments. This enabled the birds with thermoregulatory genes to be reared in hot and humid tropical conditions where the average temperature was above 25°C.

The superior performance of the birds with the naked-neck and frizzle genes, especially those with the double doses of the genes, was the result of their reduced feathers; this provided a larger surface area for heat dissipation from the skin during periods of heat stress. They also tended to reserve more nutrients and energy that could otherwise have been used for heat dissipation, for egg production (Yalcin et al., 1997; Patra et al., 2002). This made naked-neck and frizzle birds more tolerant to low dietary protein than their fully feathered counterparts, which used some of their protein intake for feather growth and development. The above observations showed clearly that incorporating the heat-tolerant genes into exotic breeds will enable them to realise their full genetic potential in hot and humid tropical environments. Not only were the genes associated with heat tolerance, their presence also elicited higher egg production and better feed efficiency in the birds (Galal et al., 2007).

The results obtained indicated no significant effects ($P > 0.05$) of the genes on the internal and external egg parameters measured (Table 2). These results contradict the findings of Abdel-Rahman (2000), Nwachukwu et al. (2006), and Islam and Nishibori (2009) that the genes responsible for feather reduction ($Na$ and $F$) in layers provided relative heat tolerance under hot climates, with naked-neck and frizzle layers outperforming their fully feathered counterparts in terms of internal and external egg characteristics. Another contrasting observation made by Mahrous et al. (2008) was that the egg albumen percentage and Haugh unit of eggs from phenotypes showing the naked-neck and frizzle traits were higher than those of their normally feathered sibs. They also observed that the presence of the $Na$ gene in combination with the $F$ gene significantly increased eggshell weight and thickness compared with eggs from normally feathered counterparts. The non-significant differences regarding egg quality of the phenotypes observed in this experiment might be attributable to the fact that, according to Merat (1990), the full potential of the genes is realised under extremely hot and humid environments (above 32°C).

The conclusion of the research was that incorporation of the heat-tolerant genes (naked-neck and frizzle) into exotic layers would allow for the realisation of the full genetic potential of introduced exotic birds that are to be reared under hot and humid environments. This was evidenced by the superior egg production performance of the naked-neck and frizzle phenotypes even under moderately warm environments, as compared with their sibs that were normal or fully feathered.

**COMMUNICATION STRATEGY AND IMPACT**

This research led to the development of exotic layers which were highly productive and adaptable to warm and humid environments in Ghana. The research findings have been presented at field days, workshops, seminars and conferences, and have been made available to stakeholders including farmers, scientists, extension officers and policymakers. Five papers have been presented at both local and international conferences (Ghana Society of Animal Production, Ghana Animal Science Association and UCC/Ilorin International Conference on Climate Change and Development) and
HEAT-TOLERANT GENES FOR IMPROVED EGG PRODUCTION UNDER HOT AND HUMID ENVIRONMENTS IN GHANA

published as proceedings and in scholarly journals (Journal of Agricultural and Biological Sciences, Ghanaian Journal of Animal Science and Journal of Science and Technology). Brochures, posters and leaflets containing pictures of the birds and showing the productive performance characteristics of all the phenotypic groups were distributed during those conferences and workshops.

In terms of the commercialisation of the project, Akate Farms, one of the biggest poultry farms in Ghana, has adopted the technology and is now multiplying the layers with the naked-neck and frizzle traits for commercial purposes. This has resulted in a tremendous reduction in foreign exchange spent on the importation of parent lines. Another beneficial outcome is that poultry farmers in Ghana who rely on Akate Farms for their birds for egg production are now assured of more highly adaptable and productive birds due to the presence of these genes, meaning that farmers do not have to incur additional expense in ameliorating the negative effects of heat stress. The demonstrated impact is increased egg production from 230–270 to about 295 eggs per annum (based on the current rate of lay of 80.7% for the birds with the heat-tolerant traits). The potential impact is increased incomes for the poultry farmers; this will in turn contribute to poverty reduction. And since birds with the heat-tolerant traits are gradually becoming extinct as a result of cultural prejudices, their use is a way of preserving these tropically relevant local chicken genetic resources, thereby ensuring food security.

ACKNOWLEDGEMENTS

The researcher would like to express his profound appreciation to the management and staff of Akate Farms and Company Limited for donating the parent birds for the project. Thanks also go to the project supervisor (Dr S.O. Olympio) for guidance and direction. I am also heavily indebted to the University of Cape Coast for granting the scholarship to enable me to do the PhD.

REFERENCES


IDENTIFICATION OF QTL CONFERRING RESISTANCE TO ETHIOPIAN STEM RUST RACES OF *PUCCINIA GRAMINIS* f.sp. *TRITICICI* IN DURUM WHEAT

J.K. Haile¹,², A. Badebo², M.M. Nachit³ and M.S. Röder¹
ABSTRACT

As a result of the recent spread of a highly virulent race of *Puccinia graminis* f.sp. *tritici* (Pgt), Ug99 (TTKSK), stem rust is becoming a serious threat to wheat production in Ethiopia and East African countries. The objective of this study was to identify quantitative trait loci (QTL) regions conferring resistance to Ethiopian stem rust races of *P. graminis* f.sp. *tritici*. A total of 95 recombinant inbred lines were evaluated for resistance to stem rust for three consecutive years at two locations in Ethiopia and genotyped using 209 microsatellite markers. Using composite interval mapping, nine QTL regions conferring resistance to Ethiopian stem rust races including Ug99 were identified on chromosomes 1AL, 2AS, 3BS, 4BL, 5BL, 6AL, 7A, 7AL and 7BL. The markers that are closely linked to these QTL could be used for marker-assisted selection for resistance to stem rust in durum wheat.

In Ethiopia, durum wheat varieties are released for production without information on resistance genes against stem rust. As a result, the genes responsible for resistance in these varieties are not known. To identify stem rust resistance (*Sr*) genes present in Ethiopian durum wheat varieties, 22 varieties released during 1966–2009 were haplotyped with 17 molecular markers linked with genes *Sr*2, *Sr*13, *Sr*22 and *Sr*35. Most of the varieties showed haplotypes for *Sr*13 and *Sr*22. This study is the first report on the identification of *Sr* genes in Ethiopian durum wheat varieties based on linked molecular markers. It will therefore assist in the identification of varieties carrying resistant alleles that provide valuable genetic material for the development of new improved varieties in future breeding programmes.

KEY WORDS: BREEDING, MARKER-ASSISTED SELECTION, MOLECULAR MARKERS, UG99

AFFILIATIONS

1 Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben, Germany.
2 Ethiopian Institute of Agricultural Research, Debre-Zeit Centre, Debre-Zeit, Ethiopia.
3 International Centre for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.
INTRODUCTION

Wheat is one of the most important cereals worldwide. With the world population increasing and food security projected to become critical, improving wheat yield potential in the developing world remains a high priority (Duveiller et al., 2007). In Ethiopia, wheat is the third biggest crop, after tef (Eragrostis tef (Zucc.) Trotter) and sorghum (Sorghum bicolor (L.) Moench), in terms of both acreage and production volumes (CSA, 2010). Although Ethiopia is rich in genetic resources of tetraploid wheat and has suitable environments for wheat production, the country does not produce enough wheat to satisfy national demand. Nearly 1 million tons are imported annually, mainly on a concessional basis or as food aid (Joshi et al., 2011). The demand for durum wheat (Triticum durum Desf.) has steadily increased in recent decades in Ethiopia, in particular due to the emergence of many food-processing industries. However, the productivity of wheat has remained low (1.7 t/ha) due to biotic and abiotic stresses. Among the biotic factors, diseases, especially stem rust, play a significant role in yield reduction.

As a result of the recent spread of a new and highly virulent race of P. graminis f.sp. tritici (Pgt), Ug99 (TTKSK and its variants), stem rust is becoming a serious threat to wheat production. Ug99 spread to Kenya in 2001 and to Ethiopia in 2003. It has since been detected in Sudan, Yemen, Iran and South Africa (Nazari et al., 2009; Pretorius et al., 2010) (Figure 1). Similar trajectories from Ug99 sites in Iran can be the gateway for Ug99 migration to Afghanistan, Pakistan, Central Asia, the Caucasus or Russia (Singh et al., 2008). A major concern is that a significant proportion of global wheat germplasm is potentially at risk from race Ug99. Reynolds and Borlaug (2006) estimated that the risk area could measure around 50 million ha globally, i.e. about 25% of the world’s wheat area. The development

FIGURE 1: THE SPREAD OF PUCCINIA GRAMINIS f.sp. TRITICI RACE UG99 AND ITS DERIVATIVES

of lines offering adequate and durable resistance to race Ug99 presents a current research area to wheat scientists worldwide. The objectives of the study were first to identify QTL that confer resistance to Ethiopian stem rust races of *P. graminis* f.sp. *tritici* including Ug99, and secondly to identify *Sr* genes present in durum wheat varieties that were released in Ethiopia during the period 1966–2009.

**MATERIALS AND METHODS**

**Plant material and experiments**

A total of 95 single-seed descent-derived recombinant inbred lines (RILs) from the cross between two durum wheat cultivars – Kristal (susceptible) and Sebatel (resistant) to stem rust – were used for QTL mapping. A total of 22 durum wheat varieties that were released in Ethiopia during 1966–2009 and four varieties from the International Centre for Agricultural Research in the Dry Areas (ICARDA) were used for haplotype analysis. *Sr* gene-carrying differentials W2691SR13 (*Sr*13), SWSR22TB (*Sr*22), W3763–SR35 (*Sr*35) and Kingbird#1 (*Sr*2) (R.P. Singh, pers. commun.) were used as reference lines.

Seven field trials were carried out over three consecutive years (2008–10) at two wheat-growing locations (Debre-Zeit, 2000 m above sea level with black soil, and Denbi, 1800 m above sea level with light sandy soil) in Ethiopia. At Debre-Zeit, the materials were evaluated twice a year, during the main season (July–October, rainfed) and during the off-season (January–April, irrigated). So it was possible to expose the materials to Ethiopian stem rust races of *Pgt* present during either season. To facilitate and optimise the natural infection, the nursery was enclosed by spreader rows containing highly susceptible wheat varieties. In addition to the natural infection, the trial was also artificially inoculated with urediniospores of race Ug99 and bulk spores collected from durum and bread wheat nurseries and farmers’ fields.

**Data collection and analysis**

**Phenotyping**

The modified Cobb scale (Peterson *et al.*, 1948) was used to measure stem rust severity in the field. The percentage of tissue infected with stem rust (0–100%) and the infection response (S, MS, MR and R, corresponding to susceptible, moderately susceptible, moderately resistant and resistant) were recorded.

**Molecular marker analysis**

Genomic DNA was isolated from pooled leaves of six plants of 15-day-old seedlings using the modified CTAB method described by Doyle and Doyle (1990). Polymerase chain reaction (PCR) and amplifications of simple sequence repeat (SSR) markers [Gatersleben wheat microsatellite (gwm), Wheat Microsatellite Consortium (wmc) and Beltsville Agriculture Research Centre (barc)] and fragment detection were performed as described by Röder *et al.* (1998). Fragment sizes were calculated using Fragment Analyzer version 1.02 (Amersham Biosciences).

The parents were screened for polymorphism using 502 wheat microsatellite markers (gwm, wmc and barc) previously mapped on the A and B genomes. Polymorphic markers between the parents Kristal and Sebatel were screened for all the RILs. A reference linkage map was created using Mapmaker version 2.0. The final genetic map used for QTL analysis was based on 209 polymorphic markers.

**QTL analysis**

Composite interval mapping (CIM) options in QTL Cartographer version 2.5 were used to detect the QTL. In addition to analysis based on single environments, QTL were identified across environments using estimated best linear unbiased prediction (BLUP). QTL were verified by logarithm of odds ratio (LOD) scores compared to an empirical genome-wide significance threshold calculated from
1000 permutations. The names of the QTL were assigned according to the International Rules of Genetic Nomenclature (McIntosh et al., 1998): e.g. QSr.ipk is QTL for resistance to stem rust detected at the Leibniz Institute of Plant Genetics and Crop Plant Research (IPK).

**Haplotype analysis**

A total of 17 PCR markers [SSRs, InDels (insertion–deletion polymorphisms) and EST (expressed sequence tags)] that are linked with Sr2, Sr13, Sr22 and Sr35 were used for haplotype analysis. PCR and amplifications of these markers were performed using procedures described at MAS Wheat (undated) and by Yu et al. (2010).

**RESULTS**

**QTL analysis of stem rust resistance**

Based on genetic mapping results using the Kristal × Sebatel population, stem rust is affected by nine additive QTL interactions, which did not interact with the environments. Sebatel carries favourable alleles at all QTL (Haile et al., 2012a). The summarised results of composite interval mapping (CIM) are presented in Table 1.

**Haplotype analysis of markers linked to known Sr genes**

Haplotypes were sorted for each stem rust resistance gene (Sr) by the size of their fragments. Similar haplotypes for each gene were grouped together and compared to the original source of the gene based on the check lines (Haile et al., 2012b). GWM533 and BARC133, two markers associated with Sr2, amplified a fragment size of 120 and 122 bp, respectively in Sebatel, Hitosa and in the Sr2 containing line Kingbird1. Markers BE403950, DUPW167, WMC580, BARC104b and BARC104c were used for haplotyping Sr13 in this study. The Sebatel, Quamy, Boohai, Cocorit71 and Cham1 varieties showed a haplotype for this gene based on the check line W2691SR13. CFA2019, CFA2123, WMC633 and BARC121 were used to haplotype the

<table>
<thead>
<tr>
<th>Chromosome</th>
<th>Marker interval</th>
<th>Interval size (cM)</th>
<th>LOD</th>
<th>R² (%)</th>
<th>Designation</th>
<th>Q × E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1AL</td>
<td>Xbarc148 – Xarc119</td>
<td>16.1</td>
<td>3.7</td>
<td>5.0</td>
<td>QSr.ipk-1A</td>
<td>NS</td>
</tr>
<tr>
<td>2AS</td>
<td>Xgwm448 – Xgwm1198</td>
<td>13.5</td>
<td>3.9</td>
<td>6.0</td>
<td>QSr.ipk-2A</td>
<td>NS</td>
</tr>
<tr>
<td>3BS</td>
<td>Xgwm779 – Xgwm389</td>
<td>9.6</td>
<td>8.6</td>
<td>34.0</td>
<td>QSr.ipk-3B</td>
<td>NS</td>
</tr>
<tr>
<td>4BL</td>
<td>Xgwm1167 – Xgwm1278</td>
<td>8.5</td>
<td>3.8</td>
<td>11.9</td>
<td>QSr.ipk-4B</td>
<td>NS</td>
</tr>
<tr>
<td>5BL</td>
<td>Xgwm408 – Xbarc142</td>
<td>27.1</td>
<td>3.7</td>
<td>5.4</td>
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<td>NS</td>
</tr>
<tr>
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<td>Xgwm494 – Xgwm1150</td>
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<td>6.5</td>
<td>9.3</td>
<td>QSr.ipk-6A</td>
<td>NS</td>
</tr>
<tr>
<td>7A</td>
<td>Xgwm974 – Xgwm631</td>
<td>14.5</td>
<td>3.9</td>
<td>5.1</td>
<td>QSr.ipk-7A.1</td>
<td>NS</td>
</tr>
<tr>
<td>7AL</td>
<td>Xbarc121 – Xgwm984</td>
<td>10.2</td>
<td>3.4</td>
<td>7.3</td>
<td>QSr.ipk-7A.2</td>
<td>NS</td>
</tr>
<tr>
<td>7BL</td>
<td>Xgwm146 – Xgwm344</td>
<td>24.9</td>
<td>7.3</td>
<td>12.6</td>
<td>QSr.ipk-7B</td>
<td>NS</td>
</tr>
</tbody>
</table>

LOD, logarithm of odds ratio, maximum of QTL peak; interval size (cM), support interval of the QTL in cM after starting point of mapping; R² (%), percentage of phenotypic variance explained by the QTL; E, environment; NS, non-significant.
Sr22 locus. Only CFA2019 amplified a haplotype fragment size in Sebatel, Boohai, Mamouri and JennahKhetifa in reference to check line SESR22TB. CFA2193, CFA2170, GWM480, BE423242, BF485004 and BE405552 were employed to haplotype Sr35. Using these markers, no variety showed a haplotype for this gene.

DISCUSSION AND CONCLUSION

In the first study, nine QTL that confer resistance to Ethiopian stem races of Pgt, including race Ug99 were identified. Pozniak et al. (2008) and Kaur et al. (2009) have reported QTL regions that were significantly associated with resistance to stem rust races of Pgt including Ug99 using different germplasm in some of the reported regions (2AS, 3BS, 4B, 5BL and 7BL). QTL for this trait were identified in this study. Two QTL regions, QSr.IPK-3B and QSr.IPK-7A.2, were identified in the region where Sr2 and Sr22, respectively, were reported.

The detected QTL regions on 1AL, 2AS, 4BL, 7A and 7BL did not possess previously characterised stem rust resistance genes of durum wheat, suggesting that durum wheat resistance to race Ug99 is oligogenic and that there is the potential to identify previously uncharacterised resistance genes of minor effect. Additionally, these QTL have not previously been detected and are thus proposed to be putative new QTL offering resistance to stem rust. If successfully validated, the markers linked with these QTL will be useful for breeding new durum wheat varieties that are resistant to Ethiopian stem rust of Pgt, including Ug99.

Based on the results of the second study, the resistance to stem rust in Sebatel might be due to combinations of Sr2 and Sr22. The other resistant Ethiopian durum wheat varieties, Yerer, Ude and Gerardo, which also showed a moderate resistance to Ethiopian Pgt races including Ug99, might be due to Sr22; however, further evaluation is needed to determine the diagnostic value of these haplotypes.

As this study is the first report on the identification of Sr genes in Ethiopian durum wheat varieties based on linked molecular markers, it gives some preliminary information for further research and provides useful information for Ethiopian wheat breeders.

The findings of the first study offer important perspectives for the transfer of stem rust resistance to new varieties by marker-assisted selection (MAS), as three or more loci from the Sebatel variety confer almost total and durable resistance to stem rust, including race Ug99. Sebatel has good yield performance and high grain quality, therefore it could be used as a donor variety to transfer stem rust resistance to new genotypes via MAS without the risk of introducing undesired traits together with the resistant gene(s). Therefore it is particularly applicable with the current state of world affairs and with the initiation of the Borlaug Global Rust Initiative to combat the potential threat that stem rust race Ug99 poses to a large percentage of world wheat germplasm. With low numbers of reported resistant varieties offering resistance to Ug99, markers closely linked to QTL conferring resistance for stem rust could help combat local and global threats from Ug99 and new virulent races.

The findings of the second study have the potential to indicate that the durum wheat varieties released in Ethiopia during the past 43 years do not carry diverse Sr genes that are resistant to the new races of stem rust. It was also confirmed in another study that these durum wheat varieties are genetically similar (Haile et al., 2012c). Therefore these results emphasise the need to broaden the genetic base of the varieties that will be released in the future to help durum wheat farmers to become more productive and secure.
COMMUNICATION STRATEGY AND IMPACT

The results of these studies were presented at wheat workshops and conferences. In addition, they feature in the Annual Wheat Newsletter and have been published in scientific journals (Haile et al., 2012a,b).

ACKNOWLEDGEMENTS

The authors are thankful to the Ethiopian Institute of Agricultural Research, IPK at Gatersleben and the German Academic Exchange Service (DAAD) for their contribution to the success of the studies. The first author is particularly thankful to Dr Marion Röder for the opportunity to conduct this research in her lab with scientific freedom and continuous scientific guidance, and for her personal kindness.

REFERENCES


LANDSCAPE-SCALE MANAGEMENT OF INVASIVE CYMBOPOGON AFRONARDUS (STAPF.) IN THE RANGELANDS OF UGANDA

S. Kabiri¹, C. Ebong², P. Kudsk⁴, S.K. Mathiassen⁴, P. Lusembo³, G.S. Byenky¹, H. Kasigwa⁵ and R. Kabanyoro³
ABSTRACT

Cymbopogon afronardus (Stapf.) is an invasive species which continues to spread over grazing areas of Uganda. Its magnitude and potential threat to rangeland ecosystems has not been established. Conversely, it can be harnessed positively to provide solutions for resource-poor farmers and pastoralists in the form of a potential bioherbicide. The objective of this study was to (1) determine the current extent of the invasion in acreage of Cymbopogon in the rangelands; (2) evaluate its landscape characteristics and the ecological impact on threatened vegetation; and (3) identify the allelopathic properties of Cymbopogon oil extracts and its potential in bioherbicide/pesticide formulations. Remote sensing and GIS techniques were used to estimate its spatial distribution and habitat characteristics. Results showed that the land cover was 9,293.6 km², equating to 11% of the rangelands. It is topographically concentrated on north-facing, steep slopes and prefers open canopy savannah. The allelopathic properties of Cymbopogon’s oil extract on seed germination and growth of Lolium perenne and Cyperus rotundus were assessed to determine the weed’s bioherbicidal properties. At all doses, both C. rotundus and L. perenne’s germination percentage, germination index, root length and vigour index were significantly different from the control (water). Cymbopogon invasion can permanently change an ecosystem structure and is likely to generate significant, negative economic consequences on the rangelands, but can be utilised as a potential bioherbicide.

KEY WORDS: ALIEN SPECIES, CATTLE CORRIDOR, ECOLOGY, GRASSLANDS, VOLATILE OILS

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INTRODUCTION

Invasive plant species reduce native plant diversity and abundance by reducing the value of land and water for human activities (Mooney, 2005). In Uganda, some of the rangelands and forest represent valuable reserves for intact plant communities, but have been overtaken by invasive alien plant species. Among them, *Cymbopogon afronardus* (Stapf.) has been recognised as an aggressive invader (Byenkya, 2004). This species continues to spread to other parts of the country, yet its magnitude and potential threat to the fragile rangeland ecosystems have not been established.

*Cymbopogon afronardus* (henceforth referred to as *Cymbopogon*) is a tussock grass that establishes from seed with leaves that contain aromatic oils (Koffi *et al.*, 2009). Its foliage has a rough texture, and it is unpalatable to both domestic and wild herbivores (Harrington, 1974). It is fast-growing and builds up thick, coarse vegetation that suppresses the germination and growth of other herbaceous plant species (Byenkya, 2004). The role of allelopathy in suppressing other plant species has not been verified. Essential oils from other *Cymbopogon* species have herbicidal properties (Paudel and Gupta, 2008) which have not been confirmed in *C. afronardus*. Hence the weed is a potential raw material for commercial bioherbicides and other pesticides. Accordingly the weed is a high-value bio-resource that can benefit poor farmers and pastoralists as managers of rangeland ecosystems. These formed the basis of this study, which aimed to (1) determine the current invasion in acreage of *Cymbopogon* in the rangelands; (2) evaluate its landscape characteristics and the ecological impact on threatened vegetation; and (3) evaluate the allelopathy in *Cymbopogon* oil extracts and its potential for use in bioherbicide/pesticide formulations.

METHODOLOGY

Study area

The rangelands in Uganda, usually referred to as the ‘cattle corridor’, cover an area measuring an estimated 84,000 km². Data were collected in Kiruhura district (00°12´S, 31°00´E), which measures 4103.5 km². The area comprises Lake Mburo National Park (260 km²), cattle ranches and pastoral households. The vegetation type is an *Acacia–Cymbopogon/Themeda triandra* savannah complex, characterised by burning and grazing. The topography consists of undulating hills and valleys separated by broad drainage lines at an altitude of 1375–1525 m. Mean annual rainfall is estimated to be between 760 and 1270 mm. The average temperature is 27.5°C, with daily variation ranging from 21.5 to 34.0°C. Dominating soil types are ferrasols, histosols, vertisols and leptosols.

Spatial distribution of *Cymbopogon* in the rangelands of Uganda

The landscape was sampled in 20 clusters of five units with a 15-m radius whose centres were spaced 120 m apart. A sample unit covered an area measuring 707 m². In these units, the vegetation selected was characterised by at least 85–100% basal cover of *Cymbopogon*. A sensitive handheld global positioning system (GPS) with 1-m accuracy was used to record the locations. Remote sensing data were obtained from the Global Land Cover Facility (GLCF) [www.landcover.org](http://www.landcover.org). A Landsat 7 Thematic Mapper (TM) satellite image was acquired on 5 June 2009. The image had a spatial resolution of 25-m pixel size and an area coverage of 185 × 172 km. ERDAS Imagine 2010 and ArcGIS 2010 software was used to identify the land cover of *Cymbopogon* and major vegetation types. Spectral signatures of the weed were generated using the supervised classification technique and maximum likelihood classifier (Cuneo *et al.*, 2009). The signatures were used to map the weed’s infestation along the cattle corridor.
Landscape characteristics and ecological impact of *Cymbopogon*

The *Cymbopogon* distribution map generated was overlaid with the FAO vegetation distribution data set of western Uganda (FAO-Africover, 2003) in a GIS environment. Quantitative analysis using spatial cross-tabulation was used to determine the conservation threat and extent of *Cymbopogon* in the rangelands and associated vegetation. The digital data were also used to derive quantitative information on the landscape characteristics of *Cymbopogon* using the ArcGIS Spatial Analyst. Digital terrain model (DTM) data at a 25-m resolution were used to produce slope and aspect layers, and the mean slopes. The various vegetation communities were derived using zonal statistics. The spatial distributions of *Cymbopogon* infestations across eight aspect classes (N, NE, E, SE, S, SW, W and NW) were examined.

Allelopathic effects of *Cymbopogon* on the germination of rangeland weeds

A volatile oil was extracted from 1 g of sliced and air-dried *Cymbopogon* leaves using 10 ml ethanol (70% v/v). The mixture was left to macerate for 15 days, after which the extract was filtered and dilutions prepared. The first dilution, 1 cH, was prepared from 0.2 ml of extract in 100 ml distilled water. Serial dilutions (v/v) of 0.6, 1.2, 2.4, 4.8 and 6% (v/v) were made by adding to the mark (100 ml) with distilled water in volumetric flasks. The dilutions corresponded with treatment concentrations 3, 6, 12, 24 and 30 cH, respectively. Forty-two Petri dishes were assembled and covered with filter paper (Whatman No. 1). The filter paper was saturated with 2 ml of each dilution of extract in six replicates in a complete randomised design. The control was the same volume of distilled water. Twenty-five seeds of both *Cyperus rotundus* and *Lolium perenne* were spread on filter paper and allowed to germinate at room temperature.

Germination variables for *L. perenne* and *C. rotundus* were recorded at 5 and 7 days, respectively. The parameters recorded included percentage of germination, germination index, root and shoot lengths (mm), dry biomass weight (g) and growth vigour index. These were calculated as described by the Association of Official Seed Analysts (AOSA, 1983).

Data were analysed by general linear model:

\[ Y_{ij} = \mu + T_i + \varepsilon_{ij} \]

where \( Y_{ij} \) is the \( j \)th observation of the \( i \)th treatment; \( \mu \) is the population mean; \( T_i \) is the treatment effect of the \( i \)th treatment; and \( \varepsilon_{ij} \) is the random error.

**RESULTS**

Spatial distribution

Spectral signatures for *Cymbopogon* dissimilar from grasslands and forest areas at different wavelengths were distinguished as shown in Figure 1(a). At near-infrared wavelengths, *Cymbopogon* had similar reflectance values to forests, while grasslands had higher brightness values. In the mid-infrared wavelengths, *Cymbopogon* had the least reflectance values, thus distinguishing the weed from other vegetation because of its high water content. Reflectance at mid-infrared wavelengths is negatively correlated with water content in the plant (Carter, 1991). Dense *Cymbopogon* at landscape scale with a commission error of 5.7% and an omission error of 7% were accurately mapped.

The overall accuracy of 83% was achieved in the analysis, which showed that in 2009, the spatial distribution of *Cymbopogon* was about 9294 km², equating to 11% of the rangelands in Uganda (Figure 1b). The total area of dense *Cymbopogon* infestation mapped in Kiruhura district alone was about 2514 km², constituting 61.3% of the total land cover of the district (Figure 1c).
Landscape characteristics and ecological impact

Slope and aspect analysis revealed a greater prevalence of *Cymbopogon* (75.8%) on north-facing steep slopes, and barely 0.1% in flat areas (Table 1). The overlay of the distribution on the digital terrain model (DTM) in Figure 2 indicated this phenomenon in Lake Mburo National Park. Linear regression of *Cymbopogon* cover with other vertical-standing vegetation (including pasture grasses and the invasive species *Acacia* spp. and *Lantana camara*) showed a weak but significantly ($P < 0.05$) negative relationship. The overall distribution of *Cymbopogon* within different vegetation types in the landscape of Kiruhura was 21.7, 20.8 and 16.8% in the closed to open woody vegetation, closed to open herbaceous vegetation, and savannah grasslands, respectively.

Allelopathic properties

The germination percentage, germination index, root length and vigour index of *C. rotundus* and *L. perenne* were significantly ($P < 0.05$) different from the control (water) at all doses (Table 2). For *C. rotundus*, root growth was more sensitive than shoot growth, while for *L. perenne*, growth parameters were more sensitive than germination to these volatile oils.

Letters refer to significance according to Duncan’s multiple comparison test: if letters are similar, the results are not significantly different at $P < 0.05$.  

**FIGURE I:** (a) REFLECTANCE VALUES FOR *CYMBOPOGON*, FOREST AND GRASSLAND; THE WIDTH OF EACH REFLECTANCE VALUE CURVE ILLUSTRATES THE MEAN REFLECTANCE VALUE $\pm 1$ SD FOR EACH LANDSAT BAND. (b) DISTRIBUTION OF *CYMBOPOGON* IN THE CATTLE CORRIDOR. (c) LAND COVER OF *CYMBOPOGON* IN KIRUHURA DISTRICT.
### Table 1: Results of Aspect Analysis of Cymbopogon in Kiruhura

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Slope angle (%)</th>
<th>Overall distribution of Cymbopogon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>2–5</td>
<td>0.1</td>
</tr>
<tr>
<td>North</td>
<td>6–9</td>
<td>0.4</td>
</tr>
<tr>
<td>North-east</td>
<td>10–13</td>
<td>1.5</td>
</tr>
<tr>
<td>East</td>
<td>14–17</td>
<td>2.2</td>
</tr>
<tr>
<td>South-east</td>
<td>18–21</td>
<td>2.9</td>
</tr>
<tr>
<td>West</td>
<td>22–25</td>
<td>6</td>
</tr>
<tr>
<td>North-west</td>
<td>26–29</td>
<td>11.2</td>
</tr>
<tr>
<td>North</td>
<td>30–32</td>
<td>75.8</td>
</tr>
</tbody>
</table>

### Table 2: Effect of Concentrations of Cymbopogon Volatile Oils on Growth of C. rotundus and L. perenne

<table>
<thead>
<tr>
<th>Dose (cH)</th>
<th>G (%)</th>
<th>GI</th>
<th>DW</th>
<th>Shoot length</th>
<th>Root length</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyperus rotundus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>54</td>
<td>a</td>
<td>8.55 a</td>
<td>0.0015 a</td>
<td>1.53 a</td>
<td>1.23 a</td>
</tr>
<tr>
<td>3</td>
<td>31.33 b</td>
<td>2.53 b</td>
<td>0.0015 a</td>
<td>1.23 a</td>
<td>0.9 b</td>
<td>40.47 b</td>
</tr>
<tr>
<td>6</td>
<td>17.33 c</td>
<td>0.81 c</td>
<td>0.0046 a</td>
<td>0.63 b</td>
<td>0.27 c</td>
<td>19.47 c</td>
</tr>
<tr>
<td>12</td>
<td>4.67 d</td>
<td>0.13 c</td>
<td>0 a</td>
<td>0 c</td>
<td>0 d</td>
<td>0 d</td>
</tr>
<tr>
<td>24</td>
<td>0 d</td>
<td>0 c</td>
<td>0 a</td>
<td>0 c</td>
<td>0 d</td>
<td>0 d</td>
</tr>
<tr>
<td>30</td>
<td>0 d</td>
<td>0 c</td>
<td>0 a</td>
<td>0 c</td>
<td>0 d</td>
<td>0 d</td>
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<tr>
<td>Lolium perenne</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>a</td>
<td>17.6</td>
<td>4 a</td>
<td>0.027 a</td>
<td>4.42 a</td>
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<td>396.9 a</td>
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<tr>
<td>0</td>
<td>90</td>
<td>a</td>
<td>17.6</td>
<td>0.027 a</td>
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<td>76</td>
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<td>0.026 a</td>
<td>2.95 b</td>
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<tr>
<td>6</td>
<td>75.33 c</td>
<td>14.03 b</td>
<td>0.025 a</td>
<td>1.67 c</td>
<td>1.87 c</td>
<td>126.8 c</td>
</tr>
<tr>
<td>12</td>
<td>50</td>
<td>d</td>
<td>11.97 c</td>
<td>0.01 a</td>
<td>0.17 d</td>
<td>0.68 d</td>
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<tr>
<td>24</td>
<td>0 d</td>
<td>2.51 d</td>
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<td>0 d</td>
</tr>
<tr>
<td>30</td>
<td>0 d</td>
<td>0.61 d</td>
<td>0 a</td>
<td>0 e</td>
<td>0 e</td>
<td>0 d</td>
</tr>
</tbody>
</table>

LOD, logarithm of odds ratio; maximum of QTL peak; interval size (cM), support interval of the QTL in cM after starting point of mapping; $R^2$ (%), percentage of phenotypic variance explained by the QTL; $E$, environment; NS, non-significant.
Maps produced from satellite imagery confirmed that landscape-scale infestations of *Cymbopogon* are now well established in the Ugandan rangelands. There are no tangible data sets to compare with previous infestations. However, Ford and Clifford (1968) reported that after a temporary evacuation in the 1960s due to tsetse flies in the area, pastoralists found that *Cymbopogon* had covered an estimated 40% of the ground cover on their return. The change in the grazing patterns during that period, induced by depopulation of the area, could have been responsible for the increase in the species.

*Cymbopogon* species, like many savannah grasses, successfully maintain themselves (in terms of biomass and number) in overgrazed ecosystems by producing large quantities of seeds (Veenendaal et al., 1996). The distinct patterns in the distribution of *Cymbopogon* in the region showed its greatest abundance on open-canopy savannah and north-facing steep slopes. This could be attributed to its preference for the less eroded, nutrient-rich soil creep. This is in contrast to much greater rates of surface run-off on south-facing slopes (Istanbulluoglu et al., 2008). The weed’s preference for open-canopy savannah and its distinctly negative relationship with other standing vegetation confirm the aggressiveness of its invasive nature. More studies will be required to link its ecology and the mechanisms through which it impacts on ecosystem functions while facilitating its success. Its wide and successful distribution in the cattle corridor may be attributed to the lack of natural enemies, reduced competition and rangeland burning. This study confirmed that *Cymbopogon* does have an allelopathic effect on other herbage. There were differences in sensitivity between species, but even at very low concentrations, *Cymbopogon* essential oils were very potent. *Cymbopogon* can thus be used to inhibit the emergence of important weeds such as *Cyperus rotundus*, making it potentially useful as a bioherbicide or mulch. Research into the formulation of *Cymbopogon* oils is still required before this technique can be applied to agriculture.
COMMUNICATION STRATEGY AND IMPACT

The extent of Cymbopogon invasive ability to permanently change ecosystem structure is strong evidence to support its nomination as a ‘key threatening process’ under state legislation. Thus the objective of the communication strategy was to raise awareness of the extent to which the invasive weed had covered Kiruhura district and the cattle corridor. The audiences targeted were pastoralists, farmers, extension workers, government officials, nature conservation officials and rangeland management experts. GIS-derived maps showing the current spread of the weed were displayed. PowerPoint presentations and leaflets in both English and local languages were handed out. These data sets were submitted to the National Agricultural Research Organisation (NARO) and the Ministry of Agriculture Animal Industry and Fisheries (MAAIF). They were used to aid the drafting of the national invasive species strategy, action plan and policy guidelines. The guidelines will be contained in a report entitled Risk Analysis Procedures, Early Detection and Rapid Response Systems for Quarantine Authorities.

A report was also submitted to ENDURE Network (www.endure-network.eu), a major source of information that provides a platform for knowledge exchange regarding all aspects of integrated pest management. The impact of this study is that it contributed to the achievement of the seventh Millennium Development Goal, to ensure environmental sustainability. In this respect, it quantified the state of the environment of Uganda’s rangelands in regard to the invasiveness of Cymbopogon. The success of Cymbopogon detection and landscape characterisation from the Landsat imagery established a basis for a landscape-scale regional control strategy and a baseline for monitoring future spread.

ACKNOWLEDGEMENTS

The authors are grateful to the EU FP6 Network of Excellence ENDURE for providing a scholarship, the Danish International Development Agency (DANIDA) under the Livestock Systems Research Programme (LSRP) of the Agricultural Sector Programme Support (ASPS), the Government of Uganda (GOU) and the World Bank’s International Development Assistance (IDA) for funding this research.

REFERENCES


AN EMPIRICAL ANALYSIS OF TISSUE CULTURE BANANA ADOPTION AND IMPACTS IN KENYA

N.S. Kabunga*
ABSTRACT

Agricultural technologies offer a great range of opportunities for development, but the rate and scale of their adoption, especially in sub-Saharan Africa, have remained persistently low. The objective of this study was to demonstrate that, when robust analytical methods are applied, the problem of low adoption ceases to be intrinsic to the technology itself, but rather is due to insufficient information dissemination and inadequate infrastructure. Using a concrete example of tissue culture (TC) bananas as opposed to conventional suckers, this study found that TC adoption rates by smallholder farmers in Kenya were significantly increased when there was uniform exposure to knowledge about the technology. Women farmers were more likely to adopt TC if they had equal access to knowledge. The study further established that TC increased banana yields by 7%, which could be increased by up to 20% with irrigation instead of rainwater. Tissue culture bananas contributed to increasing the income and food security of the more destitute households in the sample. It can be concluded that methodological pluralism should be used to empirically identify the most notable adoption constraints and the impact of technology on productivity and household welfare outcomes.

KEY WORDS: ADOPTION, BIOTECHNOLOGY, IMPACT ASSESSMENT, KENYA, TISSUE CULTURE, WELFARE OUTCOMES

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INTRODUCTION

There is general consensus among development researchers and policy-makers that the potential for future poverty reduction in developing countries is highly dependent on the generation and transmission of new and adaptable technologies to millions of smallholder farmers (Hazell, 2005; Lipton, 2006). Apparently, a variety of these and other related technologies – spanning seeds and production, soil and water conservation, marketing and product quality – have been developed and are readily available for potential uptake (FAO, 2011). However, the rate and scale of uptake of these technologies is generally lower than expected (Suri, 2011). Adoption rates are much lower in sub-Saharan Africa (Gollin et al., 2005; Moser and Barrett, 2006; Diagne and Demont, 2007; Dercon and Christiaensen, 2011; Suri, 2011). This region is in need of rapid agricultural development, enhanced food production and poverty alleviation. Several discrete studies increasingly show that investment in new agricultural technologies positively impacts on smallholder farmers in Africa and beyond (de Janvry and Sadoulet, 2002; Gollin et al., 2002; Qaim and Zilbermann, 2003; Jama and Pizarro, 2008; FAO, 2011). However, the general understanding of these effects remains hampered by a limited number of robust economic studies for informed up-scaling efforts and decision-making.

In particular, most new technologies require that farmers substantially alter traditional production practices in order to make significant gains – a process that requires access to information and other complementary input resources. The failure of existing studies to provide empirical evidence on information access and use, as well as other related institutional constraints, including the role of complementary inputs in the adoption process, limits wider use in policy-making. Moreover, it is reasonable that impact studies should address broader welfare outcomes, including the net effects of new technology adoption on household income and food security, which is rarely considered. Although relatively more empirical evidence is available for income effects, little is known about the actual effects of new technology on improving household food security. The latter could be partly due to the conceptual complexities and costs involved in defining and estimating food security at the household level (Webb et al., 2006; Barrett, 2010; de Haen et al., 2011).

Tissue culture banana plantlets, which are often free from soilborne pests and diseases (Dubois et al., 2006), were first introduced in East Africa in the late-1990s (Qaim, 1999), but have not yet been widely adopted. While field trials demonstrate significant yield advantages over traditional banana suckers (Robinson et al., 1993; Wambugu and Kiome, 2001), there is some debate surrounding the potential of TC banana and actual benefits for farmers (Mbogoh et al., 2003; Muyanga, 2009; Njuguna et al., 2010). In addition to bananas, TC technology is gaining importance in a number of other vegetatively propagated crops in Africa (Obembe, 2010).

Using the case of TC banana technology in Kenya, this study rigorously investigated adoption behaviour outcomes of a relatively knowledge- and input-intensive technology, before relaying the actual impacts of technology on enterprise productivity and welfare outcomes. The main objective was to advance the understanding that agricultural technologies are often not widely adopted due to individual and institutional constraints in technology dissemination.

To achieve this, three sets of research questions (RQs) were addressed as follows:

(1) What are the determinants of TC banana adoption among farmers? What are the determinants of information exposure, and how do differences in information exposure influence adoption determinants at the individual level and adoption rates at the population level?
(2) How does TC technology impact on banana productivity? Do heterogeneous differences in individual behaviour and farm characteristics jointly determine TC productivity effects? If yes, what are these factors and to what extent do they potentially influence productivity?

(3) How does TC banana technology impact on broader welfare outcomes: farm and household income and food security? Can simple qualitative tools for food security assessment be adapted and used for quantitative impact evaluation?

Essentially, the analytical approach developed and applied here, and the lessons derived, may also be useful for the evaluation of other knowledge-intensive package technologies and innovations in perennial crops. The paper highlights the key findings of a recent doctoral thesis (Kabunga, 2011).

**METHODOLOGY**

**Sampling methods and data**

Primary data were collected from 385 smallholder banana farmers in the central and eastern Kenyan provinces. The selection was made using TC plantlet distribution information from the major TC implementing agencies in Kenya. The sample featured 223 farmers who had adopted TC banana technology (TC adopters) and 162 farmers who continued to grow conventional banana suckers (non-TC adopters). The survey was conducted in late 2009. Each household was interviewed by a trained enumerator with ample knowledge of the local conditions, cultures and languages, using a pre-tested questionnaire. The questionnaire also included a qualitative tool, the household food insecurity access scale (HFIAS), to explore household food security indicators. Both qualitative and quantitative data were collected on a wide range of topics, including household composition; agricultural information sources; land resources and access; banana enterprise, cultivation practices and plantation management; detailed use and pattern of TC plantlets; and additional institutional backstopping. At the end of each activity day, the data collected were checked for missing entries, mistakes and conformity.

**Conceptual framework and empirical analysis**

**Heterogeneous information exposure and technology adoption**

In classical technology-adoption models, homogeneous information flow across potential adopters is implicitly assumed. However, due to the information access constraints faced by farmers in developing countries, this may simply be unrealistic. Heterogeneity in information exposure is likely, which may lead to selection (or exposure) bias in adoption parameters at both the individual and population levels (Diagne and Demont, 2007). To answer RQ1, this study employed classical analytical approaches alongside the average treatment effects (ATE) framework. The latter, common in modern impact evaluation literature (Rubin, 1973; Greene, 2003; Imbens and Wooldridge, 2009), but which has not been widely applied in adoption studies, accounted for potential selection bias and consistently estimated adoption determinants at the individual level and adoption rates at the population level (Diagne and Demont, 2007).

Further analysis investigated the changes to adoption parameters when explicit differentiation was made between awareness exposure (having heard of a technology) and knowledge exposure (understanding the attributes of a technology). This approach was relevant for TC bananas in Kenya because a fraction of potential adopters were informed of TC activities (Njuguna et al., 2010). In addition, the approach estimated the adoption gap caused by non-exposure to information. While the role of information diffusion has been widely documented in adoption studies (Rogers, 2003; Foster and Rosenzweig, 2010), no empirical analysis had explicitly demonstrated its influence on adoption
parameters. The analysis considered different levels of information exposure to have varying effects on adoption outcomes, and drew fine lines between adoption outcomes as a result of awareness or knowledge exposure.

**Impacts of TC banana technology**

For TC adopters, the benefits were usually expected to be due to either the intrinsic potential of the technology itself; the change in input use patterns and decisions; or simply that adopters and non-adopters are naturally endowed with different production potentials (Barrett *et al*., 2004; Winters *et al*., 2011). Modelling approaches that accounted for selection bias and properly captured the net effects of TC adoption on enterprise productivity and welfare outcomes of interest (farm income, household income and food security) were employed. Among the ordinary approaches were those that assume common slope coefficients across categories in pooled data samples, imposing a simple dichotomy between adopters and non-adopters (a parallel dummy shifter) (Wooldridge, 2002; Deaton, 2010). The modelling approach, however, becomes complex when the non-distinct regime assumption is overruled. This may have occurred if farm and farmer heterogeneity potentially had systematic influences on the coefficients of the individual variables, rather than just leading to a parallel shift. To model such complex processes, endogenous switching regression (ESR) models were suggested (Maddala, 1986).

**Tissue culture effect on banana productivity**

The ESR approach was employed in a Cobb–Douglas production function framework. Given that TC adoption requires changes in traditional production methods, ESR approaches were considered appropriate to account for selection bias and to cater for structural differences that might have existed across adopter and non-adopter regimes. The analysis used data collected on banana enterprise input–output relationships, household and other contextual characteristics (Kabunga, 2011). ESR approaches could allow different variable specification across regimes, but could also inform policy in terms of TC’s effects on marginal productivity of different inputs (covariate interactions) across adopter and non-adopter regimes. Moreover, this study used ESR to predict TC effects under assumed but practical policy change scenarios to synthesise major implications. In particular, conditions of full access to irrigation and exposure to agricultural extension information were assumed to predict banana yield outcomes, a method not used before in this manner.

**Tissue culture effect on welfare outcomes – incomes and food security**

The treatment-effects modelling approach (Greene, 2003), which accounts for selection bias due to observed and unobserved factors, was used to assess the net effects of TC on farm and household income as well as food security outcomes. This part of the analysis used data that were collected on household and other contextual characteristics, as well as details of all of the household’s on-farm and off-farm income sources (Kabunga, 2011). To determine household food security levels, factor analysis was used to collapse and classify a number of qualitative responses from the HFIAS tool according to their correlations and structures. The regression-based indicators generated were then used as outcome variables representing two identified levels of household food insecurity. While studies linking agricultural technologies to household income effects were relatively available, fairly limited evidence existed for household food security. Considering that this might have been partly due to a lack of low-cost but operationally reliable food security measurement tools, the use of the HFIAS tool as applied presented a novel but relatively simpler approach to future household food security impact assessments.
RESULTS

The study showed that estimated adoption parameters differ a little from those of the classical adoption model when assessing only awareness exposure. However, parameters differed considerably when accounting for knowledge exposure. This was plausible: while many farmers had heard about TC technology, its successful use required significant changes in cultivation practices, and proper understanding was not yet widespread. Looking at individual variables, education, wealth, access to credit and agricultural information, among others, increased the likelihood of TC adoption. The gender of the household head, which is insignificant in the classical model, became significant in the ATE model that corrected for knowledge exposure, implying that women farmers were more likely to adopt TC if exposed to TC knowledge than their male counterparts. Although many adoption studies have reported that new agricultural technologies are adopted more by men than by women (Feder et al., 1985), the findings suggested that the reverse may be true when women have an equal opportunity to acquire appropriate knowledge about the innovation. This is important from a policy perspective, as banana farming in Kenya is predominantly a female enterprise.

Results further showed that TC adoption rates at the population level were higher with better access to information and knowledge. Specifically, this study found that adoption rates could increase by 28% if there was uniform exposure to knowledge about TC technologies (Kabunga et al., 2012a). This emphasises the importance of accounting for information exposure in adoption research. From a development policy perspective, the challenge was to promote wider access to information about suitable innovations.

With regard to the results of the impact of TC banana technology on productivity and broader welfare outcomes, descriptive analysis showed that there were no major differences in mean value comparisons of banana yields, as well as enterprise gross margins and farm and household incomes, between TC adopters and non-adopters. However, econometric analysis revealed a negative selection bias, implying that farmers with lower than average yields and incomes were more likely to adopt TC. This was plausible because the adoption of new planting material in a perennial crop such as banana involves a longer-term investment and a high set-up cost, which farmers in older and lower-yielding plantations were more willing to undertake. Controlling for this bias, results showed gains for TC adopters, achieving 7% net yield improvements as well as increasing farm and total household income by 153 and 50%, respectively. Further simulations demonstrated that yield effects could be up to 20% with increased irrigation intensities and improved access to agricultural information (Kabunga et al., 2012b, 2014).

With regard to food security, this study makes new methodological contributions by using the HFIAS. Employing factor analysis techniques, robust results were achieved. Building on derived HFIAS indices, TC adoption was found to reduce relative food insecurity by 0.21 and severe food insecurity by 0.26 index points (Kabunga et al., 2014). These results indicated that TC technology was welfare-enhancing for adopting households, but needed to be reinforced with appropriate technology delivery and support systems.

DISCUSSION AND CONCLUSION

Although this study focused on TC banana technology adoption in Kenya, its findings have wider implications for several other technologies in similar contexts. By and large, the study showed that tissue culture can have clear positive effects on the productivity and household welfare of smallholder farmers in developing countries. However, specific constraints must be addressed in order to promote widespread and full adoption.
In addition, rigorous analytical methods need to be deployed to unearth the empirical intricacies in adoption studies and demystify impact pathways for the adoption of new technologies that may be of optimal benefit to smallholder farmers. For instance, the study clearly showed that addressing information access inefficiencies improved TC adoption rates at the population level. In addition, the findings showed that women farmers were more likely to adopt technologies if they had equal access to appropriate knowledge exposure. This demonstrates that agricultural extension and training services should pay more attention to the needs of female farmers.

At a later stage in the study, simulation results showed that TC yield gains were significantly higher for adopters with no access constraints to agricultural information and complementary inputs, especially irrigation. Not only was the provision of irrigation infrastructure found to be essential, but so too were roads and communication systems. With growing populations and the increasingly variable climatic conditions in most parts of Africa, the dependence on rainfed agriculture poses major challenges for achieving food security and poverty alleviation. Implementing viable technical change in smallholder agriculture goes beyond developing new technologies; it is about finding the most feasible pathways to deliver existing technologies and intensifying information and knowledge dissemination to foster sustainable adoption and maximum benefits to farmers. As extension services are either very expensive, or ineffective, or both, new and more efficient models of innovation delivery have to be sought. Greater use could potentially be made of modern information and communication tools.

COMMUNICATION STRATEGY AND IMPACT

This work has been published as a PhD thesis. Technical excerpts have been published as peer-reviewed journal articles in Agricultural Economics and Journal of Agricultural Economics, while one article has been published as a discussion paper and is also under review at Food Policy. In the near future, part of this work will be summarised into policy briefs for the benefit of non-technical audiences. This paper has also been presented in local and international conferences to attract the attention of practitioners, scholars and policy-makers.

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RECOVERY OF URBAN SOLID WASTE IN LOMÉ: METHODOLOGICAL APPROACH TOWARDS SUSTAINABLE COMPOST PRODUCTION

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ABSTRACT

The various forms of treating waste aim at producing high-quality compost. Most developing countries have little or no experience in this regard. The aim of the project was to ensure the continuity of production of quality compost in Lomé, Togo. The composting sector tailored to local conditions was evaluated, from the generation of waste in households to the agricultural re-use stage. The information derived over two years and two seasons not only represents the first database on the type of waste produced in Lomé, but also provides a useful decision-making tool for local officials. Analysis by non-governmental organisations of the pre-collecting process helped to identify the most relevant performance indicators. The effectiveness and efficiency of the composting process were maximised in terms of the mass balance and quality of the compost. The open-field finished product tests provided findings for improving soils and crops. An informal, centralised sorting–composting platform (<20 T/day) model was recommended and rolled out in the light of the achievements made.

KEY WORDS: AGRICULTURAL RE-USE, HIGH QUALITY, LOCAL CONDITIONS, PERFORMANCE INDICATORS

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INTRODUCTION

The policy of burying waste in landfill sites or, where appropriate, engineered landfills, and forgetting about it, thereby creating a huge number of contaminated sites for future generations, is no longer a viable option. This fundamental change has served as a milestone for environmental protection. A better waste management system based on collecting all the waste generated by urban residents to recover the recyclable component and re-using the organic component for agricultural purposes should help to improve urban sanitation while adding economic value to the process for establishing sustainable development conditions (Wicker, 2000). However, the fact that developing countries are often unfamiliar with the basics of operating a waste processing and elimination system is attributable to the lack of precise knowledge about the physical and chemical characteristics of the waste in question (Charnay, 2005; Aina, 2006).

In the specific case of composting, over 100 plants were built in several countries in the period 1960–85, including many in developing countries: India, China, Indonesia, Brazil, Colombia and the Ivory Coast, for example. However, most of the plants are at a standstill or operating at a reduced capacity, and only a few are fully operational (Gillet, 1985). The composting plants in developing countries were generally based on imported ‘turnkey’ technologies. These sophisticated and very expensive systems were indicative of a lack of knowledge about the local character of the waste, hence the setbacks being reported (ANPE, 2000).

Waste management has not always been such a concern for Lomé (Togo), as is the case for other cities in developing countries. The municipality has been running several waste management projects, but there are still many rubbish dumps on the streets and in other parts of the city, including an old quarry in Agoenyivé. The aim of this project was to maximise the effectiveness and efficiency of the composting process in the light of local conditions.

The first stage of this four-phase study involved characterising the waste created in Lomé – this initial project phase made it possible to decide on a suitable type of processing. The second phase, the key element of the process, focused on experimental composting research. The third phase involved analysing various factors with a view to securing the sector’s future and sustainability. The fourth and final phase was concentrated on outreach efforts and drawing the communities’ attention to the issue of recovering organic waste via composting.

METHODOLOGY

Characterisation of the source

Characterisations were carried out for waste reaching the final disposal site and leaving households. A 500 kg sample was taken in each case according to the MODECOM method (the official French method) in order to minimise measuring errors (Aina, 2006).

Making compost

The swath composting system was used to ensure farmers could replicate the method. The quality of the compost was improved by adding certain types of local materials known to be rich in particular elements. These were natural phosphate, a phosphorus-rich mineral found in the country’s deposits, but one that is insoluble and hence cannot be used by plants when provided directly; manure as a source of nitrogen; and ashes as a source of potassium (Koledzi et al., 2011a).

Physico-chemical analyses

Essential elements for plants were assayed in the various types of compost: total nitrogen via the Kjeldahl method, total carbon via oxidation of the organic matter, and total phosphorus via colorimetry (Bustamante et al., 2008). The cations (K⁺, Cu²⁺, Zn²⁺, Mg²⁺, Ca²⁺ etc.) and metal pollutants were determined by atomic absorption spectroscopy (Bustamante et al., 2008).
Germination index, GI

The compost extract was prepared according to the DI.VA.P.R.A method, while the GI was calculated according to the Zucconi formula (Bustamante et al., 2008).

Leaching test

The test was performed according to a liquid/solid ratio of 8 (Koledzi et al., 2011b)

Agricultural tests

The effects of composts were investigated with both food (maize, Togo’s main food crop) and vegetable crops (cabbages, carrots, beets). The compost improvers were compared with the absolute control.

Statistics

Statistical parameters were deployed to analyse the findings. For each finding, an average mean $u$ and a standard deviation $s$ were calculated to determine the distribution and deviations in the values derived on the basis of the various methods used:

$$u = \frac{1}{n}\sum_{i=1}^{n}x_i$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - u)^2}{n-1}}$$

$$ES = \frac{\sum_{i=1}^{n}(x_i - u)^2}{\sqrt{n-1}}$$

The agricultural test findings are processed with a standard error (SE).

RESULTS

Figure 1 shows the physical composition of the waste at the final disposal site during the wet and dry seasons (Koledzi et al., 2011c).

Physico-chemical analyses

The analyses showed various levels of nutrients according to the composition of each compost.
variant. Accordingly, levels of organic carbon between 17–19%, nitrogen 0.7–1.9%, potassium 1–6% and phosphorus 0.3–4% were recorded. In order to assess the eco-toxicity of composts, certain metal trace elements were also investigated: lead 0.29–0.48‰, nickel: 0.014–0.04‰ and cadmium 0.001–0.002‰. The leaching test showed that the mobilisable fraction was significant with EDTA at 0.10 to 0.15 ± 0.01 mg/kg.

Agricultural tests
Germination tests were performed to ensure the maturity of the composts. The germination index (GI) varied between 76 and 87% (Koledzi et al., 2011a). The experiment conducted in respect of maize with the various types of compost provided at the rate of 10 t/ha showed a substantial improvement in yield from 0.17 to 185.21% compared with the absolute control. Experiments conducted with cabbages, carrots and beets also pointed to the composts having a positive impact on the yields of various vegetable crops. Compared with the absolute control, the supply of composts led to production surpluses of over 90% for beets, nearly 93% for carrots and roughly 164% for cabbages.

DISCUSSION AND CONCLUSION
With high densities of 0.44 to 0.67 and a production equal to 0.91 kg/inhabitant/day (Koledzi et al., 2011c), the waste revealed a specific composition with a high level of fine fraction material (<20 mm), 46% on average during dry seasons and 56% in wet seasons for waste arriving at the final disposal site, whereas it was under 10% in households. A high level of sand was therefore collected with the waste in the transit centres and carried to the final disposal site. The level of putrescible matter in the final disposal site was between 10 and 15% (Figure 1), while it varied from 60 to 70% of the waste generated in households. The moisture content of waste was high in households but low at the final disposal site. As for organic matter, its low level at the final disposal site was related to its level (8–9%) in the fine fraction material, whereas it represents the highest fraction in terms of quantity. In the case of heavy metals, apart from iron, which ranks highest in terms of the amount in waste, lead levels were also very high in waste: 516 ± 3 mg/kg.

In the light of the characterisation findings, the composting sector is obviously a must for waste processing in the districts. In order to be sustainable, the sectors must address all the technological, cultural and socio-economic components in relation to the local conditions in the poor urban fringes of Lomé.

As for pre-collecting in the pilot district, the subscription rate is 53%. The collection process costs €27/tonne and the collection fee is €2/tonne, with workers earning a low hourly wage (0.4 T/P/D). These values represent the performance indicators of the pre-collection. This has allowed assessment of its effectiveness and indicates tools for improvement.

The experimental study of the composting process made it possible to maximise the effectiveness and efficiency of the production line and the quality of the compost. The water requirements during composting varied from 0.6 to 1.6 m³ per tonne of composted waste. The pH values in composts at the end of the process were basic (8–9), resulting in a loss of nitrogen, in the form of ammonia, and a comparatively high C/N ratio (Koledzi et al., 2011a). The loss of nitrogen during the process was linked to the emission of N₂O, N₂ and NO₂. Several authors believe that mature compost could have a C/N ratio of around 20, or between 6 and 21, or between 13.7 and 32. A high C/N ratio would result in nitrogen mineralisation, thus reducing the level of nitrogen in the soil, while a low C/N ratio would release a large amount of soluble basic salt, making the soil reductive and affecting plant growth (Koledzi et al., 2011a).
The high ash content in the waste may be the cause of these pH values, confirmed at the end of maturation by high potassium levels. The mass balance at the end of the process took the following form: for the tanks (0.69–0.71 tonne of compost per tonne of composted waste) and for the swaths (0.25–0.26 tonne of compost per tonne of composted waste), in the case of fine compost <10 mm. The recyclable rates were 6% for pre-sorted waste in tanks and 12% for raw waste composted in swaths. The organic matter levels at the end of maturation were between 27 and 34%. These values were within the range of the values recommended by the European Ecolabel.

The concentration of heavy metal pollutants was identified: only the lead level was above the compost levels normally observed. A leaching test was performed to ascertain if the lead would be transferred to plants once the compost was spread (Koledzi et al., 2011b). It was found that the higher the level of organic materials, the more lead was retained. Lead was apparently held by the organic matter and metal hydroxides. The metal levels in the compost varied according to the maturity of the compost. During the composting process, the humic concentration increased as the organic matter level decreased. The higher the concentration, the more metals were trapped, thereby reducing their bioavailability. Accordingly, there was a low risk of phytotoxicity after soil improvement, so the compost may stabilise or immobilise the solid phase metals. However, it was better to sort the materials before composting to lower the risk of food chain contamination (Koledzi and Matejka, 2011).

Great caution was required owing to the complicated nature of the biological, physical and chemical mechanisms in the soil. Accordingly, a study on the bioavailability of metals by plants types is under way. The AT4 test gives values of between 6 and $7 \pm 1$ mg O$_2$/g (MS), lower than the limit values. Furthermore, the GI exceeds 50%, showing that the composts were mature. The findings of the agricultural tests on compost soils were very encouraging in terms of the yields for two vegetable plants (carrots and beets), which is a boon for market gardeners and farmers, who have difficulty acquiring organic or mineral improvers (manure and fertilisers).

The creation of a composting platform calls for a very careful selection process on the outcomes and in light of the available market and local constraints. This organic waste management approach has made it possible to establish a long-term platform. An initial assessment of the platform is required, primarily to identify shortcomings and offer fast solutions (e.g. a leaching treatment method) so that problems do not cause the centre to be shut down.

**COMMUNICATION STRATEGY AND IMPACT**

Several resources and tools were used to disseminate the findings. Articles have been published in high-impact reviews (Koledzi et al., 2011a,b,c, 2012a,b) and several papers presented at international symposiums. A training workshop on composting techniques and use was organised for farmers throughout Togo. At the end of the event, a training manual produced by the GTVD laboratory on making compost from biodegradable organic waste was provided to the participants as a tool and to offer them ongoing support once they returned to their individual environment.

Several appearances were made on Togo’s national television station (TVT) and radio Lomé to make farmers aware of the benefits of using compost. Two documentaries on making compost, its use and benefits for farming, produced by the GTVD laboratory, were broadcast at regular intervals over 2 years on TVT, TV5 Afrique and RFI (www.rfi.fr/emission/20120506-1-vertus-compost-villes-africaines).
At the end of the study, farmers were reported to be using compost on a larger scale as a result of the public authorities communicating the message to farmers via agricultural outreach officers. The sorting–composting platform established is now processing 10 to 15 tonnes of waste a day with a workforce of 20 in the city of Lomé, due to the efforts of a household waste pre-collecting NGO (ENPRO) relying on the technical support of the GTVD laboratory in cooperation with Lomé city council, the French Centre for Partnership-based Research into Sanitation, Waste and the Environment (CEFREPADE) along with Geval and GoodPlanet as part of a carbon funding scheme. This is confirmed by the final report in the context of the CORUS project No. 6126 under the umbrella of the IRD (Research Development Institute) and the periodical reports of the ENPRO NGO composting platform under the sponsorship of the FFEM (French World Environment Fund). The platform was launched on 14 February 2012 during a ceremony attended by the ambassadors of France and the United States, officials from agricultural institutions, universities and local residents.

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EFFECT OF GENOTYPE AND POST-WEANING DIET IN ENHANCING PIG PRODUCTION WITHIN LAKE VICTORIA CRESCENT IN UGANDA

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ABSTRACT

Pig production is one of the enterprises small-scale farmers can use to maximise their labour efficiency, improve household food security, increase income to alleviate poverty, and eliminate protein malnutrition. The objective of this study was to determine the effect of genotype and diet on the growth performance and carcass characteristics of pigs. Diets were based on maize bran (MB), wheat bran (WB) and whole maize (WM). Cambrough \((n = 18, 12.0 \text{ kg})\) and Cambrough × Large White crossbred \((n = 18, 9.67 \text{ kg})\) pigs were grouped into six per pen, balancing for breed, sex and weight, and then randomly assigned to diets, replicated three times and fed for 120 days. Data were gathered on feed intake, weight gain, back fat thickness and body condition score (BCS). At 180 days of age, all male pigs were slaughtered to conduct carcass, tissue and sensory analysis. Diet and genotype significantly influenced \((P < 0.05)\) weight gain, BCS, carcass composition, dressing percentage, chilling and drip loss, pH, longissimus dorsi muscle area, fat thickness and pork sensory quality. Weight gain/day was 360 g for WM, 420 g for MB, 390 g for WB, while hot carcasses weighed 46.87, 53.92 and 47.37 kg, respectively. Pork from Cambrough pigs had significantly less \((P < 0.05)\) fat thickness (4.8 mm) than crossbreds (7.7 mm) and had significantly the best \((P < 0.05)\) scores for sensory quality. The WB diet was the best option for feeding pigs due to its low cost, in addition to giving better pig performance and pork quality than maize-based diets, which were also economically unjustifiable. It was recommended that Cambrough pigs be considered as the breed of choice because they produce leaner pork, which is demanded by most consumers today. The diet and breed technologies should be promoted in all wheat-producing and/or processing areas of Uganda.

KEY WORDS: CAMBROUGH, GROWTH RESPONSE, PORK QUALITY, WHEAT BRANS

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INTRODUCTION

Pork utilisation has been rising steadily despite religious and cultural restrictions on the consumption of pork and the prominence of other meats in many countries. Worldwide, pork production has tripled in less than 50 years (FAO, 2011). Currently, at a pork consumption level of 3.2 kg per person per year, Uganda ranks first in Africa. Promotion of pig-rearing increases the amount of meat available in the community, while at the same time enhancing pig farmers’ incomes. It also promotes food security, which is in line with meeting the first Millennium Development Goal of eradicating extreme poverty and hunger, and also supports the Comprehensive Africa Agriculture Development Programme (CAADP). While in the Western world pig business is industrialised and progressive, in developing countries many challenges remain and Africa is still a net importer of pork. In many areas, reliance on manufactured feeds does not appear to be sustainable as feed costs are prohibitive, and returns on investment are not positive. Integrating food crop and pig production may be promising, since part of the food crop could be converted to pig feed.

A survey of eight districts in the Lake Victoria Crescent (Figure 1) ranked pigs highest among livestock enterprises on smallholder farms (MUZARDI, 2006). Over the past decade, the market for pigs and pig products in Uganda has grown; Cambrough pigs were introduced into the country, and the price of pork doubled and is now on a par with other meats. Despite these good indicators for a vibrant pig sector, the lack of effective integration of pigs and crop production has been a concern, in addition to the low uptake of both the new pig breed and the relatively low-cost wheat bran, which is readily available. A research for development project was conceived, proposed and implemented with the aim of determining the appropriate common commercial feedstuffs for pig diet formulation and response by three pig genotypes to the formulated diets.
**METHODOLOGY**

The experiment was conducted at Mukono Zonal Agricultural Research and Development Institute (0°21′N, 32°45′E) (Figure 1). The institute is located at an altitude of 1,100 m a.s.l., in Mukono municipality in central Uganda. A completely randomised design (CRD) with three replications was used to study the effect of pig genotype and diet on growth and meat quality. Thirty-six weaned piglets weighing 8–15 kg and 60 days old were procured from registered local pig breeders. Two genotypes, Cambrough (CC) and Cambrough × Large White crosses (CL), were used. Using a feed resources inventory developed from a baseline survey of the wider study, five feedstuffs were selected based on availability and cost, and samples of each were collected and analysed at the Animal Science Laboratory, Makerere University. Maize bran (MB), wheat bran (WB) and whole maize (WM), which are commercially available feedstuffs, were then characterised for dry matter, total ash, crude protein, crude fibre, crude fat, calcium, total phosphorus and digestible energy. The feedstuffs were then used to constitute three iso-nitrogenous (171.2 g N/kg feed) rations (Table 1), fed as total mixed rations. Before starting the study, the pigs were dewormed, ear-tagged and weighed, and were then fed for 120 days. The weight of feed given and that rejected was recorded. Live body weight was recorded weekly using a weighing crate (GHL, Denmark). Backfat depth was recorded weekly using a digital ultrasound probe (Lenco Lean-Meter, USA) starting at 16 weeks of age.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Diet composition on DM basis</th>
<th>Cost of feedstuff/kg (UShs)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize bran</td>
<td>77.7</td>
<td>–</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>–</td>
<td>86.0</td>
</tr>
<tr>
<td>Whole maize</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fish meal</td>
<td>12.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Bone ash</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Cotton seed cake</td>
<td>7.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Lake shells</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Salt</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Vitamin–mineral premix</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Total†</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*US$1 = UShs 1990; † the cost of 100 kg of each of the diets was $27.83 (MB), $17.27 (WB) and $35.95 (WM).
At the end of the feeding trial, all males were removed from the test, fasted for 24 h, then slaughtered to conduct carcass, tissue and sensory analysis. The body condition score was taken just before slaughter by a team of 10 trained graders using the 1–5 Garth Stockmanship Standard Scale (Carr, 1998). After slaughter, internal organs and fat were removed and weighed. Hot carcass weight was taken using a spring balance (Nessane, USA) to compute the dressing percentage.

Sensory evaluation was performed using a panel of nine trained individuals experienced in sensory analysis of foods and a panel of 18 untrained pork consumers. In partitioned booths equipped with yellow light bulbs, each trained panellist was presented with one warm cube of each boiled pork sample wrapped in aluminium foil, to taste and score the degree of juiciness, tenderness, palatability, acceptability, flavour and off-flavour intensity on a scale from 1 to 9, where 1 = extremely tough, very dry, extremely bland flavour and extremely unacceptable and 9 = extremely tender, extremely juicy, extremely intense pork flavour and extremely acceptable. For the untrained panellists, skewered samples were presented in an outdoor setting; the rest of the protocol was similar to that for the trained panel. Data were entered into MS Excel software and then subjected to the analysis of variance procedure for a CRD experiment using the general linear model procedure of SAS (2004).

The model used was:

\[ Y_{ijkl} = \mu + b_i + d_j + (bd)_{ij} + s_k + \varepsilon_{ijkl} \sim N(0, \sigma^2) \]

where \( Y_{ijkl} \) = dependent variable; \( \mu \) = overall mean; \( b_i \) = genotype effect \( (i = 1,2) \); \( d_j \) = diet effect \( (j = 1,2,3) \); \( (bd)_{ij} \) = interaction between breed and diet; \( s_k \) = sex effect \( (k = 1,2) \); \( \varepsilon_{ijkl} \) is the random effect on the variable, independently and identically distributed with mean = 0 and variance = \( \sigma^2 \).

Treatment differences were considered significant at \( \alpha = 0.05 \) and treatment means were compared using the Fischer test.

**RESULTS**

The WB diet gave a significantly higher \( (P < 0.05) \) weight gain/day and better \( (P < 0.05) \) gain:feed ratio (390 g; 0.33) than the WM diet (360 g; 0.32); moreover it was half the cost. Also, WM was significantly \( (P < 0.05) \) inferior to MB in weight gain/day, though the two diets yielded similar pre-slaughter body condition scores (Table 2). Cambrough (CC) pigs were significantly superior \( (P < 0.05) \) to CL crossbreds in body weight at all stages of growth. Carcass composition followed a reverse trend to that of growth traits. Pigs fed the MB diet were inferior in terms of the weight of the rind and the total fat compared to those on WB, but were not different from pigs fed WM. Given that the composition of the 6th rib is highly correlated and is a usual proxy measure of total carcass composition, we found that the rind was 23.8% of the carcass weight of pigs fed MB, 20.2% for WB and 18.8% for pigs fed WM. However, the carcasses of pigs fed WM had the highest proportion of fat (22.2%) while those on the MB diet had 20.8% and WB at 12.1% was the lowest. The proportion of lean muscle was highest (40.7%) for WB, 34.0% for MB and 33.5% for WM.

Pigs fed WM had the lowest hot carcass weight and cold dressing percentage, and had the highest chilling loss and day 0 cooking loss (Table 3). The pH of the longissimus dorsi (LD) muscle measured 24 h after slaughter (pH24 LD) was lowest in pigs fed WB and highest for WM. Cambrough pigs were superior to CL in all slaughter traits except for pH, and they also had significantly \( (P < 0.05) \) less fat thickness than crossbreds. The internal organs (liver, heart and lungs) of pigs fed MB were heavier than the rest, but the intestines were heaviest in pigs fed WB. The MB diet gave the highest carcass measurements, followed by WB, with WM being the lowest.

With regard to the sensory characteristics of pork, the trained panellists observed that the diet affected only tenderness and juiciness, but the public
consumer panel also reported differences in flavour (Table 4). The trained panellists awarded higher scores for the various traits compared with the public panel. According to both panels, pork from pigs fed maize-based diets was more tender and achieved better acceptability scores, while that from WB was the most succulent and had the best flavour. Considering breeds, Cambrough pigs were judged to produce the better quality pork by both panels.

**DISCUSSION AND CONCLUSION**

Pig growth data showed that both diet and breed had significant effects. Initial weights did not differ between diets, since they were purposively balanced, but eventually pigs fed brans were better than those on WM. This was due to the increased nutrient intake and utilisation resulting from the refined processing of MB and WB compared with WM. The lower weight gain for WM-fed pigs could be attributed to its poor digestibility and faster rate of passage of the feed through the gastro-intestinal tract, and therefore reduced retention time for thorough digestion and utilisation. Low gastro-intestinal tract digestibility of maize starch is a result of starch being encapsulated by non-starch polysaccharides (Svihus et al., 2005). Only studies by Vasal (2006) on quality protein maize, which was a protein-fortified variety, have yielded contradictory results.

Cambrough (CC) pigs proved to be superior, recording better growth rates than crosses. The WB diet gave a fat weight which was less than half the values for MB and WM (Table 2), indicating the advantage of wheat bran in regulating fat deposition. The high fat content for maize diets was correlated with energy and overall dietary fibre content. High intramuscular fat levels were associated with protein-deficient diets (Castell et al., 1994) and were correlated with the amount of fat in the diet and the profile of the fatty acids. Cambrough pigs gave much less total fat than CL, implying that CC was better at producing lean carcasses and should be promoted for consumers preferring lean pork.

**TABLE 2: EFFECT OF BREED AND DIETS BASED ON CEREAL BRAN ON PIG GROWTH AND CARCASS COMPOSITION**

<table>
<thead>
<tr>
<th>Parameter (n = 36)</th>
<th>MB</th>
<th>Diet</th>
<th>Breed</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WB</td>
<td>WM</td>
<td>CC</td>
<td>CL</td>
</tr>
<tr>
<td>Initial weight (kg)</td>
<td>10.62</td>
<td>11.00</td>
<td>10.87</td>
<td>12.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Weight at day 180 (kg)</td>
<td>86.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75.75&lt;sup&gt;c&lt;/sup&gt;</td>
<td>84.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Weight gain/day (g)</td>
<td>420.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>390.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>360.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>403.70&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Body condition score</td>
<td>3.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.87&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.97</td>
</tr>
<tr>
<td>Rib weight (g)</td>
<td>423.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>342.75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>388.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>380.50</td>
</tr>
<tr>
<td>Rind weight (g)&lt;sup&gt;f&lt;/sup&gt;</td>
<td>101.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>69.50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>73.00&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>70.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total fat weight (g)&lt;sup&gt;f&lt;/sup&gt;</td>
<td>88.25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>41.50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>86.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lean muscle weight (g)&lt;sup&gt;f&lt;/sup&gt;</td>
<td>144.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>139.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>130.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>145.00&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup> Means in the same row with different superscripts are significantly different at P < 0.05; MB: maize bran; WB: wheat bran; WM: whole maize; CC: Cambrough; CL: Cambrough × Large white; † weight is part of the total rib weight.
Carcass weights, dressing percentages and cooking losses indicate that though MB was a good energy source for growth, it did not deliver better carcass quality than WB (Table 3) because diet energy density affects back fat deposition (Bee et al., 2002). Cambrough pigs had much thinner back fat than CL, just as they had the least total carcass fat, confirming that CC is superior in producing lean pork. Ageing pork for 24 h improved its quality. The size of feed particles in a diet positively correlates with pH\textsubscript{24} LD; hence pH was higher in pigs fed WM than WB. Cooking loss

<table>
<thead>
<tr>
<th>Parameter (n = 36)</th>
<th>MB</th>
<th>Diet</th>
<th>Breed</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WB</td>
<td>WM</td>
<td>CC</td>
</tr>
<tr>
<td><strong>Slaughter characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot carcass weight (kg)</td>
<td>53.92\textsuperscript{a}</td>
<td>47.37\textsuperscript{b}</td>
<td>46.87\textsuperscript{b}</td>
<td>51.45\textsuperscript{a}</td>
</tr>
<tr>
<td>Cold dress (%)</td>
<td>96.4\textsuperscript{a}</td>
<td>97.04\textsuperscript{b}</td>
<td>93.86\textsuperscript{c}</td>
<td>96.31\textsuperscript{a}</td>
</tr>
<tr>
<td>Chill loss (%)</td>
<td>3.55\textsuperscript{a}</td>
<td>2.95\textsuperscript{b}</td>
<td>6.13\textsuperscript{c}</td>
<td>3.69\textsuperscript{a}</td>
</tr>
<tr>
<td>Drip loss (%)</td>
<td>11.35\textsuperscript{a}</td>
<td>9.80\textsuperscript{a}</td>
<td>6.92\textsuperscript{b}</td>
<td>10.13</td>
</tr>
<tr>
<td>Cook loss on day 0</td>
<td>37.53\textsuperscript{a}</td>
<td>37.77\textsuperscript{b}</td>
<td>39.73\textsuperscript{c}</td>
<td>38.99\textsuperscript{a}</td>
</tr>
<tr>
<td>Cook loss on day 14</td>
<td>41.50\textsuperscript{a}</td>
<td>40.16\textsuperscript{b}</td>
<td>40.84\textsuperscript{b}</td>
<td>39.19\textsuperscript{a}</td>
</tr>
<tr>
<td>pH\textsubscript{24} LD</td>
<td>5.08\textsuperscript{a}</td>
<td>4.20\textsuperscript{b}</td>
<td>5.15\textsuperscript{c}</td>
<td>5.59\textsuperscript{a}</td>
</tr>
<tr>
<td>pH\textsubscript{24} shoulder</td>
<td>4.82</td>
<td>4.91</td>
<td>4.97</td>
<td>5.50\textsuperscript{a}</td>
</tr>
<tr>
<td><strong>Carcass quality and composition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longissimus area (cm\textsuperscript{2})</td>
<td>21.48\textsuperscript{a}</td>
<td>20.73\textsuperscript{a}</td>
<td>17.17\textsuperscript{b}</td>
<td>20.92\textsuperscript{a}</td>
</tr>
<tr>
<td>Fat thickness (mm)</td>
<td>5.92\textsuperscript{a}</td>
<td>5.55\textsuperscript{b}</td>
<td>7.37\textsuperscript{c}</td>
<td>4.87\textsuperscript{a}</td>
</tr>
<tr>
<td>Head weight (kg)</td>
<td>5.83\textsuperscript{a}</td>
<td>5.23\textsuperscript{b}</td>
<td>5.33\textsuperscript{b}</td>
<td>5.72\textsuperscript{a}</td>
</tr>
<tr>
<td>Trotter weight (kg)</td>
<td>2.28\textsuperscript{a}</td>
<td>2.26\textsuperscript{a}</td>
<td>2.10\textsuperscript{b}</td>
<td>2.31\textsuperscript{a}</td>
</tr>
<tr>
<td>Liver weight (kg)</td>
<td>1.20\textsuperscript{a}</td>
<td>1.12\textsuperscript{b}</td>
<td>1.03\textsuperscript{c}</td>
<td>1.13</td>
</tr>
<tr>
<td>Intestine weight (kg)</td>
<td>5.72\textsuperscript{a}</td>
<td>6.58\textsuperscript{b}</td>
<td>6.13\textsuperscript{c}</td>
<td>6.51\textsuperscript{a}</td>
</tr>
<tr>
<td>Hind limb width (cm)</td>
<td>19.00\textsuperscript{a}</td>
<td>17.75\textsuperscript{b}</td>
<td>21.10\textsuperscript{c}</td>
<td>19.23</td>
</tr>
<tr>
<td>Hind leg weight (kg)</td>
<td>7.13\textsuperscript{a}</td>
<td>6.62\textsuperscript{b}</td>
<td>5.55\textsuperscript{c}</td>
<td>6.95\textsuperscript{a}</td>
</tr>
<tr>
<td>Fore leg weight (kg)</td>
<td>8.60\textsuperscript{a}</td>
<td>7.41\textsuperscript{b}</td>
<td>6.53\textsuperscript{c}</td>
<td>7.85\textsuperscript{a}</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b,c} Means in the same row with different superscripts differ significantly at \(P < 0.05\).
TABLE 4: EFFECT OF BREED AND DIETS BASED ON CEREAL BRAN ON SENSORY SCORES FOR PORK

<table>
<thead>
<tr>
<th>Parameter†</th>
<th>MB Diet</th>
<th>Breed</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WB</td>
<td>WM</td>
<td>CC</td>
</tr>
<tr>
<td>Trained panel scores (n = 9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenderness</td>
<td>7.00a</td>
<td>7.10b</td>
<td>7.20c</td>
</tr>
<tr>
<td>Juiciness</td>
<td>5.81a</td>
<td>5.70a</td>
<td>5.10b</td>
</tr>
<tr>
<td>Flavour</td>
<td>8.00</td>
<td>8.10</td>
<td>7.90</td>
</tr>
<tr>
<td>Acceptability</td>
<td>5.86</td>
<td>6.04</td>
<td>6.10</td>
</tr>
<tr>
<td>Public panel scores (n = 18)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenderness</td>
<td>6.56a</td>
<td>6.32b</td>
<td>6.51c</td>
</tr>
<tr>
<td>Juiciness</td>
<td>5.59a</td>
<td>5.72a</td>
<td>5.44b</td>
</tr>
<tr>
<td>Flavour</td>
<td>5.76a</td>
<td>5.77a</td>
<td>5.57c</td>
</tr>
<tr>
<td>Acceptability</td>
<td>6.47a</td>
<td>6.42b</td>
<td>6.40c</td>
</tr>
</tbody>
</table>

A,b,c Means in the same row with different superscripts differ significantly at P < 0.05; † taste panel scores based on a 9-point scale (1 = extremely tough, very dry, extremely bland flavour, extremely unacceptable, 9 = extremely tender, extremely juicy, extremely intense pork flavour, extremely acceptable).

Peaked at day 7 and then declined, indicating that a week is sufficient for ageing pork. Pork quality is affected by a number of pre-slaughter conditions such as handling and physical exertion (Edwards et al., 2010), though these were insignificant in our study.

Intestine weight was higher in WB-fed pigs due to the higher fibre intake, which had an impact on energy metabolism as a result of the enlargement of the gastro-intestinal organs. Lowering the dietary fibre content through the use of dehulled grains may result in partitioning of dietary energy to growth rather than supporting increased intestine growth. It is noteworthy that no numerical differences were observed with regard to lung, heart and kidney weight, while the liver and reproductive organ weights differed significantly. The diet effect should have had a consistent effect on all the visceral organs to give credence to a direct effect; moreover, past studies (e.g. Furuya and Kaji, 1992) reported non-significant effects of high-fibre diets.

In conclusion, whole maize diets were not nutritionally or economically justifiable. Wheat bran represented the best option for producing pork at low feed cost, and provided good quality pork. The Cambrough breed gave the best performance and should be promoted, especially in regard to the production of leaner pork that many consumers prefer today.

COMMUNICATION STRATEGY AND IMPACT

This work was presented at conferences organised by the National Agricultural Research Organisation (NARO) and Makerere University. Six demonstration units were established, each stocked with Cambrough sows, a boar, sweet potato fodder gardens, and bran-based rations for two reproductive cycles. A piggery farmer field school was hosted at each unit, and in order to directly
popularise the Cambrough breed, 105 farmers received piglets during the project life, and over 600 pigs in the post-project phase. Farmer-to-farmer cross-visits were undertaken.

A book entitled Okuganyulwa mu bulunzi bw’embizzi (How To Benefit from the Piggery Business) was published. Two videos were produced and were broadcast by NARO. A radio talk show on commercial pig production was aired on CBS, a popular local FM radio. Pig-farming was taken up by 208 households as a result of this project and >60 existing piggeries were expanded. Annual pig and pork sales are expected to increase in the study districts, and the incomes of the households involved should eventually have risen by at least 40%. The two technologies are expected to impact on the livelihoods of pig farmers elsewhere in the world.

ACKNOWLEDGEMENTS
The authors are grateful to the National Agricultural Research Organisation for the funding (Project 2008/10) under the Competitive Grant Scheme; and to the farmers for actively participating in the study. The CTA/FARA/IFS/ANAFE/RUFORUM/NEPAD-AU/AGRA consortium facilitated the writing of the manuscript.

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DEVELOPMENT OF DROUGHT-TOLERANT TRANSGENIC BEAN LINES USING AN IMPROVED GENE TRANSFORMATION SYSTEM

K.M. Kwapata*
Abstract

Drought is the most devastating abiotic factor limiting plant growth and yield. Genetic improvements to make beans more tolerant to drought have been achieved using conventional breeding; however, this is limited to genes within the species’ own gene pool. The objective of this research was to develop a new genetic transformation technique with genes that confer drought tolerance. In this technique, the challenge of the recalcitrance of the species towards in vitro regeneration due to excessive phenolic waste was overcome. This was achieved by a hormonal balance of 2.5 mg l⁻¹ benzyladenine and 0.1 mg l⁻¹ of naphthalene acetic acid or indole-3-acetic acid, which promoted robust multiple shoot regeneration. The addition of 30 mg l⁻¹ of silver nitrate further reduced the inhibitory effect of phenolic compounds. Gene delivery into explants was also a major challenge in bean transformation. In this research, a comparison of the most efficient delivery method of transgenes into epical shoot meristem was investigated using Biolistic™ bombardment and Agrobacterium tumefaciens. The Agrobacterium system was found to be more efficient. The system developed was tested for stable integration and expression of the barley (HvAT1) gene, which confers drought tolerance. The significant tolerance of modified plants versus wild varieties towards drought stress was observed after 21 days of withholding moisture, with a corresponding increase in root length.

Key Words: Agrobacterium tumefaciens, Biolistic Bombardment, in vitro, regeneration

Affiliations

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INTRODUCTION

The common bean is a very important source of vegetable protein for the African region, where animal and fish protein is scarce. It supplies 22% of the total protein requirement worldwide and accounts for over 50% of all legumes consumed globally. Conventional breeding has contributed singularly to the improvement of the cultivated common bean. While plant breeding has contributed to the much-needed genetic variation necessary for trait improvement, certain genes that can enhance agronomic traits in the common bean do not exist naturally in its gene pool. Due to this limitation of plant breeding, new trait improvement approaches, such as inter-specific horizontal gene transfer via genetic engineering, need to be applied in order to complement the limitations encountered by conventional breeding (Aragão et al., 2002).

A reliable and efficient plant in vitro regeneration system is a prerequisite to the development of an efficient genetic transformation system. A general feature of common bean genotypes is their resistance to in vitro regeneration. This is because they produce significant amounts of phenolic compounds in vitro, which inhibit their regeneration. A successful in vitro regeneration depends on three major factors. The first is the type of media formulation, which is crucial in creating a balance between levels of cytokinin and auxin. The second is the age of explant, and the third the type of explant. Explants that have been tested for in vitro regeneration include embryonic axes, cotyledonary nodes, stem nodal segments and apical meristem (Veltcheva et al., 2005).

The common bean is known to be resistant not only to in vitro regeneration, but also to genetic transformation. Although inefficient, some transformation has been achieved via the Biolistic™ system. This is in contrast to other grain legumes, such as soybeans, chickpeas, pigeon peas and peas, that have proven more amenable to Agrobacterium-mediated transformation (Popelka et al., 2004). The drawback of the Biolistic™ method is that it often causes multiple gene insertions, which are sometimes fragmented and result in the instability of transgenes and low gene expression. The sole report on the successful use of Agrobacterium-mediated transformation comes from Liu et al. (2005). They describe a procedure of transforming kidney beans with a group 3 late embryogenesis abundant protein (LEA) gene from Brassica napus. Their technique bypassed the tissue culture stage due to poor in vitro regeneration and directly transformed the beans with Agrobacterium using sonication and a vacuum infiltration system. Since then, there have been no other reports of this procedure ever being repeated or of any other successful transformation technique developed using Agrobacterium. As a result, most researchers have abandoned attempts to use Agrobacterium as a vehicle for gene delivery into the common bean.

Other earlier attempts to develop a gene delivery system for the common bean involved the use of electrical-discharge to accelerate DNA plasmid into meristems. Only Russell et al. (1993) were able to show stable transformation of the bar herbicide resistance gene using this technique. However, the recovery of transgenic plants was very low (0.03%), to the extent that this was rendered impractical for future work on the genetic transformation of the common bean. Other researchers have unsuccessfully attempted to use DNA uptake by protoplast, via either polyethylene glycol or electroporation (Veltcheva et al., 2005).

Abiotic stresses, including drought, salinity and high temperatures, pose a major obstacle for crop yield and production. More than 90% of arable land experiences one or more of these stresses. In an effort to overcome or reduce these stress factors, plants have evolved to adapt by synthesising low molecular-weight osmolytes to prevent the aggregation and misfolding of proteins. Late embryogenesis abundant (LEA) proteins are a class of heat-shock proteins (HSP) that are extremely...
hydrophilic and resilient towards heat, such that they do not coagulate at boiling temperatures. These proteins may play a role in water binding, ion sequestration, and macromolecule and membrane stabilisation. In this research, the objective was to develop an efficient method of transferring foreign genes into common beans. Both bombardment and Agrobacterium-mediation gene transfer methods were used to compare their relative efficiency in delivering transgenes into the common bean.

**METHODOLOGY**

Five genotypes of common bean (Condor, Matterhorn, Sedona, Olathe and Montcalm) were used. The methodology regarding in vitro regeneration followed the protocol by Kwapata et al. (2010). Hormonal optimisation of cytokinin to auxin was achieved using 2.5 mg l⁻¹ benzyladenine and 0.1 mg l⁻¹ of naphthalene acetic acid or indole-3-acetic acid. Treatments of antioxidants for phenolic compound inhibition were: (1) water; (2) no chemical treatment; (3) 2 mg l⁻¹ ascorbic acid; (4) 5 mg l⁻¹ glutathione; (5) 15 mg l⁻¹ activated charcoal; (6) 30 mg l⁻¹ silver nitrate.

Bean genetic transformation was achieved either through bombardment or via Agrobacterium tumefaciens-mediated transformation of apical shoot meristem primordia. Four different plasmid vectors were used: pACT1F harbouring the gus gene, pBY520 harbouring the HVA1 and bar gene which confers drought tolerance and herbicide (phosphinothricin) resistance, respectively. For Agrobacterium tumefaciens-mediated transformation the binary vector pCAMBIA3301 harbouring the bar and gus-intron gene was used.

**Biolistic™ bombardment**

Apical shoot meristems of mature embryos were excised and bombarded with a gene gun. Plasmid DNA was coated onto 50 µg l⁻¹ of 10 µm tungsten particles with 2.5 M calcium chloride and 0.1 M spermidine suspended in a solution of 1:1 (v/v) of 75% ethanol and 50% glycerol. The treatments applied were bombardment pressure at three levels (500, 1000 and 1100 psi); concentration of plasmid DNA at two levels (1.5 and 3.0 µg); and bombardment frequency at three levels (1, 2 and 3), with a 24-h rest interval between bombardment events.

**Agrobacterium transformation**

Three strains of A. tumefaciens (EHA105, GV3301 and LBA4404) were used as treatments together with a co-cultivation period of 1, 5, 10 and 15 days. A concentration of 500 mg l⁻¹ of Timentin was added to regeneration media to kill the A. tumefaciens after the appropriate co-cultivation period. Agrobacterium was cultured in 50 µl LB media in the dark at 37°C in a rotator at 280 rpm for 48 h; OD₆₀₀ = 1. The pCAMBIA-3301 binary vector containing the gus gene driven by the 35S promoter with the bar gene was used for transformation.

**Southern blot hybridisation analysis**

Southern blot hybridisation analysis was conducted to assess the stability of the transgenic event and determine the gene copy numbers of HVA1. The DIG, DNA Detection Starter Kit was used. HindIII or BamHI restriction enzymes were used to digest 20 µg of genomic DNA, which was electrophoresed at 70 v on 1% agarose gel and transferred to a Hybond-N+ membrane.

**Drought tolerance test**

Seedlings were raised in the growth chamber for 3 weeks. They were then transferred to the greenhouse. The plants were watered daily for 21 days, after which moisture was withheld for another 21 days. Observations were recorded on plant survival, degree of leaf wilting, root length, plant growth and height. After the stress period, moisture was re-applied to the plants continuously for 14 days and the percentage of plants recovered was recorded.
RESULTS

In vitro regeneration

A 100% in vitro regeneration rate was achieved with a cytokinin concentration of 2.5 mg l⁻¹ benzyladenine (BA) and an auxin concentration of 0.1 mg l⁻¹ of naphthalene acetic acid (NAA) or indole-3-acetic acid (IAA). The best inhibitors of phenolic compounds were 30 mg l⁻¹ of silver nitrate and 15 mg l⁻¹ activated charcoal, although silver nitrate was slightly more effective.

Southern blot analysis of HVA1 transgene transgenic plants after bombardment

Results showed that bombarding the plant twice, using a pressure setting of 1100 psi with a concentration of 1.5 µg of plasmid DNA per bombardment, yielded the highest transformation efficiency of 8.4%. The results indicate that there was a double gene integration in all genotypes, namely Condor (Co), Sedona (Se) and Matterhorn (Ma), with the exception of Montcalm (Mo), which has a single copy number. The wild type (Wt) shows no transgene integration.

FIGURE 1: EFFECT OF SIX ANTIOXIDANT TREATMENTS ON ABILITY TO INHIBIT PHENOLIC COMPOUND PRODUCTION DURING MULTIPLE SHOOT REGENERATION: (A) WATER; (B) NO CHEMICAL TREATMENT; (C) 2 mg L⁻¹ ASCORBIC ACID; (D) 5 mg L⁻¹ GLUTATHIONE; (E) 15 mg L⁻¹ ACTIVATED CHARCOAL; (F) 30 mg L⁻¹ SILVER NITRATE
Success rate of *A. tumefaciens* transformation

The results in Figure 3 show that in order to achieve transformation efficiencies above 50%, a co-cultivation period of more than 15 days is required. Furthermore, the results have demonstrated that the GV3301 *Agrobacterium* strain is more efficient at delivering transgenes into the common bean, while LBA4404 is the least efficient. Observations also show that Sedona is a more susceptible genotype to *Agrobacterium* transformation than Matterhorn.
Water stress test

Figure 4 shows healthy plants before withholding water (A) and plants seen to be wilting and dying after moisture was withdrawn for 21 days (B). Panel (C) shows plants that had recovered from the drought simulation test after 3 days of resumption of watering. Pot number 1 is a control, non-transgenic, wild-type plant that was watered throughout the experiment. Pot 2 is the transgenic plant after 21 days of no irrigation. Pot 3 is a wild-type non-transgenic plant after 21 days of no irrigation. Panel (D) shows the root development of plants after 21 days of drought stress. Plant 1 is the control non-transgenic that was watered daily, plant 2 is the transgenic plant roots after 21 days of no irrigation, and plant 3 is the wild type non-transgenic plant roots after 21 days of no irrigation.
DISCUSSION AND CONCLUSION

The research was successful as it led to the development of a highly efficient system for in vitro regeneration. Earlier attempts had failed as a result of the wrong choice of explant for in vitro regeneration, as well as an unsuitable formula for balancing the plant growth hormones and the inability to identify a suitable anti-oxidant, such as silver nitrate, capable of minimising the effects of phenolic compounds. Though we succeeded in transferring the foreign genes into the genome of common beans via the Biolistic™ method, the success rate (8.4%) was not as high as when using Agrobacterium (68%). Earlier attempts at using Agrobacterium had failed due to the poor choice of strains and limited co-cultivation period. Earlier researchers co-cultivated for a maximum period of 4 days. In this study, it has been demonstrated that at least 15 days is required to achieve 50% transformation efficiency.

The potential of using the HVA1 transgene to alleviate symptoms of drought in the common bean has been demonstrated. This supports previous work which demonstrates the practicality of the technique for transferring the HVA1 drought tolerant protein gene from barley (Zhu, 2002). As the drought-tolerant trait is polygenic, more genes along the drought stress pathway need to be studied and engineered into common beans as a stack trait. This research therefore has strong potential to help farmers in drought-prone areas of Africa by creating improved bean seed varieties that they can plant in their fields. Furthermore, this research can also help to mitigate the effects of climate change in Africa and globally.

COMMUNICATION STRATEGY

The strategy was threefold, targeting policy-makers, farming communities and consumers. For policy-makers, public seminars highlighting the findings of the study, its relevance and importance have been conducted in Malawi. Academic journal articles and magazine features have also been published in order to increase public awareness and appreciation for GMO adoption in Africa. The next step will be towards demystifying GMO crops for wider acceptance and consumption by consumers and the farming community. In the African region, this is a key step in the communication strategy, as GMOs are plagued by negative stereotypes that have no scientific basis. Awareness-raising initiatives aimed at the farming community will centre on on-farm demonstration plots to demonstrate the improved characteristics of these GM bean varieties and their potential for improving smallholder crop productivity. For consumers who are mostly concerned about the health implications of GM crops, the communication strategy will centre on demonstrating the substantial equivalence of the health implications of the GM beans with conventional non-GM beans.

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IMPROVING THE PRODUCTION OF TARO FLOUR FOR THE PREPARATION OF PASTE IN CAMEROON AND CHAD

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ABSTRACT

The taro sector in Cameroon involves crop production, a well established tuber marketing chain, and restaurants specialising in the preparation of taro paste. In Chad, the stages in the chain include production, processing into chips and flour, followed by marketing and distribution. The brown taro flour finds little favour with urban consumers in Chad, while there is no further processing done in Cameroon. As part of an approach based on cooperation and ensuring the continuity of work undertaken to produce and use taro flour to prepare the paste, this study had two specific objectives: (1) to determine the conditions governing the production of flour from the giant swamp taro (Cyrtosperma merkusii), a tuber used in Cameroon for preparing the paste; and (2) to evaluate the impact of the stage of maturity and the drying method on the physiochemical, textural and sensorial properties of Sosso taro (Colocasia esculenta) flour and paste in Chad. The findings showed that there was a major variation in the composition of the flour, depending on the stage of maturity of the tuber. Cyrtosperma merkusii had the advantage over C. esculenta of being a source of β-carotene. The starch had highly specific techno-functional properties. An analysis of the principal components showed a link between the composition of the tuber and the functional properties of the flour, which influenced the textural/sensorial properties of the taro paste. Training of farmer stakeholders in Chad has improved the quality of the flour. The innovation rolled out in Cameroon is now being exploited by student engineers.

KEY WORDS: DRYING, FUNCTIONAL, INNOVATION, MATURITY, POSTHARVEST TECHNOLOGY, SENSORIAL

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INTRODUCTION

Taro is the most important tuber in Chad, and the second most important tuber in Cameroon (FAO, 2008). In Cameroon, the taro tuber is cooked, peeled and pounded and eaten mainly in the form of a paste; in Chad it is dried and processed into flour or chips to be eaten as a paste. The dishes created using the flours are not very popular, as consumers are put off by the intense brown colour. As part of the drive to produce quality flour for preparing the paste, a series of taro-related research activities were launched. Research by Njintang (2003) made it possible to define the taro variety and the flour production process: pre-cooking of the tuber, peeling, slicing, drying and grinding. Other research projects have focused on optimising conditions for flour production and use: cooking the tuber (Aboubakar et al., 2009), drying and grinding (Njintang et al., 2007, 2008), and preparation of the paste and its storage (Aboubakar et al., 2010). Subsequent research focused on supporting the Common Initiative Groups in taro flour production. However, the conditions for using taro to prepare the flour paste in Cameroon and Chad raised other questions. In Cameroon, the giant swamp taro, Cyrtosperma merkusii, is used instead of Colocasia esculenta to prepare the paste in lean times, but the properties of the C. merkusii tubers are still unknown. Colocasia esculenta variety Sosso is harvested at different stages of maturity, varying between 6 and 10 months, and sun-dried, which affects the properties of the flour and the paste (Hsu et al., 2003).

The objectives of the study were: (1) to define the compositional and techno-functional properties of C. merkusii taro flour and its main components, starch and mucilage; and (2) to evaluate the effects of stage of maturity and drying method on the physicochemical, functional and sensorial properties of C. esculenta variety Sosso, taro flour and paste.

METHODOLOGY

Plant material and sampling

The Cameroon giant swamp taro, Cyrtosperma merkusii H. Schott, used in this study, was harvested in the main production area in the north-western region of the country. The tuber comprises a white external sheath (epidermis) and yellow flesh, both of which are fibre-loaded and hard.
(Figure 1A). The Chad taro, *Colocasia esculenta* L. Schott, white Sosso variety, was grown in Chad’s mayo kebbi area and harvested after 6, 7, 8, 9 and 10 months (Figure 1B).

**METHODS**

**Production of flour and preparation of paste**

Flour from the giant taro harvested at 24 months maturity was produced according to the types of usage observed in households: yellow flesh alone or with the white epidermis, and according to two drying methods: sun-dried and electric oven-dried (50°C) before the grinding stage. In the case of Sosso taro, two key parameters were factored in as a response to observations made in relation to the farming system and the endogenous technical resources available: the stage of maturity of the tuber (6–10 months) and the drying method (sun and electric). Sun-drying was improved as a result of a shell-type sun-dryer, and electric oven-drying was undertaken for comparison purposes. The pastes were prepared by mixing the flour in boiling water (in a ratio of 1:3 m/v) and then using the method of Aboubakar *et al.* (2010). The mixture was carefully stirred in a pot on a hot plate using a wooden spatula until a smooth paste was achieved after 30 min.

**Nutritional and physicochemical analysis**

The analysis of the nutritional composition (moisture, ash, crude protein, total carbohydrates, crude fat, vitamins A and C, minerals Zn, Fe, Mg, Ca) of the flours was performed according to AOAC (1990). This starch-rich tuber was subject to a physicochemical (chemical composition, thermal properties) and techno-functional (water absorption capacity, rheology) characterisation. Finally, an assessment of the colour, textural and sensorial profile of the pastes produced from the flours was made in a laboratory environment (hedonic analysis) and in the city of N’djamena and Kolobo village in Chad (consumption test). The *K*-means classification test was applied to group the pastes into categories.

**RESULTS**

**Nutritional value of the flours**

The nutritional composition of taro flour showed that the tuber is a good source of carbohydrates (Table 1). The mineral content was high, particularly calcium. However, there were major variations depending on the tuber’s stage of maturity. The total sugars, proteins, crude fibres and mineral content rose sharply (*P* < 0.05) with increasing maturity.

This explained the higher levels of minerals and proteins observed for the giant taro, tubers of which remain in the ground for several years (Koch, 1986) and build up large nutrient reserves. The tuber also stood out because, unlike most taros, it had yellow flesh rich in vitamin C and carotenoids. Conversely, the use of the flesh/epidermis mixture showed a dilution of the vitamins but an increase in the proteins, fibres and minerals (Table 1).

**Physicochemical and techno-functional properties of the starches**

The behaviour of flour during cooking was analysed by measuring the water absorption capacity of the starch according to the temperature (Figure 2). At low cooking temperatures, the starch granules absorbed small quantities of water; the higher the temperature, the greater the quantity of water absorbed. Sosso taro starch harvested at 10 months of maturity could generally absorb up to 1.5 times its weight in water (maximum 350 g water/100 g), whereas giant taro starch absorbs nearly nine times its weight in water (1200 g of water/100 g), or three to four times more water than Sosso taro starch. In contrast, Sosso taro starch had a higher water solubility index. The high water-absorption capacity of giant taro starch reflected its
### TABLE 1: NUTRITIONAL COMPOSITION OF THE GIANT AND SOSSO TARO FLOURS

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Giant taro</th>
<th></th>
<th>Sosso taro</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flesh</td>
<td>Mixture</td>
<td>6 months</td>
<td>10 months</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>ED</td>
<td>SD</td>
<td>ED</td>
</tr>
<tr>
<td>N x 6.25 (g/100 g MS)</td>
<td>9.2</td>
<td>9.1</td>
<td>10.1</td>
<td>10.2</td>
</tr>
<tr>
<td>Total sugars (g/100 g MS)</td>
<td>71.7</td>
<td>71.5</td>
<td>68.6</td>
<td>69.4</td>
</tr>
<tr>
<td>Crude fibres (g/100 g MS)</td>
<td>2.2</td>
<td>2.3</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Crude ashes (g/100 g MS)</td>
<td>3.2</td>
<td>3.2</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Calcium (mg/100 g MS)</td>
<td>65.3</td>
<td>63.7</td>
<td>191</td>
<td>190</td>
</tr>
<tr>
<td>Magnesium (mg/100 g MS)</td>
<td>352</td>
<td>348</td>
<td>380</td>
<td>377</td>
</tr>
<tr>
<td>Carotenoids (mg/100 g MS)</td>
<td>1.7</td>
<td>2.7</td>
<td>0.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Vitamin C (mg/100 g MS)</td>
<td>12.1</td>
<td>16.8</td>
<td>9.1</td>
<td>12.7</td>
</tr>
</tbody>
</table>

**SD:** sun-drying; **ED:** electric drying.

### FIGURE 2: WATER ABSORPTION CAPACITY (A) AND WATER SOLUBILITY INDEX (B) FOR GIANT TARO AND SOSSO STARCHES AT 10 MONTHS

![Figure 2: Water Absorption Capacity (A) and Water Solubility Index (B) for Giant Taro and Sosso Starches at 10 Months](image-url)
gel-forming ability, as confirmed by an analysis of the smallest gelling concentration, which is 4–5% for the giant taro compared with 8–10% for Sosso taro.

**Technological application and sensorial analysis of paste**

The acceptability of taro paste varied according to the stage of maturity and the drying method. There was generally more browning when the slices were sun-dried, but this decreased as maturity advanced. Metal contaminants in sun-dried flours explained the high level of browning reported in the case of sun-drying: the cations reacted with the phenolic compounds to form brown compounds, hence the brown coloration (Malmbergrand and Theander, 1985).

**DISCUSSION AND CONCLUSION**

This study highlights the reasons for the brown colour of taro paste (stage of maturity and drying method) and the varying levels of acceptability as a result of browning. These factors also affected the texture, a key property that determines the acceptability of the paste (Njintang et al., 2007). The study showed that the factors affecting the colour and the texture changed the composition of the flour, which, in turn, had an impact on the functional and physical properties of the starches. This confirmed the association between the acceptability of the paste and the colour and consumer preference. The whiter the paste, the more it was accepted.

The more advanced the stage of maturity, the less intense the browning. The browning was also more significant for sun-drying. There was a close link between maturity and drying and the level of browning in the flour. The browning noted in the paste was triggered during the drying process. Several theories have been put forward to explain the process point at which the colour of the flour changes due to the Maillard reaction. An increase in Maillard-type browning during drying may be activated by metal ions (Cu, Fe) or their salts, alkaline pH, sugars or amino compounds. The theories of browning are controversial and many concepts have been put forward.

The optimum harvesting and drying conditions for reducing browning were an advanced stage of maturity (10 months) and electric oven-drying (50°C). However, unlike sun-drying, electric oven-drying had the disadvantage of reducing the gelling properties of the paste. Gel formation began at 10% compared with 8% for sun-drying. When giant taro with its significant gelling properties was incorporated, a suitable gel was formed and, more importantly, the vitamin and mineral content of the paste was increased as well.

Gelatinisation has generally been correlated with the availability of hydrophilic molecules such as proteins and starch (Xu et al., 2008). This theory was borne out in this study, showing a correlation between the smallest gelling concentration and the protein content ($r = -0.79; P < 0.05$), starch content ($r = -0.72; P < 0.05$), amylose content ($r = 0.78; P < 0.05$) and phosphorus content ($r = -0.76; P < 0.05$). These findings showed that the high protein, starch and phosphorus levels helped to improve the gelling power, whereas high amylose content tended to reduce it. A high gelatinisation capacity was related to the water-binding capacity (Pomeranz et al., 1977). Towards this end, a significant negative correlation between the smallest gelling concentration and the water absorption capacity was noted ($r = -0.75$).

**COMMUNICATION STRATEGY AND IMPACT**

This research was initiated with a view to promoting taro flour processing, where the stakeholders are the Common Initiative Groups (Women Development Committee of Maiborno Ngodi) from Ngaoundere in Cameroon and the Kolobo farmers’ group in Mayo-Kebbi, Chad. A taro flour system
training scheme was rolled out, comprising exchanges of knowledge between farmers, researchers and processors; taro flour-based product formulation (pastes, etc.) followed by product testing involving farmers; and a pilot taro flour processing and marketing phase involving stakeholders, with the support of the research facilities (ENSAI).

The stakeholders’ espousal of the technology took different forms in the urban and non-urban settings. The urban stakeholders and consumers were keen on being able to incorporate taro flour into various recipes (pastes, pastry, gruels, etc.). In the rural environment, the innovation resulted in a tendency for tuber producers to consume taro flour at home. Cooking recipes (gruels, bread products, snacks, etc.) created by families using taro flour and offering marketing potential are some of the factors that argue in favour of developing a taro flour system in Chad and Cameroon.

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CO-COMBUSTION OF PEAT WITH WOOD PELLETS TO REDUCE FINE PARTICLE-FORMING ALKALI EMISSION IN AMBIENT AIR

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ABSTRACT

Fine particle emission (PM) to the air is attracting considerable attention due to concerns regarding climate change, health and environmental problems. It is also evident that exposure to these PM causes severe health problems, such as cardiopulmonary disease, cancer risk and mortality. The objective of this research was to reduce the emission of fine particle-forming alkali during co-combustion of wood with peat in a full-scale (150 kW) grate fired boiler. To this end, the fine particle emissions from a 150 kW district heating grate fired boiler situated in the north of Kramfors, Sweden were studied. During the experiment, the district heating boiler was fired with wood (sawdust) fuel with a 0.10 and 20 wt% (zero, low, high) peat content, respectively. Mass concentrations and particle size distribution were measured using a DLPI (13-step low-pressure cascade impactor) with a precyclone. The particle matter was analysed for morphology and elemental composition using scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS). In addition, chemical equilibrium model calculations were used to interpret the experimental findings. The results showed that around a 50% reduction of fine particles (<1 µm) was possible when 10 wt% peat was added to wood fuel. The thermo-chemical calculations also suggested that a significant share of the potassium was retained in the bottom ash as a K-rich silicate slag and as KAlSi2O6(s) (leucite) when co-combusting wood pellets with 10 wt% peat.

KEY WORDS: BOILER, CLIMATE CHANGE, ENVIRONMENTAL, ELECTRON, HEALTH

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INTRODUCTION

Biomass is increasingly being used worldwide as a renewable energy source due to concerns regarding climate change, global warming, the need to reduce our dependency on fossil fuels, the disposal of agricultural residues, and job creation. Clean, reliable and affordable modern energy services are prerequisites for the achievement of the Millennium Development Goals. The competition for such clean wood-derived fuels introduces new potential fuel types, such as forest residues, straw, salix, sawdust and reed canary grass (Fagerström et al., 2010). The Kyoto protocol and white paper has set the goal of mitigating emissions of carbon dioxide, which is the most abundant greenhouse gas. The European Commission has set carbon dioxide reduction targets and stated how much renewable energy each of the 27 EU countries should be using in 2020 compared with 1990s levels.

Using biomass as fuel, besides mitigating greenhouse gas emissions, reducing acid rain and causing soil improvement, has additional benefits, including political benefits – using biomass as a fuel can decrease dependency on imported oil; and job creation – biomass fuels create up to 20 times more employment than coal and oil (Loo and Koppejans, 2008).

Currently, more than 10% of global energy is derived from biomass. However, combustion of biomass is considered to be a major source of fine particulate matter (PM) and hydrocarbons, such as volatile organic compounds (VOC) and aromatic hydrocarbons (PAH). One of the basic differences that distinguish solid fuels such as biomass from liquid and gaseous fuels is that the solid fuel contains a high amount of inorganic ash-forming elements. When wood combusts, inorganic elements, such as alkali metals, chlorine, sulphur and some heavy metals, are partially released to the gas phase. These inorganic elements cause the emission of harmful gases, deposition and high temperature corrosion. PM from biomass combustion is the main source of fine (<1 µm) particulate (PM$_{10}$) (Boman et al., 2004).

Ambient exposure to these PM causes severe health problems such as cardiopulmonary diseases, cancer risk and mortality. Exposure to fine particles in the ambient air causes chronic adverse effects on lung development in children aged 10 to 18, leading to clinically significant lung function impairment as children reach adulthood. Most regulatory environmental agencies group the pollution particles into two size fractions: PM$_{10}$ and PM$_{2.5}$. These size fractions correspond to the total mass concentration of particles with diameters less than 10 and 2.5 µm, respectively. Particles measuring less than 2.5 µm can easily settle in the lungs, where they may reach the alveoli region, though coarse particles are filtered in the nose and throat (WHO, 2005).

Previous results have shown that significant reduction of fine particle and deposit-forming alkali is possible by dilution of potassium (K) content (e.g. for wheat straw) or by capturing K in bottom ash/slag (e.g. for forest residues), most probably caused by the K vapour from the biomass reacting with reactive Si or clay minerals from the peat (Fagerström et al., 2010). In addition, recent research has also shown the possibility of reducing fine particles when admixing peat to forest residues in a pilot-scale fluidised bed reactor and when admixing peat to chromated copper arsenate (CCA) wood combusting in a pellet burner (15 kW) (Lundholm et al., 2007). This could therefore be an interesting option for large numbers of heat and power plants to co-fire peat with biofuels. However, very few experiments and experiences of the potential co-combusting effects have been demonstrated in small- and medium-scale grate combustors.

The objective of this work was therefore to reduce the emission of fine particle-forming alkali by co-combustion of wood with peat in a full-scale (150 kW) grate-fired boiler.
METHODOLOGY

Fuels used

The biomass fuels used in this study were softwood sawdust pellets. The softwood sawdust originates from the wood raw material used in a typical Swedish pellet mill. The peat type used was a carex-based peat sample with relatively high ash and Si content.

Appliances and experimental procedures

The particle emissions from a 150 kW district heating grate-fired boiler situated in the north of Kramfors, Sweden were studied. During the experiment, the district heating boiler was fired with sawdust fuel with a 0.10 and 20 wt% (zero, low, high) peat content, respectively. The composition of the carbon monoxide (CO), carbon dioxide (CO₂) and nitrous oxide (NO) fuel gases was analysed using a TESTO 350 XL (electrochemical cells). The gas escaping from the boiler was sampled at the exit of the flue gas at a temperature of around 150°C. A DLPI (13-step low-pressure cascade impactor) with a precentrifle and with a downstream Teflon fibre was used to determine the concentration and size distribution of particles in the flue gas. The impactor classifies particles according to the aerodynamic size in the range 0.03–10 µm. Since testing with greased substrates shows insignificant bouncing of particles, non-greased aluminium substrate foils were used in the impactor. This also enabled the subsequent chemical characterisation of the sampled particles. Particulate matter samples in the impactor were analysed for morphology and elemental composition using scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDS). In addition, chemical equilibrium model calculations were used to interpret the experimental findings.

### TABLE 1: FUEL CHARACTERISTICS – ASH-FORMING MAIN ELEMENTS (AVERAGE VALUES OF THREE ANALYSED SAMPLES AND CORRESPONDING STANDARD DEVIATION)

<table>
<thead>
<tr>
<th>Parameter (wt% of dry substance)</th>
<th>Softwood sawdust pellet</th>
<th>Peat pellet</th>
<th>Wood/peat mixture 90/10*</th>
<th>Wood/peat mixture 80/20*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash content</td>
<td>0.4 ± 0</td>
<td>2.6 ± 0.06</td>
<td>0.62</td>
<td>0.84</td>
</tr>
<tr>
<td>Si</td>
<td>0.0181 ± 0.0025</td>
<td>0.463 ± 0.063</td>
<td>0.0626</td>
<td>0.107</td>
</tr>
<tr>
<td>Al</td>
<td>0.0036 ± 0.00056</td>
<td>0.142 ± 0.0067</td>
<td>0.0175</td>
<td>0.0313</td>
</tr>
<tr>
<td>Ca</td>
<td>0.0920 ± 0.0052</td>
<td>0.241 ± 0.018</td>
<td>0.107</td>
<td>0.122</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0031 ± 0.00071</td>
<td>0.261 ± 0.018</td>
<td>0.0289</td>
<td>0.0546</td>
</tr>
<tr>
<td>K</td>
<td>0.0385 ± 0.0011</td>
<td>0.0361 ± 0.0039</td>
<td>0.0383</td>
<td>0.0380</td>
</tr>
<tr>
<td>Mg</td>
<td>0.0154 ± 0.00092</td>
<td>0.0740 ± 0.007</td>
<td>0.0212</td>
<td>0.0271</td>
</tr>
<tr>
<td>Na</td>
<td>0.00265 ± 0.00092</td>
<td>0.0233 ± 0.0049</td>
<td>0.00471</td>
<td>0.00677</td>
</tr>
<tr>
<td>P</td>
<td>0.0052 ± 0.00042</td>
<td>0.0311 ± 0.0029</td>
<td>0.00779</td>
<td>0.0104</td>
</tr>
<tr>
<td>S</td>
<td>0.0056 ± 0.00085</td>
<td>0.112 ± 0.0035</td>
<td>0.0163</td>
<td>0.0269</td>
</tr>
<tr>
<td>Cl</td>
<td>0.01 ± 0.0</td>
<td>0.03 ± 0.0</td>
<td>0.012</td>
<td>0.014</td>
</tr>
</tbody>
</table>

* Calculated values.
RESULTS

During the sampling stage, the CO and NO emissions varied between 20–30 and 70–135 mg/Nm³, respectively, at 8% O₂ d.g. for all sawdust/peat experiments.

Particle characterization

Total mass concentration measured using the DLPI showed that the particle distribution was bimodal (0.020–10 µm) (Figure 1). When burning sawdust pellets alone, the fine mode (<1 µm) PM̵c̵, clearly dominated the particle emissions. When 10 wt% peat was added to the fuel mixture, the fraction of fine particles (PM₅) decreased.

The results of the SEM-EDS analyses (Figure 1) showed that the fine PM for all fuel types/mixtures was dominated by potassium, chlorine, sulphur, sodium and zinc. The results of this experiment (Figures 1 and 2) showed a reduction of fine particle alkali by co-combusting peat with wood. Adding 20 wt% of peat to the fuel mix did not reduce the fine particle emissions further; instead, it dramatically increased emissions of coarse particles (1–10 µm), which were not higher for the 10% peat/wood mixtures. The results show that around a 50% reduction in fine particles (<1 µm) is possible when 10 wt% peat is added to wood fuel.

The results of the thermo-chemical calculations showed a reduction of the fraction of alkali in the fuel that is volatilised from the bed when admixing peat to the sawdust fuel. In the temperature range typically found on the burning grate (i.e. 1000–1100°C) the reduction was around 50% when admixing 10 wt% peat to the sawdust fuel (Figure 4). This tallied with the corresponding experimental combustion results. In pure sawdust combustion, the potassium was mainly predicted to be found in the gas phase as KCl (g) and potassium hydroxide (KOH) (g) in bed temperatures relevant to grate-firing (i.e. above 1000°C) (Figure 4). When co-combusting sawdust pellet with peat pellet fuel, the thermo-chemical calculations suggested that a significant share of the potassium is retained in the bottom ash as a K-rich silicate slag and as KAlSi₂O₆(s) (leucite). Furthermore, the results showed that in general, the fuel type and the proportion of peat to wood mixture greatly affected fine particle emissions levels during combustion. The present study clearly showed that the reduction of fine particles (<1 µm) was possible when co-combusting wood pellets with peat pellets in grate-fired boilers. When 10 wt% peat was added to the wood/peat fuel mixture, the fraction of fine particles was significantly decreased (about half of that emitted during pure softwood pellet combustion).

DISCUSSION AND CONCLUSION

According to previous research, the main reason for the reduction in fine potassium when burning peat with woody fuel was the binding of K to the bottom ash and slag, rather than forming fine particles such as potassium chloride (KCl) and potassium sulphate (K₂SO₄) (Öhman et al., 2010). The results of the SEM-EDS analyses (Figure 1) showed that for all fuel types/mixtures the fine PM was dominated by potassium, chlorine, sulphur, sodium and zinc. The results of this experiment (Figures 1 and 2) showed a reduction of fine particle alkali by co-combusting peat with wood. Adding 20 wt% of peat to the fuel mix did not reduce the fine particle emissions further; instead, it dramatically increased emissions of coarse particles (1–10 µm), which were not higher for the 10% peat/wood mixtures. The results show that around a 50% reduction in fine particles (<1 µm) is possible when 10 wt% peat is added to wood fuel.
FIGURE 1: PARTICLE MASS SIZE DISTRIBUTION AS GIVEN BY THE DLPI MEASUREMENTS

FIGURE 2: ELEMENTAL COMPOSITION (AVERAGE VALUES ± STDEV) PRESENTED ON OXYGEN, CARBON AND ALUMINIUM-FREE BASIS, OF THE FINE MODE PARTICLES (e.g. IMPACTOR STAGE 3, GMD 0.10 µm OR STAGE 4, GMD 0.19 µm) SAMPLED DURING COMBUSTION OF SAWDUST, SAWDUST MIXED WITH 10% PEAT, AND SAWDUST MIXED WITH 20% PEAT.
Over 3 million people worldwide continue to cook using wood. Approximately 60% of African families cook with traditional biomass (wood). Smoke and gaseous emissions pour out of burning wood, animal dung and crop residues, causing lung disease and respiratory illnesses in women and children. The World Health Organization estimates that more than 1.5 million people die each year from the indoor air pollution generated by cooking with solid fuels in poorly ventilated homes or shelters (www.who.int). Of these deaths, 24% occur in Africa. As demonstrated by this research, using upgraded and efficient biomass fuels such as wood–10% peat mixture pellet fuels in special boilers/burners and house stoves can mitigate more than 50% of cancer-causing fine particles and decrease the associated death rate. In general, switching to more efficient fuels such as wood–10% peat mixture pellet fuels would help tackle climate change, environmental degradation and unemployment.

**COMMUNICATION STRATEGY AND IMPACT**

To promote and communicate the study findings to different audiences, various communication strategies and tools are being used, including online media, academic audiences, stakeholder meetings and periodic informal meetings. The paper has been uploaded to various online platforms (ltu.se, essays.se, uppsatser.se). Presentations and briefings have been delivered to government officials and staff with policymaking, programmatic and budgetary responsibilities, with a strong emphasis on the interpretation and potential application of the results.

**ACKNOWLEDGEMENTS**

My heartfelt thanks first of all to the Swedish Energy Agency for funding this work. Many people have helped me from inception to completion of this
research. I am grateful to all of them. Special thanks go to my supervisor, Professor Marcus Öhman, at Luleå university of Technology, for his valuable support and guidance, and Dr Jonathan Fagerström of Umeå University, for his cooperation and kind assistance during measurements. NEOVA Company is gratefully acknowledged for supplying the fuel.

REFERENCES


CLIMATE CHANGE AND WATER RESOURCE AVAILABILITY IN THE OKPARA BASIN IN BENIN (WEST AFRICA): WHAT COPING STRATEGIES ARE AVAILABLE?

R. Ogouwalé, M. Boko and C.S. Houssou*
ABSTRACT

Against the backdrop of climate change, water resource availability has become of grave concern for the authorities and rural communities. The climate in Benin was characterised using the Standardized Precipitation Index for the 1965–2009 period. Referencing against the figures for 1971–2000, an analysis was made of the climate projections based on scenarios A1B and B1 of the IPCC. The downward trend in rainfall in the Okpara Basin was roughly 16% during deficit years. At the same time, temperatures will increase by 2°C. By 2050, rainfall amounts are set to decline in the region of 20 to 41% in the case of scenario B1, and 60 to 70% in the case of scenario A1B. The maximum temperatures will be up by 2.02°C and 1.9°C in scenario A1B, and by 2.08 and 2.1°C in scenario B1. This situation has an impact on flow patterns and, by extension, on water resource availability, which is dwindling. Eighty-five per cent of the people interviewed reported that the number of conflicts on water usage has increased over the past 10 years. Communities developed endogenous strategies to deal with this, but in a dry climate scenario the water supply problems could intensify, leading to frequent and violent conflicts in the area. Building on the current strategies and guaranteeing food security with a view to achieving the Millennium Development Goals means fleshing out various climate change-related initiatives such as the harnessing of surface water, crop diversification, and the management of seasonal migrations.

KEY WORDS: CLIMATE CHANGE, COPING STRATEGIES, FOOD SECURITY, OKPARA BASIN (BENIN)

AFFILIATIONS

* University of Abomey-Calavi, Benin.
INTRODUCTION

Rainfall amounts have dwindled in West Africa over the past three decades. Research conducted by Sirculon (1986) and Olivry et al. (1995) shows that the declining rainfall in West Africa has coincided with a change in climate patterns.

In Benin, Afouda (1990), Houndénou (1992) and Ogouwalé et al. (2003) reported that the lower rainfall associated with thermal heating has led to a degradation of the ecological environment, adversely affecting the availability of resources and the productivity of the ecosystems. Various regions in Benin, particularly the Okpara Basin, have proved to be vulnerable, as evidenced by the decline in water resource availability and ecosystems (Boko, 1988). Similarly, the growing demand for water has led to competition and even conflicts between the different groups (farmers, stockbreeders and households) in the Okpara Basin.

This research seeks to determine how climate change will affect water resource availability in the Okpara Basin by 2050 in order to recommend integrated and sustainable management strategies so as to guarantee food security in the area.

The Okpara Basin is located between 7°30´ and 9°54´N and 1°30´ and 3°18´E, with a surface area of 12,710 km² (Figure 1).
METHODOLOGY

Climate parameter trends for the reference period (1971–2000) were identified via the graphical method. The linear trend equation is of the form \( y = at + b \), where \( y \) = temperature, \( t \) = time, and \( a \) and \( b \) are constants. The Standardized Precipitation Index (SPI) was used to characterise the insufficient rainfall (McKee et al., 1993). The SPI’s formula is:

\[
SPI = \frac{P_i - P_m}{\sigma}
\]

where \( P_i \) = actual rainfall; \( P_m \) = mean rainfall and \( \sigma \) = standard deviation.

RESULTS

Rainfall and thermometer trend in the basin

The rainfall trend in the Okpara Basin is generally a downward one (Figure 2).

The climate projections deployed in this study are derived from the REMO regional model based on the A1B and B1 scenarios of the IPCC (Nakicenovic and Swart, 2000).
A defining feature of the 1965–2009 period was the recurrence of dry years as in 1977, 1980, 1983, 1987, 1986, 1989 and 2005. The 1975–84 decade was the driest. The deviation between the 1965–74 and 1975–84 decades was about 52%.

Unlike the rainfall, the temperatures generally tended to rise in the Okpara Basin (Figures 3 and 4) and were consistent with those highlighted regionally and globally (Paturel et al., 1999; Mahé, 2001).

The maximum temperatures rose by 2.35°C to 3.31°C between 1965 and 2009, respectively, while the minimum temperatures at the two stations increased by 2°C between 1965 and 2009. The temperature’s upward trend led to increased evaporation, constituting a climate pressure factor affecting water resources, particularly surface water in the Basin. These observations are consistent with the findings by Ardoin-Bardin (2004) and Totin (2010).

Future climate approaches in the Okpara Basin

In the Okpara Basin, by 2050, in relation to 1971–2000 (Figure 5), the months of January and November will see an increase of about 61 and 70% according to scenario B1, and of 42 and 19% according to scenario A1B.

The two scenarios point to significant rainfall amount deviations by 2050, which are set to be 20 to 41% in the case of scenario A1B, and 60 to 70% in the case of scenario B1 (Figure 6). On the same basis, there is also likely to be an increase in the minimum and maximum temperatures. More specifically, on an average basis, relative to the 1971–2000 reference period, the maximum temperatures will rise by 2.02 and 1.9°C in scenario B1; and by 2.08 and 2.1°C in scenario A1B in Parakou and Savé, respectively.
Hydrological implications of the climate dynamics

The impact of rainfall deficits and higher temperatures in the Okpara Basin on the flow patterns is evident in the reduced surface water resources (Figure 7).

An analysis of this figure shows that the maximum flows were 196 mm prior to the 1970s, after which the flows dropped below 100 mm. Accordingly, the average annual flow patterns declined by about 80 mm during the 1970s and 1980s compared with the 1990–2005 period. The deficit compared with the average is about 92%. This situation has various implications for water resource availability in the Basin. The scant and insufficient level of rainfall means people living in the areas have to dig holes in the marshland bed in order to obtain water supplies (Plate 1) for off-season farming (Plate 2).

The water supply problem is sparking off conflicts between farmers and shepherds in the Basin over this resource. Eighty-five per cent of interviewees reported that the number of water usage conflicts has risen over the past 10 years. This already challenging hydro-climate situation forms the backdrop to the looming climate change, signs of which are already apparent. In the case of a dry climate scenario in the Basin, the water supply problems would worsen, triggering frequent violent conflicts in the Okpara Basin.

Improving endogenous coping strategies in the Basin

An effective and sustainable response to the climate change burdens means urgently improving the endogenous coping strategies in the Basin. To this end, three coping strategies have been identified: water demand management (demands for irrigation and demands for human settlements); better supplies; and water resource conservation. These various types of sustainable water supply management systems for the local community should be facilitated because of the stated national strategies for this area.
FIGURE 7: YEAR-TO-YEAR VARIATION IN FLOW PATTERNS IN THE OKPARA BASIN IN KABOUA

PLATE 1: WATER SUPPLY IN A HOLE IN N’DALI (SOURCE: R. OGOUWALÉ, MARCH 2008)

PLATE 2: OFF-SEASON FARMING ON MARSHLAND IN KIKA (SOURCE: R. OGOUWALÉ, MARCH 2008)
DISCUSSION AND CONCLUSION

The rainfall and temperature conditions were shown to impact on the average flow patterns in the Okpara Basin. This situation is expected to worsen by 2050, owing to the threefold threat of lower rainfall amounts, higher minimum and maximum temperatures, and increased population pressure on natural resources in general and water resources in particular (IPCC, 2001; Totin, 2010).

The scale of climate change and water problems in the Okpara Basin has resulted in modern techniques being recommended in view of water resource vulnerability to climate change and environmental changes.

COMMUNICATION STRATEGY AND IMPACT

With a view to disseminating the research achievements, the beneficiaries are divided into two categories. (1) Local elected representatives and support officers, employees from the Ministry of Water, Ministry of Agriculture, Stockbreeding and Fisheries, and community radio stations. These beneficiaries are informed of the research achievements via training sessions (workshops and seminars), video presentations, working groups, distribution of leaflets, etc. (2) Farmers, stockbreeders and women. These beneficiaries are informed of the findings and coping techniques via
awareness-raising sessions and community radio station broadcasts in the various localities. Women are brought in via the tontine groups. In return, they are required to educate their husband farmers and stockbreeders. Associations representing farmers and stockbreeders and opinion leaders will also be mobilised. Resources include video and audiotapes, comic books, songs, etc.

Once the schemes have been applied, an integrated conflict reduction system reflecting all the demands of stakeholders in the area will be formulated for pastoralists and farmers in the Okpara Basin. The focus will be on applying a rotation method, particularly around permanent water bodies or streams, where pastoralists will be required to observe migratory herding routes and farmers to ensure their fields are well away from these routes.

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REFERENCES


MARKER-ASSISTED SELECTION FOR IMPROVEMENT OF HIGH AND EARLY ROOT PRODUCTIVITY IN CASSAVA (MANIHOT ESCULENTA CRANTZ)

B. Olasanmi\textsuperscript{1,2,3}, M.O. Akoroda\textsuperscript{1}, E. Okogbenin\textsuperscript{2,3}, C. Egesi\textsuperscript{3} and M. Fregene\textsuperscript{2,4}
ABSTRACT

Late root bulking is a major factor leading to the rejection and abandonment of improved cassava genotypes in sub-Saharan Africa. Early-bulking varieties shorten the growth period from planting to harvesting by 5 months or more. These varieties are suitable for environments with a short rainy season, in which reduced exposure to biotic and abiotic stresses leads to increased productivity. The objective of this research was to use molecular markers to fast-track selection of early bulking and high root yield (EB-HY) cassava genotypes that will lead to early-maturing varieties. To improve cassava for early productivity, nine cassava populations were developed at NRCRI, Umudike, Nigeria. The progenies were evaluated for EB-HY at seedling, clonal and preliminary yield trial stages 7 months after planting (MAP). The progenies were genotyped at 542 simple sequence repeat (SSR) marker loci using bulked segregant analysis to identify markers associated with EB-HY in cassava. Thirty-two selected genotypes and two checks were evaluated for EB-HY at Umudike, Otobi and Ibadan at 7 MAP in a randomised complete block design with three replications. The collected data were subjected to statistical analyses. There were significant differences among the genotypes for all the variables at different evaluation stages. Nine SSR markers were closely associated ($r = 0.3-0.5$; $P < 0.05$) with EB-HY in six populations. Seven of the markers with a regression coefficient of 0.2 or more were linked to major quantitative trait loci associated with EB-HY in cassava. Genotype plus genotype × environment biplot analysis identified different elite genotypes at different locations. The significant relationship ($r = 1$) observed between fresh root yield (FRY) and dry root yield (DRY) suggests that DRY is highly a function of FRY. Therefore a breeder may select with high accuracy for DRY in cassava using FRY data. The EB-HY cassava genotypes with higher FRY than the checks across the three locations offer cassava growers high productivity in under 12 months.

KEY WORDS: DRY ROOT YIELD, EARLY BULKING, GENOTYPE, LATE ROOT BULKING, PROGENIES, QUANTITATIVE TRAIT LOCI

AFFILIATIONS

1 University of Ibadan, Nigeria.
2 International Centre for Tropical Agriculture (CIAT), Cali, Colombia.
3 National Root Crops Research Institute (NRCRI), Umuahia, Nigeria.
4 Donald Danforth Plant Science Center, St Louis, USA.
INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the most important of the root crops in the tropics and ranks fourth after rice, sugarcane and maize as a source of calories for human needs (CIAT, 1992; IITA, 2000). Since its introduction into Africa in the 16th century, cassava has spread throughout sub-Saharan Africa to become one of the dominant starchy staples in people’s diets. It is cultivated in about 40 African countries, stretching through a wide belt from Madagascar in the south-east to Senegal and Cape Verde in the north-west, and famine rarely occurs in areas where it is widely grown (Nweke et al., 2002). Cassava ranks first among the major food crops in Nigeria in terms of calories per unit time and area. It supplies 70% of the total calorie intake of about 60 million people in Nigeria (Ezulike et al., 2006) and it is gradually gaining importance as an industrial crop. In most rural communities in Nigeria, hardly a day would pass without the consumption of at least one meal of cassava.

Apart from being the major source of carbohydrate for most Nigerians, it has other diverse uses in pharmaceutical, confectionery and livestock industries in Nigeria (Eke-Okoro and Dixon, 2000). Its production and processing provide employment and income for the rural poor, especially women and children (Sarma and Kunchai, 1989). However, cassava’s long growth cycle makes it relatively difficult for the crop to be readily available on time to farmers and consumers for food and income (Olusanmi et al., 2012). Furthermore, rainfall patterns in some parts of the tropics, where rain lasts for about 6–8 months, create a distinction between rainy and dry seasons. Most of the cassava-growing zones in Nigeria, for example, fall within the agro-ecological zones where there is such a distinction between the two seasons. This means that the cassava plants grow effectively for about 5–7 months in a year in such areas.

Growing demand for cassava as food, feed and industrial raw material has made genotypes with high yield and early bulking attributes highly desirable, hence improvement of early bulking may have the dual advantage of producing early bearing varieties and improved crop yields (Okogbenin and Fregene, 2002). Cultivation of the early-bulking and high-yielding (EB-HY) cassava genotypes will reduce the time farmers need to wait before they can reap food and income from their farms, thereby improving the role of cassava as a food security crop (Olusanmi, 2010). The importance of cassava to humanity in ensuring food security, and its ever-increasing economic importance as an export crop and a drought-tolerant crop, justify the need to improve cassava for early bulking and high root yield. While biotechnology cannot replace conventional breeding methods, its integration with the latter has the potential to facilitate improvement in crop yield and quality. The objective of this study was therefore to use molecular markers to fast-track selection of EB-HY cassava genotypes that will lead to early-maturing cassava varieties.

METHODOLOGY

Nine cassava-mapping populations (COB-1 to COB-9) were developed at NRCRI, Umudike using six elite varieties from the African cassava germplasm as parents in 2005 (Table 1). The three female parents had been classified earlier as early-bulking varieties and the three male parents as late-bulking varieties at NRCRI (Umudike, unpublished data).

The seeds were sown in the greenhouse and the seedlings were transplanted to the field 10 weeks later. The progeny were evaluated for EB-HY at seedling, clonal and preliminary trial stages 7 months after planting (MAP) at Umudike between 2006 and 2008. The genotypes were evaluated for resistance to cassava mosaic disease.
(CMD), a devastating cassava disease in Africa at 1, 3 and 5 MAP. The parameters measured at harvesting included fresh root yield (FRY); fresh shoot weight (FSW); number of storage roots (NOORT); and harvest index (HI). The progeny in each population were genotyped at 542 simple sequence repeat (SSR) marker loci. Bulked segregant analysis was used to identify the SSR markers associated with EB-HY in each of the nine populations.

The 542 SSR markers used to screen the nine populations cover the entire cassava genome to enable detection of a good number of quantitative trait loci (QTLs) associated with EB-HY in cassava. The identified SSR markers were used to select EB-HY genotypes in the respective populations. Thirty-two EB-HY genotypes selected after preliminary evaluation trial and two controls (TMS 30572 and TMS 98/0505) were evaluated for EB-HY at three locations (Umudike, Otobi and Ibadan) in Nigeria (Figure 1) at 7 MAP in 2008. TMS 30572 is the national check, while TMS 98/0505 is an EB-HY variety released by IITA, Ibadan. The experimental design used at each location was randomised complete blocks with three replications. The data collected from the genotyping study were subjected to correlation and regression analyses, while the field data were subjected to analysis of variance (ANOVA) and genotype plus genotype × environment (GGE) biplot analysis.

**RESULTS**

A total of 4,134 seeds were generated from the nine crosses, and 39% of the seeds emerged as seedlings in the nursery. The progeny in each population segregated for resistance to cassava mosaic disease and significant differences (\( P < 0.05 \)) were observed for FRY (Table 2), FSW, NOORT and HI at seedling, clonal and preliminary evaluation stages. Significant genotype × environment interaction (\( P < 0.05 \)) was also observed for all the traits studied across locations. Nine SSR markers were closely associated (\( r = 0.3–0.5; P < 0.05 \)) with EB-HY in six of the nine hybrid populations. Seven of the nine QTLs used for marker-assisted selection (MAS) in this study were linked to major QTLs.

**TABLE 1: NINE CASSAVA HYBRID POPULATIONS DEVELOPED FROM SIX ELITE VARIETIES**

<table>
<thead>
<tr>
<th>Population</th>
<th>Female parent</th>
<th>Male parent</th>
<th>Number of progeny</th>
</tr>
</thead>
<tbody>
<tr>
<td>COB-1</td>
<td>TMS 30572</td>
<td>TMS 30555</td>
<td>181</td>
</tr>
<tr>
<td>COB-2</td>
<td>TMS 30572</td>
<td>NR 8212</td>
<td>119</td>
</tr>
<tr>
<td>COB-3</td>
<td>TMS 30572</td>
<td>NR 8083</td>
<td>124</td>
</tr>
<tr>
<td>COB-4</td>
<td>TMS 97/2205</td>
<td>TMS 30555</td>
<td>148</td>
</tr>
<tr>
<td>COB-5</td>
<td>TMS 97/2205</td>
<td>NR 8212</td>
<td>133</td>
</tr>
<tr>
<td>COB-6</td>
<td>TMS 97/2205</td>
<td>NR 8083</td>
<td>101</td>
</tr>
<tr>
<td>COB-7</td>
<td>TMS 98/0505</td>
<td>TMS 30555</td>
<td>272</td>
</tr>
<tr>
<td>COB-8</td>
<td>TMS 98/0505</td>
<td>NR 8212</td>
<td>199</td>
</tr>
<tr>
<td>COB-9</td>
<td>TMS 98/0505</td>
<td>NR 8083</td>
<td>217</td>
</tr>
</tbody>
</table>
The GGE biplot analysis identified different promising EB-HY genotypes for each of the locations (Figure 2). The best genotypes at each location cluster around the location in the figure. There was a positive correlation between FRY/DRY and the number of roots/plant (NOORT), harvest index (HARVEST), and total biomass (BIOMASS) as indicated by the acute angle between their respective vectors (Figure 3). The significant relationship ($r = 1$) observed between FRY and DRY at 7 MAP, as demonstrated by the genotype × trait biplot analysis (Figure 3), suggests that DRY is a function of FRY, regardless of differences in the dry matter content of the genotypes evaluated.

Table 2 shows the mean DRY of the selected EB-HY genotypes and the two controls across the three locations. Six of the genotypes had higher mean DRY than TMS 98/0505. The top EB-HY genotypes identified at Umudike (COB-4-74, COB-4-100, COB-7-180, COB-7-197 and COB-5-57), Ibadan (COB-5-53, COB-6-1, COB-5-4, 5-17 and COB-4-75) and Otobi (COB-7-25, COB-5-53, COB-6-4, COB-1-139 and COB-4-75) had DRY of 4.84–5.96, 7.19–8.43 and 9.59–13.15 t/ha, respectively. However, only COB-7-25 had significantly higher mean DRY than the controls across the locations.
DISCUSSION AND CONCLUSION

The significant differences observed among the genotypes in each population for EB-HY and associated traits (FRY, FSW, NOORT and HI) showed that the mapping populations are useful for genomic study of the traits. The study findings support previous research which found that early yield in cassava is highly influenced by harvest index, foliage and root number (Okogbenin and Fregene 2002). The highly significant relationship observed between DRY and FRY in this study indicated that a breeder may select with high accuracy for DRY in cassava using the FRY data at 7 MAP.

FIGURE 2: GENOTYPE PLUS GENOTYPE × ENVIRONMENT (GGE) BIPLOT BASED ON THE FRESH ROOT YIELD (t/ha) OF 32 EARLY-BULKING CASSAVA GENOTYPES AND TWO CONTROLS GROWN AT THREE LOCATIONS IN NIGERIA IN 2008

PCI = 64.7%, PC2 = 18.9%; sum = 83.6%. All genotypes are prefixed by COB-, except TMS 98/0505 and TMS 30572. Test sites are given in block letters. PC = principal component.

FIGURE 3: GENOTYPE × TRAIT (GT) BIPLOT OF 32 EARLY-BULKING CASSAVA GENOTYPES AND TWO CONTROLS AT THREE LOCATIONS IN NIGERIA IN 2008

Evaluated for fresh root yield (FRY), dry root yield (DRY), harvest index (HARVESTI), number of storage roots (NOORT), total biomass (BIOMASS), fresh weight of leaves, petiole and non-plantable stems (LEAVPET), stump weight (STUMPWLT), and plantable stem yield (STEMWT).
### TABLE 2: MEAN DRY ROOT YIELD (t/ha) OF SELECTED EARLY BULKING AND HIGH-YIELD CASSAVA GENOTYPES AND TWO CONTROLS AT THREE LOCATIONS IN NIGERIA 7 MONTHS AFTER PLANTING

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Umudike</th>
<th>Ibadan</th>
<th>Otobi</th>
<th>Mean</th>
<th>% Rel. index</th>
</tr>
</thead>
<tbody>
<tr>
<td>COB-7-25</td>
<td>4.68</td>
<td>6.58</td>
<td>13.15</td>
<td>8.14</td>
<td>128.5</td>
</tr>
<tr>
<td>COB-5-53</td>
<td>3.13</td>
<td>8.43</td>
<td>10.44</td>
<td>7.33</td>
<td>115.9</td>
</tr>
<tr>
<td>COB-6-4</td>
<td>4.77</td>
<td>6.64</td>
<td>10.27</td>
<td>7.23</td>
<td>114.2</td>
</tr>
<tr>
<td>COB-4-75</td>
<td>4.37</td>
<td>7.19</td>
<td>9.59</td>
<td>7.05</td>
<td>111.4</td>
</tr>
<tr>
<td>COB-4-100</td>
<td>5.68</td>
<td>6.71</td>
<td>8.07</td>
<td>6.82</td>
<td>107.7</td>
</tr>
<tr>
<td>COB-5-4</td>
<td>2.98</td>
<td>7.62</td>
<td>9.45</td>
<td>6.68</td>
<td>105.6</td>
</tr>
<tr>
<td>TMS 98/0505</td>
<td>4.02</td>
<td>6.56</td>
<td>8.41</td>
<td>6.33</td>
<td>100.0</td>
</tr>
<tr>
<td>COB-5-57</td>
<td>4.84</td>
<td>5.74</td>
<td>8.38</td>
<td>6.32</td>
<td>99.8</td>
</tr>
<tr>
<td>COB-5-36</td>
<td>4.24</td>
<td>6.46</td>
<td>8.23</td>
<td>6.31</td>
<td>99.7</td>
</tr>
<tr>
<td>COB-4-27</td>
<td>3.76</td>
<td>6.31</td>
<td>8.81</td>
<td>6.29</td>
<td>99.4</td>
</tr>
<tr>
<td>COB-7-180</td>
<td>5.39</td>
<td>5.21</td>
<td>7.79</td>
<td>6.13</td>
<td>96.8</td>
</tr>
<tr>
<td>TMS 30572</td>
<td>4.47</td>
<td>5.62</td>
<td>8.03</td>
<td>6.04</td>
<td>95.4</td>
</tr>
<tr>
<td>COB-7-197</td>
<td>4.86</td>
<td>5.63</td>
<td>7.52</td>
<td>6.00</td>
<td>94.8</td>
</tr>
<tr>
<td>COB-4-77</td>
<td>2.75</td>
<td>6.56</td>
<td>8.64</td>
<td>5.98</td>
<td>94.5</td>
</tr>
<tr>
<td>COB-5-17</td>
<td>3.96</td>
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<td>6.58</td>
<td>5.97</td>
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</tr>
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<td>COB-4-74</td>
<td>5.96</td>
<td>5.13</td>
<td>6.44</td>
<td>5.84</td>
<td>92.3</td>
</tr>
<tr>
<td>COB-1-139</td>
<td>3.87</td>
<td>3.22</td>
<td>10.05</td>
<td>5.71</td>
<td>90.3</td>
</tr>
<tr>
<td>COB-5-28</td>
<td>2.57</td>
<td>5.10</td>
<td>8.80</td>
<td>5.49</td>
<td>86.7</td>
</tr>
<tr>
<td>COB-6-1</td>
<td>1.89</td>
<td>7.80</td>
<td>6.69</td>
<td>5.46</td>
<td>86.3</td>
</tr>
<tr>
<td>COB-5-61</td>
<td>2.55</td>
<td>6.49</td>
<td>7.04</td>
<td>5.36</td>
<td>84.7</td>
</tr>
<tr>
<td>COB-5-24</td>
<td>2.10</td>
<td>6.13</td>
<td>7.74</td>
<td>5.32</td>
<td>84.1</td>
</tr>
<tr>
<td>COB-1-163</td>
<td>2.41</td>
<td>4.71</td>
<td>8.06</td>
<td>5.06</td>
<td>79.9</td>
</tr>
<tr>
<td>COB-5-86</td>
<td>2.78</td>
<td>5.24</td>
<td>7.15</td>
<td>5.06</td>
<td>79.9</td>
</tr>
<tr>
<td>COB-6-19</td>
<td>3.46</td>
<td>5.19</td>
<td>6.20</td>
<td>4.95</td>
<td>78.2</td>
</tr>
<tr>
<td>COB-5-12</td>
<td>3.60</td>
<td>3.14</td>
<td>7.93</td>
<td>4.89</td>
<td>77.3</td>
</tr>
<tr>
<td>COB-5-48</td>
<td>2.06</td>
<td>4.71</td>
<td>7.35</td>
<td>4.71</td>
<td>74.4</td>
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<tr>
<td>COB-6-31</td>
<td>1.34</td>
<td>6.26</td>
<td>6.30</td>
<td>4.63</td>
<td>73.2</td>
</tr>
<tr>
<td>COB-1-103</td>
<td>1.67</td>
<td>5.10</td>
<td>6.91</td>
<td>4.56</td>
<td>72.0</td>
</tr>
<tr>
<td>COB-5-11</td>
<td>3.21</td>
<td>4.43</td>
<td>5.83</td>
<td>4.49</td>
<td>70.9</td>
</tr>
<tr>
<td>COB-4-79</td>
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<td>5.31</td>
<td>5.69</td>
<td>4.26</td>
<td>67.3</td>
</tr>
<tr>
<td>COB-6-41</td>
<td>1.63</td>
<td>4.79</td>
<td>5.77</td>
<td>4.06</td>
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</tr>
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<td>COB-5-44</td>
<td>2.74</td>
<td>4.10</td>
<td>5.24</td>
<td>4.03</td>
<td>63.6</td>
</tr>
<tr>
<td>COB-5-104</td>
<td>2.69</td>
<td>4.13</td>
<td>5.01</td>
<td>3.94</td>
<td>62.3</td>
</tr>
<tr>
<td>COB-4-52</td>
<td>2.37</td>
<td>3.74</td>
<td>4.20</td>
<td>3.44</td>
<td>54.3</td>
</tr>
<tr>
<td>Mean</td>
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<td>5.69</td>
<td>7.70</td>
<td>5.59</td>
<td>88.23</td>
</tr>
<tr>
<td>CV (%)</td>
<td>37.1</td>
<td>22.6</td>
<td>23.4</td>
<td>19.6</td>
<td>19.6</td>
</tr>
<tr>
<td>LSD</td>
<td>1.8</td>
<td>2.8</td>
<td>2.42</td>
<td>1.42</td>
<td></td>
</tr>
</tbody>
</table>

% Rel. index = percentage relative index in relation to the best check (TMS 98/0505).
The SSR markers identified in this study were useful in selecting for EB-HY in the respective cassava population. The seven markers with regression coefficient (phenotypic variation) of 20% or more were candidate markers linked to major QTLs associated with EB-HY in the respective cassava population, while the remaining two are linked to minor QTLs.

Non-association of any of the 542 markers with EB-HY in the remaining three populations may be due to the fact that there were still gaps in the cassava genetic maps, leading to some markers being unlinked (Okogbenin, 2004). This suggested the cassava genome should be saturated with more molecular markers to identify QTLs associated with EB-HY in such populations, and even detect more markers associated with the trait in each of the six populations for which at least one marker was identified.

Increased production can result from an increase in the land area cultivated or in yield per land area. The latter can be achieved by improvement in the yield capability of the plant or by shortening its growth cycle. Most of the cassava cultivars currently grown in Africa mature in 12 months or more. Cassava varieties developed in this study combine both early-bulking and high-yielding potentials. Therefore a farmer cultivating EB-HY cassava variety under irrigation or in areas where there is sufficient soil moisture almost year-round can harvest twice within the same period when other farmers who cultivate the late-bulking variety harvest only once. Cultivation of EB-HY cultivars will ensure optimal utilisation of soil nutrients and other resources by the plants during the rainy season to ensure rapid accumulation of assimilates in the storage roots at the early growth stage. This will therefore reduce the time farmers wait before they can reap some food/income from their farms and thereby improve the role of cassava as a food security crop. Also, these varieties may be important to young farmers starting their own farm and requiring early harvest. The EB-HY genotypes identified in this study have been further evaluated in three seasons at different locations in Nigeria. The four top genotypes are currently being evaluated in pre-release trials at 14 locations under the Nigerian Government’s Cassava Transformation Agenda. The selected top genotypes will be evaluated further at 65 sites in 13 states in Nigeria with Agricultural Development Programmes (ADPs). The best varieties, when finally released to farmers, will ensure high root productivity, thereby helping to achieve food security. The farmers will also have more roots to sell, translating to increased income, and therefore poverty reduction.

**COMMUNICATION STRATEGY AND IMPACT**

The results of this study will be communicated through government agencies, non-governmental organisations and farmer-to-farmer distribution systems. The best genotypes selected after pre-release trials will be recommended to the Nigerian government for official release to farmers in Nigeria. Planting materials of the released varieties will be multiplied and distributed/sold to farmers, possibly at subsidised rates, to ensure farmers have access to the planting materials at affordable prices. Farmers in other countries in Africa, Asia and South America, where cassava is mainly grown, will also be offered planting materials of the varieties from Nigeria to cultivate in their countries. Cassava breeders in other parts of the world can use the varieties and identified molecular markers in their breeding programmes for further improvement of cassava for EB-HY.

Some of the findings from this study have been published in conference proceedings and journal papers, others are being prepared for publication in international journals to afford other scientists in the world access to information which may be useful for their breeding programmes.
Cultivation of EB-HY cassava varieties can contribute to increased productivity and possibly reduced production costs and food prices. Opportunities for diversification (e.g. production of ethanol for biofuels and a range of food products) can be expanded. Resource-poor farmers will be able to boost cassava productivity under adverse climatic conditions and improve nutritional impact. Interestingly, they can grow the EB-HY varieties using their prevailing agricultural practices because cultivation of the varieties does not require any new farming technology.

ACKNOWLEDGMENTS

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CLIMATE, CATTLE REARING SYSTEMS AND AFRICAN ANIMAL TRYPANOSOMOSIS RISK IN BURKINA FASO*

S. Pagabeleguem¹, M. Sangaré¹, Z. Bengaly¹, M. Akoudjin¹, A.M.G. Belem² and J Bouyer³,⁴
ABSTRACT

In sub-Saharan countries infested by tsetse flies, African animal trypanosomosis (AAT) is considered as the main pathological constraint to cattle breeding. Africa has known a strong climatic change and its population was multiplied by four during the past half-century. The aim of this study was to characterise the impact of production practices and climate on tsetse occurrence and abundance, and the associated prevalence of AAT in Burkina Faso. Four sites were selected along a south–north transect of increasing aridity. The study combines parasitological and entomological surveys. For the parasitological aspect, blood samples were collected from 1,041 cattle selected through a stratified sampling procedure including location and livestock management system (long transhumance, short transhumance, sedentary). Parasitological and serological prevalence specific to livestock management systems show a gradual increase from the Sahelian to the Sudano-Guinean area ($P < 0.05$). Livestock management system had also a significant impact on parasitological prevalence ($P < 0.05$). Tsetse diversity, apparent densities and their infection rates overall decreased with aridity, from four species, an apparent density of 53.1 flies/trap/day and an infection rate of 13.7% to an absence at the northern edge of the transect, where the density and diversity of other biting flies were on the contrary highest ($P < 0.001$). The climatic pressure clearly had a negative impact on tsetse abundance and AAT risk. However, the persistency of tsetse habitats along the Mouhoun river loop maintains a high risk of cyclical transmission of Trypanosoma vivax. Moreover, an ‘epidemic mechanical livestock trypanosomosis’ cycle is likely to occur in the northern site, where trypanosomes are brought in by cattle transhuming from the tsetse infested area and are locally transmitted by mechanical vectors. In Burkina Faso, the impact of tsetse thus extends to a buffer area around their distribution belt, corresponding to the herd transhumance radius.

KEY WORDS: LIVESTOCK MANAGEMENT SYSTEM, PARASITOLOGICAL SURVEY, TRANSHUMANCE RADIUS, TSETSE FLIES

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INTRODUCTION

The climatic change and its impact on environments vary extensively in space and time (Müller, 2009) due to local socio-cultural and biophysical conditions. However, the increase of the frequency and amplitude of extreme climatic events (extreme temperatures, droughts, flooding, etc.) is generally fast, like the extreme vulnerability of West African small producers to cope with these changes. These events are not caused by natural variations of the climate only: they are exemplified by an increased exploitation of natural resources, particularly land use (Hulme et al., 2001). For example, from some 30 million inhabitants in 1900, the West African population increased to 306 million in 2010, and could reach between 550 and 700 million in 2050 (Courtin and Guengant, 2011). The development of extensive agriculture and the increase in human density are associated to landscape fragmentation in the Mouhoun river basin (Guerrini et al., 2008).

Associated to extreme climatic events are huge consequences on the environment and sustainable development, particularly for African producers who depend strongly on ecosystem services like natural grazing (TerraAfrica, 2009). These changes have also an impact on vectors’ environment, and thus on their geographical distribution and density. This situation causes a modification of the host–vector contacts and hence of the epidemiology of vector diseases, particularly African animal trypanosomoses (AAT) (Van den Bossche et al., 2010).

Indeed, these diseases represent the main constraint to the development of more intensive livestock production systems in sub-Saharan Africa (Swallow, 1999), notably in areas with high agricultural potential. Cattle breeding has an important place in the economy and socio-cultural activities of populations. Thus controlling trypanosomoses and their vectors becomes a major step to increase the productivity of livestock production systems and contribute to small producers’ food security. Several methods are proposed for the control and reduction of trypanosomosis negative impacts on animal production. However, the impact of the present instability of tsetse flies’ natural habitats caused by climatic changes and anthropic pressure must be taken into consideration (Van den Bossche et al., 2010). The global objective of this survey was to analyse the relative impact of production practices, particularly transhumance, and climatic conditions on the epidemiology of AAT and their main vectors (tsetse) in Burkina Faso.

MATERIALS AND METHODS

Study area

The survey was achieved in four sites along a south–north transect in Burkina Faso (Figure 1). These sites were selected according to cattle production systems and the agro-ecological area to which they belong: Folonzo, in the Sudano-Guinean area (16°60´W and 9°87´N), which is a welcome area for transhumant herds; Koumbia, in the Sudanese area (15°50´W and 11°07´N), which is a welcome, transit and attachment area for transhumant herds; Dédougou, in the Sudano-Sahelian area (15°55´W and 12°49´N), a welcome, transit and attachment area for transhumant herds; and Djibo, in the Sahelian area (13°60´W and 14°10´N), an attachment area for transhumant herds.

Parasitological surveys

Blood samples were taken at the jugular vein from a total of 1,041 cattle (Table 1). In each livestock-rearing system, cattle were selected randomly without criteria of age, sex or breed. However, the sex and the age of the animals, the date of the last treatment against AAT and the type of trypanocid used were recorded. The sample was composed of Fulani zebus and half-bred between Fulani zebus and ‘Baoulé’ trypanotolerant cattle and in the majority by females (73.63%). Animals belonged mainly to Fulani cattle farmers.
Two diagnosis methods were used for blood examination of the samples: the Buffy-coat (BCM) (Murray et al., 1997) to detect active infections by trypanosomes; and the indirect ELISA method to detect antitrypanosomes antibodies in plasma, attesting past or present infections of the animal with trypanosomes (Desquesnes, 1997). The BCM allowed the diagnosis of trypanosome species based on morphological, mobility and size criteria (Murray et al., 1997).

**Entomological surveys**

All biting flies were trapped, immediately followed by tsetse flies dissection. In each of the four sites (Figure 1), ten standard biconical traps (Challier and Laveissière, 1973) were set at intervals of 100 m along cattle-watering points. The trapping lasted 72 h with harvests every 24 h. Tsetse and other biting flies were numbered by species and by trap, and apparent density per trap (ADT) per day was calculated.

Non-teneral tsetse flies were dissected using a binocular microscope. The dissection started with the proboscis, then the salivary glands and finally the mid-gut. After dissection, these organs were placed between a slide and a cover slip in a drop of Ringer’s solution, and then observed using a microscope (640) for parasite detection. Flies with an infected organ were collected in eppendorf tubes of 0.5 ml containing 30 ml of sterile distilled water (each organ independently) and stored at 220°C for ulterior PCR (polymerase chain reaction) analysis to determine the species of trypanosome involved, with primers for *T. vivax* and *T. congolense*.

**FIGURE 1: LOCATION OF THE STUDY SITES ALONG THE CLIMATIC GRADIENT IN BURKINA FASO**

- Sahelien area
- Sudano-sahelian area
- Sudanese area
- Sudano-guinean area

Legend

- South-north aridity transect

Djibo
Dédogou
Koumbia
Folonzo

North
savannah type (Desquesnes and Davila, 2002). In the same way, females’ physiological age was determined by the dissection of the reproductive system (ltard, 1966).

**Statistical analyses**

Rates of infection of cattle and tsetse in different sites were compared using the chi-square test and binomial mixed-effects models, where the cattle-rearing system and the site represented the stationary effects. The herd was considered as a random effect. The ADP were compared overall using a Kruskal–Wallis rank sum test (Hollander and Wolfe, 1973) and then by pairs using the Steel-type nonparametric multiple comparisons test (npmc) (Munzel and Hothorn, 2001). Tests were performed using the R-2.9.2-win32 software.

The mean number of infectious flies by trap and by day was calculated as an indicator of cyclical transmission risk (Bouyer et al., 2006). The relative risks and their confidence intervals were obtained from bootstrapping in the ADT and infectious rate distributions from each site, assuming spatial homogeneity within a given site (5000 Monte Carlo simulations, @risk software).

**RESULTS**

**Parasitological surveys**

Parasitological and serological prevalences were different between sites ($P < 0.05$). They gradually increased along the climatic gradient of the Sahelian area toward the Sudano-Guinean area (Table 2), from 0 to 20% and 18 to 83% for parasitological and serological prevalence, respectively ($P < 1023$).

Parasitological investigations allowed detecting active infections by *T. vivax* and *T. congolense* with predominance of *T. vivax* in Dédougou and Koumbia and of *T. congolense* in Folonzo. No case of active infection by *T. brucei brucei* was identified in any of the sites (Table 2). In Djibo, no case of active infection by any trypanosome species was found.

The cattle-rearing system had a significant impact on the parasitological prevalence ($P = 0.02$) but not on the serological prevalence ($P = 0.77$).

In Dédougou and Koumbia, parasitological prevalences were significantly higher in the sedentary rearing system than in those practising long transhumance toward the subhumid and

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**TABLE 1: DISTRIBUTION OF SAMPLED ANIMALS IN SITES ACCORDING TO CATTLE REARING SYSTEMS**

<table>
<thead>
<tr>
<th>Cattle-rearing system</th>
<th>Site</th>
<th>Djibo</th>
<th>Dédougou</th>
<th>Koumbia</th>
<th>Folonzo</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long transhumance</td>
<td></td>
<td>59</td>
<td>55</td>
<td>164</td>
<td>-</td>
<td>278</td>
</tr>
<tr>
<td>Short transhumance</td>
<td></td>
<td>178</td>
<td>-</td>
<td>-</td>
<td>63</td>
<td>241</td>
</tr>
<tr>
<td>Sedentary</td>
<td></td>
<td>159</td>
<td>130</td>
<td>200</td>
<td>33</td>
<td>522</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>396</td>
<td>185</td>
<td>364</td>
<td>96</td>
<td>1041</td>
</tr>
</tbody>
</table>

Sites are ordered by increasing annual rainfall from the left to the right. –, Non-identified cattle rearing system.
humid areas of the south ($P < 0.05$). In Djibo, animal carriers of antitrypansomes antibodies were identified in the three cattle-rearing systems (Table 2). \textit{T. congolense} was predominant in the transhuming herds in all the sites ($P < 10^{-3}$).

In the whole area, the mean hematocrit of seropositive animals was not significantly different ($P > 0.05$) from that of seronegatives: 32.63 and 33.04% in Djibo, 30.63 and 31.35% in Dédougou, 32.58 and 32.92% in Koumbia, and 25.77 and 28.13% in Folonzo.

**Entomological surveys**

Tsetse fly densities varied significantly along the climatic gradient ($P < 10^{-3}$). No tsetse was captured in Djibo, contrary to Folonzo where the ADT was $53.10 \pm 70.15$; $8.16 \pm 5.55$ in Koumbia and $27.24 \pm 23.72$ in Dédougou (Figure 2). The difference between Koumbia and Dédougou was not significant ($P = 0.09$) whereas all the other pair-comparisons were highly significant ($P < 0.02$).

The specific density analysis shows that \textit{Glossina tachinoides} has the largest spectrum of distribution. The highest ADT for this species, $39.63 \pm 56.69$, found in Folonzo, was significantly higher than in Dédougou ($21.62 \pm 20.18$, $P < 0.05$) and Koumbia sites ($7.03 \pm 5.34$, $P < 0.001$). The ADT of \textit{G. tachinoides} in Dédougou was also significantly higher than in Koumbia ($P < 0.001$). \textit{G. palpalis gambiensis} was present in three sites, but with lower ADT ($1.87 \pm 2.71$ in Koumbia, $0.36 \pm 0.76$ in Dédougou and $0.79 \pm 1.28$ in Folonzo) compared with those of \textit{G. tachinoides}. \textit{G. morsitans submorsitans} and \textit{G. medicorum} were found only in Folonzo with ADT of $10.5 \pm 15.23$ and $0.6 \pm 1.30$, respectively. The tsetse fly diversity decreased with the aridity gradient, from 4 to 0. At the opposite, the diversity of other biting flies increased from 1 to 4 with the aridity gradient (Table 3), and the apparent densities were higher ($P < 0.001$) in the drier site (Djibo) than in the three other sites, where they were similar ($P > 0.05$).

The tsetse infection rates were significantly different between Dédougou (93 flies dissected), Koumbia (34) and Folonzo (146) ($P = 0.038$). Rates of infections were 9.5% (SD 1.8%) by microscopy and 4.8% (SD 1.3%) only by PCR ($P < 0.05$), suggesting that almost half of the flies were infected by nonpathogenic species of trypanosomes for

**TABLE 2: Parasitological and serological prevalences by trypanosome species according to cattle rearing system and site**

<table>
<thead>
<tr>
<th>Site</th>
<th>Parasitological prevalences (%)</th>
<th>Serological prevalences (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Djibo</td>
<td>Dédougou</td>
</tr>
<tr>
<td>CRS</td>
<td>Lt  St  Sed Lt  Sed Lt  Sed Lt  Sed Lt  Sed</td>
<td></td>
</tr>
<tr>
<td>Tv</td>
<td>0    0    0   0.8  0.6  10.5  9.5  3.0</td>
<td></td>
</tr>
<tr>
<td>Tc</td>
<td>0    0    0   0    0    0    12.7 18.2 5.1 6.2 8.8 25.5 15.4 19.5 31 50.8 27.2</td>
<td></td>
</tr>
<tr>
<td>Tbb</td>
<td>0    0    0   0    0    0    0    0    0    6.8 0.6 0.6 0   5.4  2.4  7.5  0    0</td>
<td></td>
</tr>
<tr>
<td>T.spp/CRS</td>
<td>0    0    0   0.8  1.2  10.5 22.2 21.2 13.6 15.2 23.3 34.5 42.3 62.2 64.5 79.7 90.9</td>
<td></td>
</tr>
<tr>
<td>T.spp/Site</td>
<td>0    0.54 6.32 19.79 18.43 40.02 63.46 83.33</td>
<td></td>
</tr>
</tbody>
</table>

Sites are ordered by increasing annual rainfall from the left to the right. CRS: Cattle rearing systems; St: Short transhumance; Lt: Long transhumance; Sed: sedentary; *long transhumance not identified in this site; **short transhumance not identified in this site; Tv: Trypanosoma vivax; Tc: T. congolense; Tbb: T. brucei brucei; T.spp: all trypanosome species together.
cattle. The highest proportion of flies infected, all trypanosomes species together, was observed in Folonzo (13.70%; \(P = 0.03\)), by comparison with those in Koumbia (2.94%) and Dédougou (5.38%) (Figure 3). Tsetse infections by *T. brucei brucei* were observed exclusively in Folonzo in *G. tachinoides* (1.37%).

Overall, the risk of cyclical transmission, measured as the apparent density of infectious fly per trap per day, was 1.18 (95% CI 0–3.65) in Dedougou, 0.31 (0.07–0.67) in Koumbia and 7.27 (3.66–12.59) in Folonzo. It was thus 23.04 (2.80–122.29) times more important in Folonzo than in the two other sites \(P < 0.05\), between which it was not significantly different \(P > 0.05\).

The physiological ages of 59 tsetse in Dédougou, 23 in Koumbia and 43 in Folonzo were measured. The mean age was significantly lower in the site of Koumbia (28 ± 18 days) than the two others \(P = 0.007\). There was no difference between the mean age of the flies in Dédougou (39 ± 20 days) and Folonzo (38 ± 13 days) \(P = 0.74\).

**DISCUSSION**

The importance of AAT prevalence decreased with the aridity degree in our study area, with the exception of Dédougou where the Mouhoun river loop allows the persistency of high tsetse densities (Bouyer *et al.*, 2005, 2006). The fact that some

---

**FIGURE 2: DISTRIBUTION OF BITING FLIES ALONG THE CLIMATIC GRADIENT IN BURKINA FASO**

Sites are ordered by increasing annual rainfall from the left to the right. Boxplots present the median (bold line), quartiles (boxes), 95% confidence intervals (horizontal lines) and erratic values (dots).
TABLE 3: APPARENT DENSITIES OF MECHANICAL VECTORS ALONG THE CLIMATIC GRADIENT

<table>
<thead>
<tr>
<th>Site</th>
<th>Djibo</th>
<th>Débougou</th>
<th>Koumbia</th>
<th>Folonzo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alythotus agrestis</td>
<td>14.81 (23.95)</td>
<td>0(0)</td>
<td>0(0)</td>
<td>0.53(0.90)</td>
</tr>
<tr>
<td>Tabanus suedis</td>
<td>0.23(0.51)</td>
<td>0.28(0.84)</td>
<td>0(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Tabanus taeiola</td>
<td>0.35(0.85)</td>
<td>0(0)</td>
<td>0.07(0.26)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Tabanus gratus</td>
<td>0(0)</td>
<td>0(0)</td>
<td>0.66(1.56)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Chrysops distinctipennis</td>
<td>0(0)</td>
<td>0.03(0.19)</td>
<td>0(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Stomoxys niger</td>
<td>1.08(4.33)</td>
<td>0(0)</td>
<td>0.21(0.62)</td>
<td>0(0)</td>
</tr>
<tr>
<td>ADT (all species)</td>
<td>16.46(26.87)</td>
<td>0.31(0.85)</td>
<td>0.93(1.62)</td>
<td>0.53(0.90)</td>
</tr>
<tr>
<td>Species richness</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Trap*days</td>
<td>26</td>
<td>29</td>
<td>29</td>
<td>30</td>
</tr>
</tbody>
</table>

Sites are ordered by increasing annual rainfall from the left to the right.

FIGURE 3: TSETSE INFECTION RATES ALONG THE ARIDITY GRADIENT

Sites are ordered by increasing rainfall from left to right.
sites are more infected than others demonstrates the spatial heterogeneity of the AAT along the climatic gradient.

The predominance of *T. vivax* over *T. congolense* in Koumbia and Dédougou could be related to a better transmission by riverine tsetse (Reifenberg *et al.*, 1997). On the contrary, the high prevalence of *T. congolense* in Folonzo reveals the importance of contacts between animals and *G. morsitans submorsitans*, known as efficient vectors for this trypanosome (Cherenet *et al.*, 2004; Merid *et al.*, 2007). This hypothesis is reinforced by the fact that, at the time of the entomological survey, *G. morsitans submorsitans* was found abundant in the area (10.5 ± 15.23 tsetse/trap/day). The absence of *T. brucei brucei* in cattle and its weak seroprevalence, confirms tendencies observed in recent parasitological studies conducted in Burkina (Bouyer *et al.*, 2009; Dayo *et al.*, 2010). In the study of Dayo *et al.* (2009), *T. congolense* was also found to be highly predominant in cattle, in a site close to Folonzo.

Three typical cycles have been described to characterise the epidemiological settings of AAT, including sylvatic trypanosomosis, interface trypanosomoses and endemic livestock trypanosomosis. Koumbia and Dédougou can be considered as within the endemic livestock trypanosomosis cycle, where cattle are the main hosts and wild fauna tends to disappear. On the contrary, Folonzo represents a typical interface trypanosomoses situation where the wild fauna is still abundant and the pressure of cyclical vectors very high. It would be interesting to investigate whether the strains of *T. vivax* transmitted in the latter cycle are more virulent than in the two other sites, as observed for *T. congolense* in Southern Africa (Van den Bossche *et al.*, 2011). The higher parasitological prevalence in sedentary animals in Dédougou and Koumbia could be explained by higher trypanocid treatment frequencies in transhumant cattle. Even if this was not evidenced from interviews with livestock owners, previous studies have found that such information can be very unreliable and often many more treatments can be given than would be apparent. The resident cattle are concentrated along the last water points (Mouhoun and Bougouriba, respectively), and experience high contact intensity with riverine tsetse that are good vectors of *T. vivax*. This transmission might be seasonally relayed by mechanical vectors, particularly abundant in late rainy season and cold dry season in our study area (September–November) (Koné *et al.*, 2011). Similar observations were done in Gambia using parasitological follow-up of transhumant and sedentary animals (Wacher *et al.*, 1993).

The absence of parasitological prevalence in all cattle rearing systems in Djibo might be explained by the combined effect of the absence of cyclical vectors and the frequency of trypanocid treatments by the breeders (before, during and after the return from transhumance in the trypanosomian endemic area). This site is located far upon the northern limit of tsetse, which was very well characterised during former surveys in the study area (Bouyer *et al.*, 2005; Guerrini *et al.*, 2008; Courtin *et al.*, 2010). The majority of antibodies detected in animals in Djibo probably result from past infections. This hypothesis is supported by the absence of significant difference between the hematocrit of seropositive and seronegative animals. Sedentary and low transhumance herds are probably contaminated locally by the mechanical vectors from animals infected during their transhumance in the endemic AAT area. Indeed, the latter could maintain an intermittent epidemic transmission of AAT (Desquesnes *et al.*, 2009), explaining the serological predominance of *T. vivax* in this site. All these animals (sedentary animals infected mechanically and animals infected during transhumance) are treated several times during the year and were exempt of parasites during the survey, but remain seropositive for a long time (ca. 3 months) (Desquesnes, 1997).
This migratory situation, which always existed, could be exemplified by the climatic accidents and anthropic pressure effects that increase herd movements (Van den Bossche et al., 2010).

The sedentary herds in Djibo cannot be considered as within the three epidemiological cycles formerly described (Van den Bossche et al., 2010) and we thus hypothesise a fourth cycle named ‘epidemic mechanical livestock trypanosomosis’, where local transmission is seasonal and ensured by mechanical vectors, where cattle are the main hosts, and where trypanosomes are brought in by cattle coming back from transhumance in the tsetse-infested area.

With a mean apparent density of infectious tsetse of 0.74 (95% CI 0.04–2.01), the cyclical transmission risk can be considered as high in Déouguou and Koumbia, according to former studies (Bouyer et al., 2006; Guerrini and Bouyer, 2007), and very high in Folonzo: 7.27 (3.66–12.59). This observation, as well as the growing diversity of tsetse species from the Sahelian to the Sudano-Guinean area, is probably related to climatic conditions (rainfall and temperature) (Van den Bossche et al., 2010), the fragmentation degree of vegetal formations caused by the demographic pressure (Guerrini et al., 2008), and the presence of wild fauna in Folonzo.

Nowadays, tsetse flies have regressed in the sahelian area where they have been captured until 1935 (Courtin et al., 2010). The presence of a permanent hydrographic network, such as the Mouhoun river loop in Dédougou (Bouyer et al., 2006), or the Niayes in Senegal, however, allows riverine tsetse to persist in high densities in some sahelian sites (Bouyer et al., 2005, 2010), as observed in this survey in Dédougou. Tsetse flies’ absence in Djibo is attributable to the modification of the hygrometric conditions and temperatures (drought episodes of 1970–90) associated to anthropic pressure on the plant and animal resources leading to the disappearance of tsetse forest habitats and wild hosts. The same factors lead to the disappearance of G. morsitans submorsitans in Dédougou and Koumbia (Rouamba et al., 2009). Riverine flies, however, seem more resilient thanks to an opportunistic feeding behaviour associated to learning capacities (Bouyer et al., 2007) and linear dispersal along rivers (Bouyer et al., 2009).

The reduction of the mean age of the tsetse population in Koumbia indicates a higher adult mortality, which is probably a result of the perturbation/deterioration of their habitat. The reduction of the lifespan also favours trypanosome species having a short extrinsic cycle life as T. vivax (10 days), in comparison to those with longer cycle as T. congolense (14 days) and T. brucei brucei (30 days) (Cuisance et al., 2003).

Thus this study confirmed that aridity and landscape fragmentation are associated to a reduction of the biodiversity of hosts, cyclical vectors and transmitted parasites in Burkina Faso (Van den Bossche et al., 2010). Moreover, the impact of tsetse appeared not limited to their distribution area, but extended to a buffer area corresponding to the transhumance radius of herds, where transmission is probably relayed by mechanical vectors. The situation documented here contributes only partially to characterising the impact of production systems and climate on tsetse populations and prevalence of AAT in Burkina Faso. It would be interesting to investigate whether similar situations are encountered elsewhere and using other methods (namely monitoring of AAT incidence).

ACKNOWLEDGEMENTS

We thank the CIRDES for the excellent working conditions, and M. Céne Bila, Léopold Millogo, Memê Youl and all technicians in the CIRDES for their contributions to the success of this work. Supported by the French Ministry of Foreign and European Affairs, the AIRD, through the RIPECSA programme.
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FACTORS BEHIND THE FAILURE OF AGRICULTURAL POLICIES IN SUB-SAHARAN AFRICA: THE CASE OF CAMEROON

S. Nguiakam*
ABSTRACT

Over the past eight years, substantial budgets have been allocated to various areas of agricultural development in Cameroon. However, from the results of the most recent household survey it emerged that rural poverty is on the increase. The purpose of this study was to identify factors related to the failure of the agricultural policy implemented in Cameroon between 2002 and 2008. The methodology used was a model that combined factor analysis (multiple correspondence analyses) and scoring. The analysis showed that agricultural performance was the result of a large number of factors acting together, but at different intensities. Three main groups of factors behind the failure of agricultural policies have been identified: physical, ecological and climatic conditions (sudden epidemics, price instability and drought) which represent 28% of the setback; strategic and operational failures of government (problems of governance, poor strategic choices – 48%); and public behaviour (general low level of education of the population, sociological factors – 24%). The main conclusion reached was that the government’s share of responsibility for the setback was found to be on a par with the other factors behind the failure of agricultural policies. Therefore the authorities need to redefine agricultural policy, boost the capacity of operational public institutions, and strengthen support for rural producers.

KEYWORDS: CAPACITY, GOVERNANCE, PERFORMANCE, RESPONSIBILITY

AFFILIATIONS

* Ministry of Economy, Planning and Regional Development, Cameroon.
INTRODUCTION

World food prices have rocketed since 2008, highlighting the major shortcomings of certain African countries, particularly those that are heavily reliant on food imports. This has also emphasised the vulnerability of agriculture, which in many countries continues to be small-scale subsistence farming that tends to be unproductive and uncompetitive, rather than market-driven.

Africa is still the world’s only net food-importing region, even though the continent has sufficient resources (labour, land and water) to cater for the food demands of all Africans throughout the continent. The food crisis therefore represented an opportunity for the affected governments to finally realise just how urgent it is to put farming back at the centre of their development agenda. In Cameroon, this realisation has led to hefty budget appropriations being earmarked to fund various agricultural development schemes: organisation, supervision, support and infrastructure development.

Literature on how government efforts have affected the agricultural sector has long adopted a macroeconomic approach to analysing the issues, in the light of historical and theoretical factors.

Ribier and Le Coq (2007) believe that developing countries in general, and African countries in particular, tend to provide less support to agriculture than developed nations, even though the sector is proportionally more significant in terms of employment, contribution to GDP and exports. Various outside factors have succeeded in blunting the impact of the African countries’ agricultural policies, but the structural adjustment programmes have, without doubt, been the most burdensome (Ribier and Diegui, 2002).

Conversely, Losch (2005) points to the support offered for the ‘demo-economic’ transition. According to this argument, the most widespread frame of reference for the future of agriculture and farming communities worldwide, including Africa, is based on the generally implicit theory of an evolutionary model of national economies premised on the history of agricultural and industrial revolutions. The thinking is that, as agricultural employment was gradually absorbed by other fields of economic activity, particularly in Europe in the 19th and 20th centuries, this development will very likely be repeated over the coming decades in countries where the majority of the population lives off farming. This transposition of the evolutionary model to the current situation in the least developed countries is, however, becoming increasingly irrelevant.

Several factors raise serious questions about the actual impact of all the government initiatives. First of all, the findings of the most recent Cameroon survey amongst households (ECAM 3, 2007) highlighted the extent to which rural poverty is on the increase. What is striking, however, is the impressive number of projects and schemes benefiting from a significant level of human and financial resources, supported by the government and development partners, even though the return on this (in terms of productivity and better living conditions for the rural community) is not always evident. The budget allocation for the agricultural sector rose from 42 billion CFA in 2002 to 98 billion in 2010.

This begs the question: what are the factors behind the failure of all the government measures designed to improve the lot of rural communities in recent years? What are the reasons for the poor agricultural performance? How much responsibility does the government bear for the agricultural policy? What steps should be taken and what systems should be rolled out to maximise the effectiveness and efficiency of the government’s measures in favour of the farming sector?

The main purpose of this study was to pinpoint the factors behind the failure of Cameroon’s agricultural policies over the past 6 years and to quantify the extent to which each factor identified was to blame. In specific terms, this involved:
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• determining the different links in the chain of outcomes relating to the government’s activities in the agricultural sector (evaluating how the human, financial and material resources are employed and allocated to the various activities, how the activities are organised and spread throughout the country and among the many stakeholders);
• evaluating the beneficiaries’ structures, working methods, interaction with the administration, and knowledge of the facilities on offer from the administration;
• determining the government’s share of the responsibility and the impact of outside factors (the so-called counter-factual developments) that apparently bear a tremendous amount of the responsibility for the mixed results of Cameroon’s agricultural policy.

METHODOLOGY

The following tools were applied in a bid to achieve the study objectives. A major statistical survey was undertaken in 55 administrative departments (out of the country’s 58 departments). The selected samples were consistent with the criteria of comprehensiveness for the farm project managers and heads of the decentralised services, spatial coverage, diversification and the prioritisation of the beneficiaries of direct support schemes for producer organisations.

Accordingly, interviews were set up for 116 project managers, 1,346 leaders of associations or organisations representing producers, and 1,263 members of associations or organisations representing producers.

A multiple correspondence analysis (MCA) was carried out, followed by an ascending hierarchical classification in order to make an inventory of the factors behind the failure of agricultural policies, and analyse their interrelationship. The factorial co-ordinates decided upon were taken as numerical explanatory variables for a discriminant analysis.

Discriminant analysis was used to look for linear combinations of quantitative indicators in order to discover the classification found with the MCA. The discrimination criterion is:

**inertia between the groups / inertia in the groups**

Remember the inertia of a set of \( n \) points \( x_i \) (weighted \( p_i \) whose sum is 1) relative to a reference point \( y \) and a distance \( d \) is defined as the average square difference of \( x_i \) to \( y \) (Hastie et al., 2001):

\[
\text{Inertia}_{\chi}(x_i, p_i)_{i=1}^{n} = \sum_{i=1}^{n} p_i \cdot d^2(x_i, y)
\]

Scoring was used to quantify the share borne by each factor identified. The score was simply the discriminant variable according to Fisher. The Fisher function was then calculated, ultimately expressed as a linear combination of indicators to produce the score function. If \( F \) is the Fisher function,

\[
F = \begin{bmatrix}
  f_1 \\
  f_2 \\
  \vdots \\
  f_k
\end{bmatrix},
\]

\[
f_j = \frac{(z_j - \bar{z}_j)}{\sqrt{\epsilon_j}}
\]

or \( \bar{z}_j \) is the average of the group coordinates \( i \) on the factorial axis number \( j \), of variance \( \epsilon_j \). The score \( S \) of a factor was derived via (Tuffery, 2002):

\[
S = \sum_{j=1}^{k} d_j z^j
\]

RESULTS

In the wake of the interviews conducted among the local officials and the public, and the modelling described in the methodology, the main constraints were identified and ranked according to scores, to determine the scale of each constraint. These factors were grouped into three categories, as follows.
The constraints grouping: this covered all the factors exogenous to the local economic policy and directly affecting the sector’s activities. These include natural factors (climate), the international economic environment (prices), geography (located far from consumer centres) or regional contagion (cross-border insecurity). In any event, the constraint associated with these factors could not be attributed to the government or the Cameroon public. Exogenous constraints accounted for a 27.5% share of the responsibility for failure of agricultural policies (Table 1).

Agricultural policy: this covered factors that an effective agricultural policy could have mitigated or eliminated, and for which the government was directly responsible. They were attributable to governance issues, lack of foresight and poor strategic decisions. These factors accounted for a 48% share of the responsibility for the failure of agricultural policies (Table 2).

Public behaviour: people play a key role in agricultural policymaking, as they are responsible for production, so they play a major role in the ultimate

### Table 1: Extent to Which Exogenous Factors Were Responsible for the Failure of Agricultural Policies

<table>
<thead>
<tr>
<th>Factor</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 Insecurity</td>
<td>3.22</td>
</tr>
<tr>
<td>1.2 Sudden epidemics</td>
<td>4.76</td>
</tr>
<tr>
<td>1.3 Price instability</td>
<td>4.43</td>
</tr>
<tr>
<td>1.4 Invasion by locusts, elephants and other</td>
<td>3.59</td>
</tr>
<tr>
<td>1.6 Epizootics</td>
<td>1.57</td>
</tr>
<tr>
<td>1.7 Low rainfall and drought</td>
<td>1.38</td>
</tr>
<tr>
<td>1.1 Distance from consumer centres</td>
<td>8.56</td>
</tr>
<tr>
<td>1 Natural and other uncontrollable factors</td>
<td>27.50</td>
</tr>
</tbody>
</table>

### Table 2: Extent to Which Government Approaches Were Responsible for the Failure of Agricultural Policies

<table>
<thead>
<tr>
<th>Factor</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.6 Lack of funds/difficulty in raising funds</td>
<td>5.86</td>
</tr>
<tr>
<td>2.5 Mismanagement of funds</td>
<td>6.25</td>
</tr>
<tr>
<td>2.4 Supply of inputs/seed</td>
<td>8.56</td>
</tr>
<tr>
<td>2.3 Land-locked situation</td>
<td>8.88</td>
</tr>
<tr>
<td>2.2 Slowdown of related activities</td>
<td>9.11</td>
</tr>
<tr>
<td>2.1 Price of inputs</td>
<td>9.22</td>
</tr>
<tr>
<td>2 Government agricultural policy</td>
<td>47.89</td>
</tr>
</tbody>
</table>
success or failure. This covered all the patterns of behaviour that could be linked to sociology and were not very conductive to development. Public behaviour was 24% responsible for the failure of agricultural policies (Table 3).

Other factors were poor communication channels between young people and the elderly, and the low female participation rates in the process of drawing up agricultural policies (Figure 1).

**DISCUSSION AND CONCLUSION**

The main conclusion was that the government bears the same amount of responsibility as the other factors for the failure of agricultural policies. This relatively unexpected conclusion shows that the government may be reproached for demonstrating a lack of dynamism, but should not be regarded as the only party at fault. Those

**TABLE 3: EXTENT TO WHICH PUBLIC BEHAVIOUR WAS RESPONSIBLE FOR THE FAILURE OF AGRICULTURAL POLICIES**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Public behaviour</td>
<td>24.22</td>
</tr>
<tr>
<td>3.1 Sociological factors</td>
<td>6.45</td>
</tr>
<tr>
<td>3.2 Rural exodus</td>
<td>4.29</td>
</tr>
<tr>
<td>3.3 Agro-pastoral conflicts</td>
<td>3.89</td>
</tr>
<tr>
<td>3.4 Poor response to government incentives</td>
<td>3.81</td>
</tr>
<tr>
<td>3.5 Land issues</td>
<td>2.09</td>
</tr>
</tbody>
</table>

**FIGURE 1: PERCENTAGE OF WOMEN (LEFT) AND YOUNG PEOPLE (RIGHT) IN THE ADMINISTRATIONS**
FACTORS BEHIND THE FAILURE OF AGRICULTURAL POLICIES IN SUB-SAHARAN AFRICA: THE CASE OF CAMEROON

in charge of the decentralised services and project managers were also aware that the challenges were intricate; some were outside the government’s control, and the public itself was not completely divorced from the situation. This conclusion therefore transcends the agricultural sector: it concerns all the country’s political forces and the development model itself needs re-examining (Figure 2). However, a shift in focus in the sector would appear to be crucial in the short term.

COMMUNICATION STRATEGY AND IMPACT

First steps are to establish an authentic farm input access policy based on low-cost local production and outreach programmes to promote their intensive deployment; revise the procedures for granting loans and qualify the importance given to financial support in government initiatives; roll

FIGURE 2: RANKING OF CONSTRAINTS TO DEVELOPMENT IN CAMEROON’S RURAL AREAS

Level 5: Physical, ecological and climate constraints
In spite of the country’s high level of natural resources and reserves of land, certain natural disasters, such as drought, low rainfall, endemic epizootic diseases, flooding, invasions by locusts and elephants, seed-eating birds and others, hamper activities in the sector.

Level 4: Public behaviour
The population’s overall low level of education, certain sociological factors, the poor public response to government incentives and the lack of interest in joint initiatives are obstructing the sector’s development.

Level 3: Strategic and operational failures of administrations
The agricultural policies are badly coordinated, barely operational and their implementation is marred by serious shortcomings attributable to the administrations in charge of the policies.

Level 2: Located far from the main port
Rural areas are not easily accessible and those located far from the country’s main port suffer from chronic disadvantages.

Level 1: Nurksian lock
Incomes from the rural sector are systematically deployed to import consumer products and so do not have a knock-on effect in the sector.
out a bimodal sustainable funding system tailored to agro-pastoral and fisheries activities; boost the operational abilities of the public institutions and their interrelations; strengthen the rural producers’ structure by involving decentralised structures and local authorities in decision-making; and involve women and young people in operational activities and the decision-making process. These new approaches should be put into practice in conjunction with a suitable reform of the government’s intervention strategy framework for rural areas.

ACKNOWLEDGEMENTS

Special thanks in particular to Mr Koffi N’Guessan, former head of the ENSEA, who, during my studies, motivated me and inspired me to work for the progress of our beloved continent. Many thanks also to Mr Vincent Kouete, former head of the CAAI attached to Cameroon’s Ministry of the Economy, who spared no effort to help me complete this research.

REFERENCES


EFFECT OF EGG YOLK IN SEMEN EXTENDER, pH AND COOLING METHODS ON CHILLED BOVINE SEMEN CHARACTERISTICS

F. Ngoula¹, D.N. Tarla² and H.P. Bayemi³
ABSTRACT

Artificial insemination is currently solely dependent on frozen semen, since chilled semen can only be preserved for a limited time. The objective of this research was to extend the preservation period of chilled semen. It evaluated the effect of five egg yolk concentrations (10, 15, 20, 25 and 30%) in citrate semen extender, and different pH adjustments of the extender, on the characteristics of chilled bovine semen. Similarly, four methods of semen cooling were tested: from 35 to 5°C using a water bath; 35 to 5°C without the water bath; 35 to 20 and then to 5°C with the water bath; and 35 to 20 then to 5°C without the water bath in the refrigerator. The post-thaw live cell concentration (LCC), individual (IM) and progressive motilities (PM) were monitored daily using a light microscope and haemocytometer. The data were grouped into three preservation periods: days 1–4, days 5–8, and days 9–12. Analyses showed that whatever the preservation period, the IM, PM and LCC at 10% egg yolk were significantly higher ($P < 0.05$) than those in other egg yolk concentrations. At 9–12 days of preservation, the IM (15.42 ± 06.90%), PM (05.83 ± 05.57%) and LCC (01.83 ± 01.47 × 10⁶/ml) of the semen when cooled from 35 to 20 then to 5°C in the water bath were significantly higher ($P < 0.05$) when compared with all other cooling methods studied. The PM (44.17 ± 15.93%) and LCC (18.75 ± 03.68 × 10⁶/ml) in the extender with unadjusted pH were significantly higher ($P < 0.05$) from days 5–8, as well as from days 9–12 (12.00 ± 11.83% and 04.90 ± 02.92 × 10⁶/ml, respectively), compared with those of all other levels of adjusted pH. In conclusion, semen viability is prolonged for up to 12 days in an extender with unadjusted pH, containing 10% egg yolk and cooled through the water bath.

KEY WORDS: ARTIFICIAL INSEMINATION, LIVE-CELL CONCENTRATION, MOTILITY, PRESERVATION, VIABILITY

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INTRODUCTION

Animal rearing in the tropics faces the challenge of providing quality protein in recommended quantities to the masses at comparatively low cost. This is largely because these animals are highly rustic and less productive, resulting in increased prices of meat and milk, leaving the poor, who barely survive on less than a dollar a day, to consider meat consumption a taboo. They are therefore obliged to opt for cheap foodstuffs mostly of plant origin, which are relatively low in protein and calories (FAO et al., 2012).

In addition, pastures are reducing both in size due to the population boom and urbanisation, and in productivity as a result of overgrazing and weed invasion. This makes it difficult to produce sufficient animals to feed the ever-growing and highly demanding human population. This means it is essential to find ways in which to increase total meat and milk production without necessarily increasing the number of animal heads and production costs.

Beef accounts for about two-thirds of the total meat consumption of an average Cameroonian, with an annual production of 94,000 tons (MINEPIA, 2002). Here, frozen semen for artificial insemination (AI) is imported from abroad. This greatly increases the production cost, since the equipment and material such as liquid nitrogen and its containers are expensive and sophisticated, coupled with the cost of importation and the complexity of custom and shipment procedures. This limits its acceptability by local indigenous farmers.

Chilled semen, as an alternative to frozen semen, has a short viability period of about 4 days (Campbell et al., 2003). Extending this period would mean that chilled semen could be more widely used, including in enclave regions, which may take a couple of days to reach. The main objective of this study, therefore, was to help increase cattle production by extending the preservation period of chilled semen destined for AI.

More specifically, it:

• tested the effect of five levels of egg yolk incorporation in citrate egg yolk extender on the post-thaw characteristics of chilled bovine semen;
• compared the viability of spermatozoa at an adjusted pH of 7.4 and an unadjusted pH during preservation;
• tested the effect of semen cooling methods on its post-thaw properties.

METHODOLOGY

This study was carried out in 2009/10 at the Institute of Agricultural Research for Development (IRAD) Bambui AI station of the Northwest Region of Cameroon. Semen was randomly collected from four bulls. The first of the three experiments tested the effect of five levels of egg yolk concentration (10, 15, 20, 25 and 30%) in a citrate-egg yolk extender on the post-thaw properties of chilled bovine semen in five replicates.

The experimental variable in the second experiment was the pH of the extender, which was either unadjusted, or adjusted daily to 7.4 using buffer solutions during preservation.

The third experiment tested the effect of semen cooling methods on its post-thaw properties with four treatments (T):

• T1, cooling from 35 to 5°C using a water bath in the refrigerator;
• T2, cooling directly in the refrigerator from 35 to 5°C without a water bath;
• T3, cooling from 35 to 20 then from 20 to 5°C with a water bath in the refrigerator;
• T4, cooling from 35 to 20 then from 20 to 5°C without the water bath.

In these experiments, the extender was prepared at 35°C with the specified concentration of egg yolk, as well as the cooling method specified for that treatment and the pH adjustment. The individual and progressive motilities of the sperm cells were monitored daily using a light microscope after
eosin–nigrosin staining, and registered. The live cell concentration of the semen was monitored using a Neubauer hemocytometer. The effects of the various treatments were compared through analysis of variance after data transformation to log (x + 1) (Yadolah, 2008) due to their high variations, followed by the Duncan multiple range test (DMRT) to separate means when statistical differences were detected. A P value of <0.05 was considered statistically significant.

RESULTS

As illustrated in Table 1, whatever the concentration of egg yolk in the extender, the individual (IM) and progressive motilities (PM) and post-thaw live cell concentration (LCC) generally decreased significantly with time (P < 0.05).

Comparing different egg yolk treatments:
- from days 1 to 4, the IM and PM as well as the LCC generally decreased as the egg yolk concentration in the extender increased;
- from days 5–8 of preservation, the IM at 10% egg yolk was significantly higher (P < 0.05) when compared with those at 25 and 30% egg yolk concentration;
- from days 9–12, the IM and PM as well as the LCC generally decreased with increasing egg yolk concentration in the extender.

<table>
<thead>
<tr>
<th>Egg yolk concentration (%)</th>
<th>Preservation period (days)</th>
<th>Semen characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IM (%) (n = 20)</td>
<td>PM (%) (n = 20)</td>
</tr>
<tr>
<td>10</td>
<td>1–4</td>
<td>84.00 ± 11.19</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>49.25 ± 21.04</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>23.50 ± 21.10</td>
</tr>
<tr>
<td>15</td>
<td>1–4</td>
<td>83.75 ± 09.30</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>45.75 ± 19.95</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>19.25 ± 18.08</td>
</tr>
<tr>
<td>20</td>
<td>1–4</td>
<td>80.00 ± 13.57</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>40.75 ± 16.80</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>14.00 ± 15.44</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>33.00 ± 17.35</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>09.75 ± 12.08</td>
</tr>
<tr>
<td>30</td>
<td>1–4</td>
<td>75.50 ± 16.85</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>31.00 ± 15.78</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>06.50 ± 09.05</td>
</tr>
</tbody>
</table>

n = Sample size analysed; IM, individual motility; PM, progressive motility; LCC, live cell concentration.
Statistically, the IM of the semen with 10% egg yolk was significantly higher \((P < 0.05)\) when compared with that containing 30% egg yolk. The PM at 10% egg yolk was significantly higher \((P < 0.05)\) when compared with all the other concentrations. In addition, significant differences were recorded between the LCC at 10 and 15% when compared with those containing 20, 25 and 30% egg yolk.

Data in Table 2 show that the PM and LCC of the semen in the extender with unadjusted pH was significantly higher \((P < 0.05)\) when compared with

<table>
<thead>
<tr>
<th>pH adjustment</th>
<th>Preservation period</th>
<th>IM (%) ((n = 28))</th>
<th>PM (%) ((n = 28))</th>
<th>LCC ((10^6/ml)) ((n = 28))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted</td>
<td>1–4</td>
<td>82.50 ± 13.06</td>
<td>76.25 ± 17.34</td>
<td>31.75 ± 05.62</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>52.50 ± 13.73</td>
<td>44.17 ± 15.93</td>
<td>18.75 ± 03.68</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>23.00 ± 13.58</td>
<td>12.00 ± 11.83</td>
<td>04.90 ± 02.92</td>
</tr>
<tr>
<td>Adjusted on day 1</td>
<td>1–4</td>
<td>81.67 ± 14.67</td>
<td>77.50 ± 16.99</td>
<td>35.67 ± 09.52</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>35.83 ± 15.50</td>
<td>27.92 ± 15.73</td>
<td>14.83 ± 06.98</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>05.00 ± 04.71</td>
<td>01.00 ± 02.11</td>
<td>01.10 ± 01.45</td>
</tr>
<tr>
<td>Adjusted on day 1 and 2</td>
<td>1–4</td>
<td>79.58 ± 16.85</td>
<td>73.75 ± 20.01</td>
<td>35.25 ± 09.71</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>30.42 ± 16.44</td>
<td>23.75 ± 15.24</td>
<td>12.75 ± 06.84</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>03.00 ± 03.50</td>
<td>00.50 ± 01.58</td>
<td>00.80 ± 01.03</td>
</tr>
<tr>
<td>Adjusted from day 1 to 3</td>
<td>1–4</td>
<td>80.42 ± 15.44</td>
<td>71.82 ± 20.89</td>
<td>35.58 ± 09.38</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>28.75 ± 18.11</td>
<td>21.25 ± 15.97</td>
<td>12.75 ± 07.56</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>00.50 ± 01.58</td>
<td>00.00 ± 00.00</td>
<td>00.10 ± 00.32</td>
</tr>
<tr>
<td>Adjusted from day 1 to 4</td>
<td>1–4</td>
<td>80.42 ± 15.44</td>
<td>73.33 ± 20.60</td>
<td>35.58 ± 09.38</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>24.58 ± 16.02</td>
<td>17.92 ± 14.38</td>
<td>11.00 ± 06.92</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>02.00 ± 02.58</td>
<td>00.50 ± 01.58</td>
<td>00.30 ± 00.48</td>
</tr>
<tr>
<td>Adjusted from day 1 to 5</td>
<td>1–4</td>
<td>80.42 ± 15.44</td>
<td>73.33 ± 20.60</td>
<td>35.58 ± 09.38</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>27.08 ± 17.38</td>
<td>20.83 ± 15.50</td>
<td>09.92 ± 07.23</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>01.50 ± 02.42</td>
<td>00.50 ± 01.58</td>
<td>00.20 ± 00.63</td>
</tr>
<tr>
<td>Adjusted from day 1 to 6</td>
<td>1–4</td>
<td>80.42 ± 15.44</td>
<td>73.33 ± 20.60</td>
<td>35.58 ± 09.38</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>29.17 ± 16.07</td>
<td>21.25 ± 15.39</td>
<td>11.00 ± 06.61</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>02.00 ± 03.50</td>
<td>00.50 ± 01.58</td>
<td>00.10 ± 00.32</td>
</tr>
</tbody>
</table>

\(n = \) Sample size analysed; IM, individual motility; PM, progressive motility; LCC, live cell concentration.
all the other levels of pH adjustment for the 5–8 and 9–12 days preservation periods, as well as its IM at 9–12 days of preservation.

The results given in Table 3 show that, irrespective of the treatment, there was a significant decrease \( (P < 0.05) \) in the IM, PM and LCC with preservation time. The LCC of the semen when cooled from 35 to 5°C in a water bath was significantly higher \( (P < 0.05) \) during the first preservation period of 1–4 days than the other cooling methods studied. During the last preservation period of 9–12 days, the IM and LCC of the semen cooled from 35 to 20 then to 5°C were significantly higher \( (P < 0.05) \) when compared with all the other cooling methods studied.

**DISCUSSION AND CONCLUSION**

Egg yolk provides the nutrients which the sperm cells need and prevents the efflux of cholesterol and phospholipids, as it attaches firmly to these cell membranes. It also acts as a cryoprotectant (Gangyi *et al.*, 1998), shielding the cells and preventing extreme temperature drops, especially

### Table 3: Effect of the Various Cooling Methods on Post-Thaw Properties of the Semen

<table>
<thead>
<tr>
<th>Cooling method</th>
<th>Preservation period</th>
<th>Semen characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IM ((%)) ((n = 12))</td>
</tr>
<tr>
<td>T1</td>
<td>1–4</td>
<td>82.50 ± 13.06</td>
</tr>
<tr>
<td></td>
<td>1–4</td>
<td>82.08 ± 11.77</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>40.41 ± 18.64</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>03.75 ± 05.28</td>
</tr>
<tr>
<td>T2</td>
<td>5–8</td>
<td>35.83 ± 15.50</td>
</tr>
<tr>
<td></td>
<td>1–4</td>
<td>75.42 ± 16.44</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>36.67 ± 16.00</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>06.67 ± 04.92</td>
</tr>
<tr>
<td>T3</td>
<td>9–12</td>
<td>03.00 ± 03.50</td>
</tr>
<tr>
<td></td>
<td>1–4</td>
<td>79.58 ± 13.89</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>41.25 ± 12.99</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>15.42 ± 06.90</td>
</tr>
<tr>
<td>T4</td>
<td>1–4</td>
<td>80.42 ± 15.44</td>
</tr>
<tr>
<td></td>
<td>1–4</td>
<td>80.42 ± 14.37</td>
</tr>
<tr>
<td></td>
<td>5–8</td>
<td>36.25 ± 11.89</td>
</tr>
<tr>
<td></td>
<td>9–12</td>
<td>04.58 ± 04.98</td>
</tr>
</tbody>
</table>

\(n = \) Sample size analysed; IM, individual motility; PM, progressive motility; LCC, live cell concentration.
during cooling. As the egg yolk concentration increases, the extender becomes more viscous and the sperm cells therein tend to expend more energy in swimming than in less viscous samples. It was therefore evident that the solution containing the least egg yolk concentration (10% egg yolk) gave the best results with respect to the parameters studied, as it had the longest preservation period (up to 12 days). Given that semen samples are used for AI even when their PM drops to 30% (Rouge, 2002), semen at 10% egg yolk could be used for up to 9 days.

The second experiment demonstrated that it was better not to adjust the pH of the extender at all because as the level of adjustment intensified, the viability of the semen decreased progressively. This could be because, as buffer solutions were incorporated into the extender, they caused an imbalance in the ionic composition of the sperm cells, the cell membranes of which are highly permeable (Kent, 2000). This imbalance was a shock to the cells, the susceptibility of which was expressed through a reduction in motility with time (Hafez, 1987). The constant drop in pH of the diluted semen samples with preservation time was due to the metabolic activity of the sperm cells that produced lactic acid from glycolysis, which tends to lower the pH (US Patent, 2005).

With respect to the methods of cooling, treatments involving the water bath gave better results than those without the water bath. This is in all probability because cooling without the water bath provokes a slight cold shock, which was expressed through the decreased viability of the samples (Brinsko et al., 1999).

The main conclusions, which could help improve the quality of chilled bovine semen destined for AI, include the following:

• egg yolk incorporation in bovine semen extender at a 10% concentration yields better results, and can be used for up to 9 days in citrate extender under refrigeration conditions;
• the use of the water bath in semen cooling yields better comparative results than those cooled without the water bath;
• adjusting the pH of semen during storage to 7.4 had no positive effect on its post-thaw properties.

**COMMUNICATION STRATEGY AND IMPACT**

Based on these results, the productivity of local cattle can be improved for both milk and meat production through AI with chilled semen, collected from high value bulls. By organising extension services, farmers can be educated on chilled semen usage, and local AI stations created from which they can easily obtain this semen at an affordable price. This will offer local farmers the potential to produce up to 15 litres of milk daily with these crossbreeds produced from AI, compared with the current production rate of around 3 litres/cow/day registered with local Fulani breeds (Ndambi et al., 2008). Similarly, they will experience an increase in meat production, as the crossbreed offspring from AI have better growth rates and body weights. This can contribute towards achieving the first Millennium Development Goal, which seeks to halve the number of people worldwide living in chronic hunger and on less than a dollar daily by 2015.

**ACKNOWLEDGEMENTS**

Special heartfelt thanks go to the entire technical team working under the cattle section of IRAD Bambui for their untiring support during the process of data collection in the field.

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EVALUATING MECHANISMS OF SILAGE-MAKING TECHNIQUES USED BY SMALLHOLDER DAIRY FARMERS IN MASAKA, UGANDA

H.S. Teklehaimanot*
ABSTRACT

Year-round animal feed scarcity is one of the major constraints to smallholder livestock production systems in Uganda. To tackle this issue, the National Agricultural Research Organization (NARO) of Uganda, along with its development partners, introduced a silage-making technique (SMT) in the district of Masaka. SMT helps to preserve the excess supply of feed during the rainy season for subsequent use during the dry season. However, SMT adoption by smallholder farmers remains very low. The objective of this study was to evaluate SMT mechanisms that hinder or facilitate its utilisation. The research was guided by a technographic methodological approach and a realistic evaluation analytical framework. Findings showed that the low rate of SMT uptake by smallholder dairy farmers was mainly related to the fragmentary nature of silage-making. Results further demonstrated that the significant variation in the rate of SMT uptake depended on access to secured or sustainable markets, access to land, group labour, and possession of productive animals. In conclusion, the study highlighted that adoption and adaption are interlinked, continuous and multi-directional processes. Furthermore, the integration of SMT within existing practices requires the full participation of actors to work closely in capturing the socio-technical mechanisms beyond the technical offering itself.

KEY WORDS: FEED SCARCITY, INTEGRATION, REALISTIC EVALUATION, SOCIO-TECHNICAL, TECHNOGRAPHY
INTRODUCTION

The smallholder dairy sub-sector of Uganda is an important provider of food, generating income and creating employment. However, the year-round scarcity of animal feed, both in quantity and quality, is one of the major constraints to smallholder production systems. The availability of animal feed follows the rainfall patterns, with the feed supply rapidly declining following the rainy season. Thus security of adequate feed supply year-round is always crucial to the vast majority of smallholders who depend on livestock for their livelihood. To tackle the issue of animal feed scarcity, the National Agricultural Research Organization (NARO) of Uganda, along with its partners, introduced a silage-making technique (SMT) in the district of Masaka. However, despite ongoing efforts by experts, adoption of the technique in Uganda by smallholder farmers remains very low (Mwebaze, 2002). The aim of this study was to evaluate the mechanisms that affect the utilisation of SMT by smallholder dairy farmers.

METHODOLOGY

The research was guided by a technographic methodological approach and a realistic evaluation analytical framework, which allowed the use of diverse observational and analytical methods. The first stage of the study involved analysing quantitative household survey data gathered through face-to-face interviews with randomly selected smallholder farmers ($n = 60$). The data were analysed using the Statistical Package for the Social Sciences (SPSS). Simple descriptive statistics such as frequencies and means were used to interpret results. A logit regression model was also used to determine factors likely to influence the adoption of the SMT. Data were collected via in-depth interviews with farmers, researchers and extension agents, and secondary data sources. Subjects were well informed about the research objective, and their responses were voluntary.

RESULTS

Results of the multiple regression model show that SMT adoption was not significantly affected by the cumulative effects of all the explanatory variables at a 5% significance level (Table 1). Among all the factors, only gender was found to significantly ($P < 0.05$) affect adoption. This was due to the few male farmers who were using the SMT. However, the other variables, including age, land size, farm experience, livestock holding, size of the pasture cultivated area, the ownership of local or improved cattle and membership of a farmers group, were not found to influence adoption of the SMT.

Some of the main factors that were found to impede the rate of adoption of SMT included lack of technical know-how (53.3%), higher investment requirement (26.7%), lack of storage space (6.7%), lack of interest (6.7%) and lack of adequate land (1.7%). Given that the majority of the respondents lacked knowledge regarding SMT, an in-depth analysis of the mechanisms that hinder or support the adoption/adaption of SMT could not be adequately undertaken. Therefore the combined use of quantitative and qualitative analytical methods was required to further capture and understand the mechanisms as to why farmers adopted, adapted, discontinued or completely rejected SMT. To this end, farmers who received training were selected for the case study using a purposive and snowballing sampling technique.

Findings from the case study showed that the low rate of silage adoption by smallholder dairy farmers related mainly to the fragmentary nature of SMT implementation. SMT had been implemented without participatory research and proper value-
chain analysis via demonstrations and training as part of the forage development projects. Socio-economic elements, such as the marketing of milk and credit provision, had not been incorporated into the projects. Moreover, there was limited research that specifically evaluated the economic or technical feasibility of SMT for smallholder farmers before and after project implementation. Several stakeholders were identified in this study, but partnerships among the actors promoting SMT in the district were weak. Duplication of activities and uncoordinated efforts were observed in Masaka. Training, demonstrations and input provision were provided to smallholder farmers from every direction (NARO, extension office, non-governmental organisations) in an unstructured manner. Projects often failed to involve farmers and other key actors, from initial problem identification throughout the SMT implementation process.

In spite of the low adoption rate of SMT, the study detected considerable variation in the rate of uptake between the sub-counties, Kingo 43% and Bukulula 3%, respectively. This difference was primarily associated with access to a secured milk market, group labour, small land size and ownership of productive animals.

Access to market was found to be crucial for the successful utilisation of SMT. One of the differences between farmers in Kingo (relatively higher rate of adoption) and Bukulula (relatively lower rate of adoption) was that farmers in Kingo have access to a secured market, where they have a year-round contractual agreement to sell their milk to MADDO (Masaka Diocesan Development Organization). The other difference was that 72% of farmers in Kingo owned an improved breed of dairy animals, while

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficients</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>-0.113*</td>
<td>0.051</td>
</tr>
<tr>
<td>Age of household</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Farm experience</td>
<td>-0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Land size</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Livestock keeping</td>
<td>0.000</td>
<td>0.011</td>
</tr>
<tr>
<td>Size of pasture cultivated area</td>
<td>-0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Local cattle</td>
<td>0.000</td>
<td>0.006</td>
</tr>
<tr>
<td>Improved cattle</td>
<td>-0.007</td>
<td>0.009</td>
</tr>
<tr>
<td>Membership of farmers group</td>
<td>-0.006</td>
<td>0.032</td>
</tr>
<tr>
<td>Family size</td>
<td>-0.001</td>
<td>0.012</td>
</tr>
<tr>
<td>Constant</td>
<td>0.205</td>
<td>0.131</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.134</td>
<td></td>
</tr>
</tbody>
</table>

Dependent variable = adoption of silage-making technique (0 = No, 1 = Yes).
Independent variables = gender, age, farm experience, land size, livestock keeping, local cattle, improved cattle, and membership.
* Significant at 5% level of probability.
Only 30% of farmers in Bukulula owned such animals, although having improved cattle did not significantly affect adoption of SMT.

In the district, dairy cattle management was often the responsibility of the women and elders, as their male counterparts were away carrying out off-farm activities. One of the reasons for the failure of SMT adoption in Bukulula sub-county was labour. Farmers from Bukulula who had previously tried SMT but later discontinued its use stated that their main obstacle was its increased labour requirement. In the sub-county of Kingo, farmers were organised into farmer groups, so that each member of the group would have access to a free labour source to cope with the increased labour requirements. Moreover, the high cost of materials for ensiling and lack of capital for investment were additional hindering factors. Farmers do not have access to credit for the SMT or any other forage conservation programmes.

Smallholder dairy farmers in the district of Masaka own small plots of land dedicated to forage production. The survey results showed that 46.7% of the farmers owned less than half an acre to produce forage, which is insufficient for silage making. Greater proportions were allocated to food crops (30%) and cash crops (30%).

In Masaka, farmers were advised to start ensiling 1 month before the onset of the dry season by harvesting the forage in the middle of the wet season to improve silage quality. However, farmers in the sub-county of Kingo encountered spoilage due to the higher moisture content of the forage.

**FIGURE 1: INNOVATIVE DESIGN OF SILO PIT BY FARMERS IN KINGO SUB-COUNTY**
when they ensiled a large quantity of forage as advised by the experts. This problem was overlooked by the researchers and extension officers.

To alleviate the problem, farmers in the sub-county conducted an experiment to redesign the underground silo into a unique slanted silo (Figure 1) that causes the excess moisture to seep into the ground. Finally, they were able to solve the problem and feed their animals. The design differed from the flat floor silo demonstrated by the experts.

DISCUSSION AND CONCLUSION

In the district of Masaka, a silage-making technique had been implemented as a promising solution to feed scarcity, especially during the dry season. However, adoption rates were low. It was evident that the SMT projects were not based on a detailed value-chain analysis and lacked the participation of stakeholders, especially farmers. This ignored the crucial understanding of the socio-technical relationship that is necessary for the ‘performance’ of actors in SMT projects. Our study identified several stakeholders working in the district who could potentially play a complementary role in the development and dissemination of silage-making. An effective partnership, which put farmers at the centre, between the potential actors would help to resolve the fragmentary project implementation and duplication of programme activities that was evident in the district. Concerted efforts by individuals and institutes with clear task division is therefore essential in order to share the wealth of experience and promote uptake of the SMT.

The empirical finding of this study suggests that to integrate silage into the existing dairy farming practices, an effort must be made to give farmers access to a secured market. This is especially important in the case of small-scale silage projects in East Africa, where farmers face the difficulty of finding a market for silage. For instance, the uptake of SMT in Kingo sub-county was higher than that in Bukulula, mainly due to the fact that farmers in Kingo have for years enjoyed access to a secured milk market, which further motivates them to innovate in solving their problems of silage spoilage and labour shortage. Similarly, ownership of improved animals also encouraged farmers to utilise the SMT to feed their animals. Farmers in Kingo reported that it was more profitable to feed silage to improved breed cows than to the local breed. This was primarily due to the higher milk yield of improved animals over local breeds after feeding them silage, generating a rapid return on their investment in SMT. A review of the reasons for the non-adoption of SMT in tropical countries found that efforts did not often yield sufficient returns on investment unless the technique became part of production systems generating a regular income for farmers (Mannetje, 2000).

Smallholder farmers in Masaka, Uganda, as in the rest of sub-Saharan Africa, are overstretched with multifaceted problems. They are facing many challenges as they endeavour to support themselves with the limited resources available. As described above, even though farmers are able to make quality silage, they tend to reject SMT due to the higher capital and workload requirements. This suggested that farmers’ understanding of the techniques involved in making good quality silage does not guarantee their adoption. A historical analysis of the delayed adoption of SMT in England demonstrated that, despite the continuous effort made to promote SMT for about a century, it was unattractive to most smallholder farmers due to its higher capital requirement (Brassley, 1996). Since SMT requires a lot more than the family’s labour, efforts are still required to reduce its higher labour requirement.

Smallholder farmers in the district lack the capability to use the technique. They are diverse in what they do, and in what they consider a priority. Indeed, farmers with small or no landholding have a limited
capacity to produce a large amount of forage for silage-making. As the findings of this study show, although farmers received training and demonstrations (some more than twice), they were not interested in adopting the technique. This suggests that targeting programmes to the context is essential in order to have an impact on the livelihood of smallholder farmers. It was evident that silage programmes proposed for smallholder farmers with the assumption of excess forage availability during the rainy season failed to take into account the differing social realities under which the SMT works. In this regard, Pawson and Tilley (1997) highlighted that interventions never work indefinitely in the same way and in all circumstances, and not for all people. Thus refining the assumptions on which programmes are based and targeting them to the specific contexts in which they can work is important to improve the effectiveness and outcomes of intervention programmes.

This study has demonstrated that the processes of adoption and adaptation of SMT are interlinked. The proactiveness exhibited by farmers in Kingo in solving their problem by redesigning the pit silo sends a strong message to policy-makers, researchers and extension agents. This is because the technical offering introduced through demonstration and training cannot be regarded as a complete package. Instead, farmers need to test and evaluate whether or not the solution satisfies their requirements before adopting it. This proves that the implicit assumption that farmers are recipients of technological packages is flawed. From his work in the developing world, Richards (1989) suggested that agricultural intervention needed to be understood as a performance, in which technical artifact is only one part. Thus, by working closely with farmers in an interactive and participatory manner, researchers and other development officers could play a key role in a joint fact-finding mission aimed at solving farmers’ problems. Silage-making programmes should not only focus on the technical solution to solve the problem of feed scarcity, but also need to consider the wider socio-technical system beyond the technique itself. This also implies a need for closer integration of research and promotion efforts within NARO and between its partners.

COMMUNICATION STRATEGIES AND IMPACT

The research results have been shared and communicated to the stakeholders (including 100 smallholder dairy farmers) through feedback workshops. Leaflets were distributed to farmers during field days, agricultural shows and farmer workshops. The output of the study was also directly presented in summary form to NARO, ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) and other stakeholders during the regional and national review and planning meetings held in Kenya, Burundi, Uganda and Tanzania. The study informed development officers, researchers and policy-makers as to how to enhance the effectiveness of the programme by understanding the socio-economic context of smallholders. It provided an important entry point to researchers and development practitioners to intervene and understand the challenges facing farmers in integrating technical solutions into existing practices. Recommendations were used to formulate the second phases of ASARECA’s Crop–Livestock project.

ACKNOWLEDGEMENTS

I would like to thank the Netherlands Fellowship Programme (NFP), Wageningen University, ASARECA, NARO-NaLIRRI and Masaka Agricultural District Production offices for the financial and technical support. I am grateful to the animal nutrition research team at Namulonge and the farmers for their unwavering support.
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POULTRY LITTER AS AN ALTERNATIVE FEED RESOURCE FOR BEEF CATTLE IN ERITREA

T.A. Tewoldebrhan*
ABSTRACT

One of the major challenges facing farmers in developing countries such as Eritrea is maintaining a sustainable supply of animal feed. The objective of this study was to evaluate poultry litter as an alternative feed for beef cattle. Litter from replacement, layer and broiler birds was collected, sun-dried and analysed for crude protein (CP), crude fibre (CF), ash and fat. The CP content (%DM) for the replacement, layer and broiler litter was 21, 19 and 18%, respectively, while the ash content for the corresponding litter was 15, 39 and 17%, respectively. The litter was ensiled with leftover bread in plastic containers at a ratio of 2.5:3.0 for 21 days. The ensiling process resulted in a product with a higher CP content and a wholesome appearance, which was palatable and safe. Sixteen Barka cattle were selected and divided into four groups (each with four animals) and a 90-day feeding trial was conducted. The four treatments (T) consisted of: T1 control diet with 30% wheat bran; T2 30% replacement litter; T3 30% layer litter; and T4 30% broiler litter. T1–T4 each received a combined addition of 36.3% leftover bread, 30.3% taff straw, 2.4% fishmeal and 1% salt. The feeding system was restricted and each group consumed all of the available feed (7.44 kg of DM/cattle/day). Average body weight gains (ABG) for T1, T2, T3 and T4 were 1.093, 1.019, 0.673 and 0.966 kg/day, respectively. ABG for T1, T2 and T4 were not significantly different ($P > 0.05$), whereas the ABG of cattle fed on T3 were significantly different ($P < 0.05$) compared with the others. It was concluded that wheat bran could be substituted by replacement and broiler litter. Furthermore, feeds containing poultry silage could reduce the cost of feed for farmers fattening their cattle.

KEY WORDS: BARKA CATTLE, ENSILING, LEFTOVER BREAD, POULTRY LITTER, TAFF STRAW, WHEAT BRAN

AFFILIATIONS

* Ministry of Agriculture, Asmara, Eritrea.
INTRODUCTION

Scarcity of animal feeds is one of the major constraints that limit beef production in Eritrea. The main challenge therefore is how to increase feed supply and improve feeding practices. The conventional grain diets are very expensive, so there is an urgent need to explore alternative feeding systems. One such alternative that is locally readily available is poultry litter, which is rich in crude proteins and minerals. Due to the high fibre and non-protein nitrogen content of the litter, ruminant animals including cattle are best suited to such utilisation of poultry waste.

Poultry litter must be processed in order to eliminate pathogens, improve storage characteristics and enhance palatability (Fontenot, 1996). The ensiling of poultry litter is a simple and cost-effective technique. To ensile poultry litter, a rich source of fermentable carbohydrate must be added. The addition of a carbohydrate source is believed to enhance the palatability of the product (Kayouli and Lee, 2000). In this study, leftover bread was used as the source of fermentable carbohydrate. The objectives of this study were to determine the effect of ensiled poultry litter with leftover bread on the body weight gain (BWG) of cattle, and to compare the effect of the different kinds of poultry litter (layer, replacement and broiler) on the BWG of cattle.

METHODOLOGY

Ensiling process

Poultry litter (replacement, layer and broiler) was collected from commercial farms. The poultry litter was a mixture of bird excreta, wasted feed, feathers and bedding materials such as sawdust, wood shavings and straw. Immediately after collection, the litter was spread on plastic sheets and sun-dried for 2 days. Samples of the collected litter were diagnosed for salmonellosis. Leftover bread was collected from several sources, including the University of Asmara cafeteria, other educational institutions, restaurants and snack bars. The leftover bread and poultry litter were separately weighed and mixed. The mixture was composed of 45.5% poultry litter and 54.5% leftover bread on percentage dry matter (%DM). Water (80 l/100 kg mixture) was added to increase the moisture content to around 50%. The mixtures of poultry litter and leftover bread were firmly packed and pressed by hand into the plastic containers. A plastic sheet was inserted between the lids of the containers and the ensiled material to make it airtight, excluding oxygen. The silage was prepared daily and each container was opened after a period of at least 21 days.

Feeding trial

This study was conducted in the western lowlands of Eritrea in Zoba Gash Barka at Gash Setit Agro Industry and Trade Farm. The farm is located about 15 km from Tessenie. Sixteen Barka cattle of similar weight (291–294 kg) and age (3–4 years) were randomly assigned into four treatment groups (T1–T4), each with four animals. Barka cattle in the control group (T1) were fed on a commercial-type ration consisting of 30% wheat bran, 36.3% leftover bread, 2.4% fish meal, 30.3% taff straw and 1% salt as dry matter. The cattle in each of the remaining three silage groups (T2, T3 and T4) received a combination of 2.4% fish meal, 30.3% taff straw, 1% mineral salt and 30% replacement, layer and broiler litter, respectively, ensiled with leftover bread (36.3%).

Feeding was restricted and given at a rate of 7.44 kg DM/cattle/day. To avoid the effect of variable amounts of energy on the body weight of the animal, the rations were made virtually isocaloric for all treatment groups. The cattle were weighed every 2 weeks and the figures recorded. In addition, leftovers from the treatment feeds were collected and weighed daily. All the animals had unrestricted access to water at all times. The research was conducted for 105 feeding days, including a 15-day adaptation period.
Chemical and statistical analysis

All feeds were analysed for DM, crude protein (CP) (Kjeldahl-N×6.25), fat, crude fibre (CF) and ash according to the standard procedures described by AOAC (1984). The trials were conducted in a completely randomised design (CRD). Live weight gain and dry matter intakes (DMI) in terms of the metabolic weight of the animals were determined using one-way analysis of variance.

RESULTS

Feed composition

Salmonella was not detected in any of the sun-dried poultry (layer, replacement or broiler) litter used in the study. Leftover bread ensiled with the three different kinds of poultry litter resulted in silage that was wholesome, consistent in colour, and had a pleasant aroma. The CP content in the ensiled material for replacement, layer, and broiler litter increased from 16.44, 15.27 and 15.02% to 21.36, 19.47 and 17.94%, respectively (Table 1). The silage for replacement litter was higher in ether extract (1.14%) and lower in ash (10.20%) content than the layer and broiler litter. The ash content of the silage of layer litter (20.78%) was higher than from replacement (10.20%) and broiler litter (11.81%).

Nutrient intake and animal performance

All of the silages were palatable and readily consumed by the animals. Barka cattle adapted to the silages of the poultry litter after 3–5 days. Dry matter intakes (DMI) were 7.41, 7.40, 7.41 and 7.41 kg/day for the animals fed the control diet (T1), ensiled leftover bread with replacement litter (T2), ensiled leftover bread with layer litter (T3), and ensiled leftover bread with broiler litter (T4), respectively. The DMI of metabolic weight expressed as grams per unit of metabolic size (W_{kg}^{0.75})/day for T1, T2, T3 and T4 were 91.4, 92.7, 97.1 and 94.1, respectively. Intakes in terms of metabolic weight were not statistically different (P > 0.05) among the treatments. Cattle in all

<table>
<thead>
<tr>
<th>Component</th>
<th>Leftover bread + replacement litter</th>
<th>Leftover bread + layer litter</th>
<th>Leftover bread + broiler litter</th>
</tr>
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<tr>
<td>Dry matter (%)</td>
<td>48.99</td>
<td>47.77</td>
<td>50.14</td>
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<tr>
<td>Crude protein (%DM)</td>
<td>21.36</td>
<td>19.47</td>
<td>17.94</td>
</tr>
<tr>
<td>Ash (%DM)</td>
<td>10.20</td>
<td>20.78</td>
<td>11.81</td>
</tr>
<tr>
<td>Crude fibre (%DM)</td>
<td>7.34</td>
<td>6.84</td>
<td>16.36</td>
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<tr>
<td>Ether extract (%DM)</td>
<td>1.14</td>
<td>0.68</td>
<td>0.64</td>
</tr>
<tr>
<td>NFE (%DM)</td>
<td>59.96</td>
<td>52.23</td>
<td>53.25</td>
</tr>
<tr>
<td>Energy (MJ/kg DM)*</td>
<td>14.04</td>
<td>12.26</td>
<td>12.16</td>
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</table>

* Calculated value.
four treatment groups gained weight throughout the experimental period (Figure 1). Cattle fed on T1, T2, T3 and T4 gained 1.093, 1.019, 0.673 and 0.966 kg/day respectively. Differences for weight gains obtained for T1, T2 and T4 were not statistically significant \((P > 0.05)\) (Table 2). Weight gain obtained from cattle fed on T3 was significantly different \((P < 0.05)\) from the remaining three groups. BWG for cattle in T2 and T4 groups were significantly higher than that of T3 \((P < 0.05)\).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>LSD</th>
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<tr>
<td>Number of animals</td>
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<td>4*</td>
<td>4</td>
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<tr>
<td>Live weight (kg) – initial</td>
<td>293.9</td>
<td>293.4</td>
<td>291.7</td>
<td>290.9</td>
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<tr>
<td>Live weight (kg) – final</td>
<td>392.3</td>
<td>385.1</td>
<td>352.3</td>
<td>377.8</td>
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<tr>
<td>Feeding period (days)</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td></td>
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<tr>
<td>Average daily gain (ADG)</td>
<td>1.093a</td>
<td>1.019a</td>
<td>0.673b</td>
<td>0.966a</td>
<td>0.2264</td>
</tr>
</tbody>
</table>

Number in a row with different superscripts differ significantly \((P < 0.05)\). LSD = least significant difference.

* One animal was lost from the group and was not replaced.

![Figure 1: Weekly Average Body Weight of Cattle Fed a Conventional Feed Lot-Type Control Diet or Ensilages of Poultry Litter with Leftover Bread](image-url)
DISCUSSION AND CONCLUSION

In this study, it was observed that the CP value increased after ensiling. This increase in CP value in all ensiled litter could be due to the increased lactic acid bacteria, which were a potential source of protein after being lysed by the low pH during the stable phase of fermentation. No mould growth was detected in the silages as the plastic containers were sealed with airtight lids. Furthermore, the high ratio of leftover bread to poultry litter (54.5:45.5) provided sufficient sugar for fermentation.

During the feeding period, the silages were offered to the animals by mixing them thoroughly with taff straw to avoid selection. As a result, the offered feed was consumed by all treatment groups with insignificant differences in DMI. This result is similar to those previously reported by Caswell et al. (1977), who found no significant difference in DMI for cattle fed ensiled broiler litter compared to those fed soybean meal. Other researchers (Al-Rokayan et al., 1998) also reported that the addition of poultry litter had a positive effect on DMI.

The BWGs obtained in this study tallied with the results obtained in Kenya, where Odhuba (1986) fed steers ensiled layer litter with sorghum forage and the steers gained 0.98 kg/day, whereas steers fed cottonseed cake gained 1.10 kg/day. Hadjipanayiotou et al. (1993) found that bull calves fed ensiled maize forage with poultry manure gained slightly less weight than the control group (fed more cotton seed hulls and concentrates), but differences were not statistically significant. Silages for replacement litter were higher in CP and ether extract than layer litter and broiler litter (Table 1); this could explain why animals fed on ensilages of replacement litter gained more than the other two groups. The decreased BWG scores for T3 (cattle fed layer litter) could be attributable to the ash content of the ensiled material. Minerals are required in trace amounts. Any excess is excreted from the body. Accordingly, cattle fed on T3 gained less than the other two silage groups (T2 and T4).

The disadvantages of the high ash content of litter from layers have previously been reported. For instance, Shah and Muller (1982), Odhuba (1986) and McDonald et al. (1995) found that the high ash content of layer litter reduced the level of organic matter and digestibility, which consequently was responsible for its low metabolisable energy. Furthermore, Parsons (2006) reported that meals that contain higher ash resulted in an imbalance of amino acid.

The results of this study demonstrated that correctly prepared silage of poultry litter and leftover bread had a pleasant aroma and a wholesome appearance, which was a safe and palatable feed for livestock. Cattle fed ensiled replacement and broiler litter with the inclusion of 30% of the ration gained 93.23 and 88.38% more weight, respectively, than animals fed conventional feedlot type of diet, which contained 30% wheat bran. Wheat bran can be completely substituted by replacement and broiler litter in rations for Barka cattle.

COMMUNICATION STRATEGY AND IMPACT

The on-farm feeding trial at Gash Setit Agro Industry and Trade Farm, and the use of cheap and readily available local feed resources, enabled farmers to easily adopt the feeding practice. Furthermore, between 2009 and 2010, stakeholders such as the extension agents from the Ministry of Agriculture and a number of NGOs were disseminating this innovative animal feeding technique to farmers via workshops, training and demonstration sites. Accordingly, many beef and dairy producers are more aware that ensiled poultry waste represents a cheap, safe and palatable feed for livestock and are using it as an alternative feed resource in Eritrea.
ACKNOWLEDGEMENTS

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ACRONYMS
<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<td>AAT</td>
<td>African Animal Trypanosomiasis</td>
</tr>
<tr>
<td>ABSF</td>
<td>African Biotechnology Stakeholders Forum</td>
</tr>
<tr>
<td>ACP</td>
<td>African, Caribbean and Pacific</td>
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<td>ADP</td>
<td>Agricultural Development Programme</td>
</tr>
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<td>AEATREC</td>
<td>Agricultural Engineering and Appropriate Technology Research Centre</td>
</tr>
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<td>AFD</td>
<td>French Development Agency</td>
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<td>AGRA</td>
<td>Alliance for a Green Revolution in Africa</td>
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<td>ANAFE</td>
<td>African Network for Agriculture, Agroforestry and Natural Resources Education</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variances</td>
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<td>AOAC</td>
<td>Association of Official Analytical Chemists</td>
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<td>ARTES</td>
<td>Africa Rainfall and Temperature Evaluation System</td>
</tr>
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<td>ASARECA</td>
<td>Association for Strengthening Agricultural Research in Eastern and Central Africa</td>
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<td>ASPS</td>
<td>Agricultural Sector Programme Support</td>
</tr>
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<td>AU</td>
<td>African Union</td>
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<tr>
<td>AUC</td>
<td>African Union Commission</td>
</tr>
<tr>
<td>BARC</td>
<td>Beltsville Agriculture Research Centre</td>
</tr>
<tr>
<td>BIOTA</td>
<td>Biodiversity Monitoring Transect Analysis</td>
</tr>
<tr>
<td>BMZ</td>
<td>German Ministry for Economic Cooperation and Development</td>
</tr>
<tr>
<td>CAADP</td>
<td>Comprehensive African Agricultural Development Programme</td>
</tr>
<tr>
<td>CAQDAS</td>
<td>Computer Aided Qualitative Data Analysis Software</td>
</tr>
<tr>
<td>CARS</td>
<td>Chitedze Agricultural Research Station</td>
</tr>
<tr>
<td>CEPHYR</td>
<td>Centre for Phytotherapy Research and Development</td>
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<tr>
<td>CFTRI</td>
<td>Central Food Technological Research Institute</td>
</tr>
<tr>
<td>CFU</td>
<td>Colony forming unit</td>
</tr>
<tr>
<td>CGIAR</td>
<td>Consultative Group on International Agricultural Research</td>
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<td>CIAT</td>
<td>International Centre for Tropical Agriculture</td>
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<td>CIDA</td>
<td>Canadian International Development Agency</td>
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<td>CIFRED</td>
<td>Interfaculty Centre of Training and Research in Environment for Sustainable Development</td>
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<td>CIMMYT</td>
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<td>CIRAD</td>
<td>French Agricultural Research Centre for International Development</td>
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<td>CIRDES</td>
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<tr>
<td>CMD</td>
<td>Cassava mosaic disease</td>
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<td>CNRS</td>
<td>National Centre for Scientific Research</td>
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<td>COPES-AOC</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>---------</td>
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<tr>
<td>CP</td>
<td>Crude protein</td>
</tr>
<tr>
<td>CPA</td>
<td>Consolidated Plan of Action</td>
</tr>
<tr>
<td>CRUS</td>
<td>Conseil R?gional des Unions du Sahel</td>
</tr>
<tr>
<td>CTA</td>
<td>Technical Centre for Agricultural and Rural Cooperation</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
</tr>
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<td>DAAD</td>
<td>German Academic Exchange Service</td>
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<td>DANIDA</td>
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<tr>
<td>DCG</td>
<td>Drylands Coordination Group</td>
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<td>DelPHE</td>
<td>Developing Partnerships in Higher Education</td>
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<td>DFID</td>
<td>Department for International Development</td>
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<tr>
<td>DM</td>
<td>Dry matter</td>
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<td>DNRP-GAPCC</td>
<td>Dutch National Research Program on Global Air Pollution and Climate Change</td>
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<td>EASST</td>
<td>European Association for the Study of Science and Technology</td>
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<td>ECA</td>
<td>Eastern and Central Africa</td>
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<td>FANTA</td>
<td>Food and Nutrition Technical Assistance Project</td>
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<td>FAO</td>
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<td>FARA</td>
<td>Forum for Agricultural Research in Africa</td>
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<td>FASDEPEND</td>
<td>Food and Agriculture Sector Development Policy</td>
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<td>GCP</td>
<td>Generation Challenge Programme</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GEF</td>
<td>Global Environmental Facility</td>
</tr>
<tr>
<td>GPRS II</td>
<td>Growth and Poverty Reduction Strategy Phase II</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>GRESE</td>
<td>Research Group on Water, Soil and the Environment, University of Limoges</td>
</tr>
<tr>
<td>HPI</td>
<td>Heifer Project International</td>
</tr>
<tr>
<td>HPLC</td>
<td>High Performance Liquid Chromatography</td>
</tr>
<tr>
<td>IBPGR</td>
<td>International Board for Plant Genetic Resources</td>
</tr>
<tr>
<td>ICARDA</td>
<td>International Centre for Agricultural Research in the Dry Areas</td>
</tr>
<tr>
<td>ICRAF</td>
<td>World Agroforestry Centre</td>
</tr>
<tr>
<td>ICRISAT</td>
<td>International Crops Research Institute for the Semi-Arid Tropics</td>
</tr>
<tr>
<td>ICSU</td>
<td>International Council for Science</td>
</tr>
<tr>
<td>ICSW</td>
<td>International Conference on Solid Waste Technology and Management</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>IDA</td>
<td>World Bank’s International Development Assistance</td>
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<tr>
<td>ACRONYMS</td>
<td>Meaning</td>
</tr>
<tr>
<td>----------</td>
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</tr>
<tr>
<td>IDRC</td>
<td>International Development Research Council</td>
</tr>
<tr>
<td>IFAD</td>
<td>International Fund for Agricultural Development</td>
</tr>
<tr>
<td>IFPRI</td>
<td>International Food Policy Research Institute</td>
</tr>
<tr>
<td>IFS</td>
<td>International Foundation for Science</td>
</tr>
<tr>
<td>IITA</td>
<td>International Institute of Tropical Agriculture</td>
</tr>
<tr>
<td>ILRI</td>
<td>International Livestock Research Institute</td>
</tr>
<tr>
<td>INERA</td>
<td>Environment and Agricultural Research Institute</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPK</td>
<td>Leibniz Institute of Plant Genetics and Crop Plant Research</td>
</tr>
<tr>
<td>IRAD</td>
<td>Institute of Agricultural Research for Development</td>
</tr>
<tr>
<td>IRD</td>
<td>Research Development Institute</td>
</tr>
<tr>
<td>ISFM</td>
<td>Integrated soil fertility management</td>
</tr>
<tr>
<td>ISO</td>
<td>International Studies Organisation</td>
</tr>
<tr>
<td>ISSEA</td>
<td>Sub-regional Institute of Statistics and Applied Economics</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Unit</td>
</tr>
<tr>
<td>JKUAT</td>
<td>Jomo Kenyatta University of Agriculture and Technology</td>
</tr>
<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institute</td>
</tr>
<tr>
<td>KNUST</td>
<td>Kwame Nkrumah University of Science and Technology</td>
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<tr>
<td>LCA</td>
<td>Life cycle analysis</td>
</tr>
<tr>
<td>LSD</td>
<td>least significance difference</td>
</tr>
<tr>
<td>LSRP</td>
<td>Livestock Systems Research Programme</td>
</tr>
<tr>
<td>LW</td>
<td>Live weight</td>
</tr>
<tr>
<td>MAAIF</td>
<td>Ministry of Agriculture, Animal Industry and Fisheries</td>
</tr>
<tr>
<td>MADDO</td>
<td>Masaka Diocesan Development Organization</td>
</tr>
<tr>
<td>MARD</td>
<td>Ministry of Agriculture and Rural Development</td>
</tr>
<tr>
<td>MDG</td>
<td>Millennium Development Goal</td>
</tr>
<tr>
<td>ME</td>
<td>Metabolizable energy</td>
</tr>
<tr>
<td>MEADEN</td>
<td>Mission Study for Planning and Development of the Northern Province</td>
</tr>
<tr>
<td>MS</td>
<td>Mass Spectrometry</td>
</tr>
<tr>
<td>NAA</td>
<td>Naphthalene acetic acid</td>
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<tr>
<td>NARI</td>
<td>National Agricultural Research Institute</td>
</tr>
<tr>
<td>NARL</td>
<td>National Agricultural Research Laboratories</td>
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<tr>
<td>NARO</td>
<td>National Agricultural Research Organization</td>
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<tr>
<td>NCST</td>
<td>National Council of Science and Technology</td>
</tr>
<tr>
<td>NEPAD</td>
<td>New Partnership for Africa’s Development</td>
</tr>
<tr>
<td>NERICA</td>
<td>New Rice for Africa</td>
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<tr>
<td>NFP</td>
<td>Netherlands Fellowship Programme</td>
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<tr>
<td>NGO</td>
<td>Non Governmental Organisation</td>
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<tr>
<td>ACRONYMS</td>
<td>FULL NAME</td>
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<tr>
<td>NIFOR</td>
<td>Nigerian Institute for Oil Palm Research</td>
</tr>
<tr>
<td>NORAD</td>
<td>Norwegian Agency for Development Cooperation</td>
</tr>
<tr>
<td>NPCA</td>
<td>NEPAD Planning and Coordinating Agency</td>
</tr>
<tr>
<td>NPK</td>
<td>Nitrogen Phosphorus Potassium</td>
</tr>
<tr>
<td>NRCRI</td>
<td>National Root Crops Research Institute</td>
</tr>
<tr>
<td>NSI</td>
<td>Cameroon National Statistical Institute</td>
</tr>
<tr>
<td>NVI</td>
<td>National Veterinary Institute</td>
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<tr>
<td>OCADES</td>
<td>Organisation Catholique pour le Développement et la Solidarité?</td>
</tr>
<tr>
<td>OIE</td>
<td>World Organisation for Animal Health</td>
</tr>
<tr>
<td>OPV</td>
<td>Open-pollinated variety</td>
</tr>
<tr>
<td>PAH</td>
<td>Aromatic hydrocarbons</td>
</tr>
<tr>
<td>PAR</td>
<td>Participatory Action Research</td>
</tr>
<tr>
<td>PCR</td>
<td>Polymerase chain reaction</td>
</tr>
<tr>
<td>PID</td>
<td>Participatory Innovation Development</td>
</tr>
<tr>
<td>PM&amp;E</td>
<td>participatory monitoring and evaluation</td>
</tr>
<tr>
<td>PRA</td>
<td>Participatory Rapid Appraisal</td>
</tr>
<tr>
<td>PROLINNOVA</td>
<td>Promoting Local Innovations in Ecologically-oriented Agriculture and Natural Resource Management</td>
</tr>
<tr>
<td>PRSV</td>
<td>Papaya ringspot poty-virus</td>
</tr>
<tr>
<td>PTD</td>
<td>Participatory Technology Development</td>
</tr>
<tr>
<td>QTL</td>
<td>Quantitative trait loci</td>
</tr>
<tr>
<td>RBT</td>
<td>Rose Bengal Test</td>
</tr>
<tr>
<td>RCBD</td>
<td>Randomized complete block design</td>
</tr>
<tr>
<td>RDA</td>
<td>Recommended dietary requirement</td>
</tr>
<tr>
<td>RIPIECSA</td>
<td>Interdisciplinary and Participatory Research on Interactions between Climate, Ecosystems and Society in West Africa</td>
</tr>
<tr>
<td>RUFORUM</td>
<td>Regional Universities Forum for Capacity Building in Agriculture</td>
</tr>
<tr>
<td>SAS</td>
<td>Statistical Analysis Systems Institute</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>SEM</td>
<td>Standard error of the mean</td>
</tr>
<tr>
<td>SEM/EDS</td>
<td>Scanning electron microscopy/energy dispersive spectroscopy</td>
</tr>
<tr>
<td>SF</td>
<td>Specifi Frequency</td>
</tr>
<tr>
<td>SOAP</td>
<td>West African Society of Parasitology</td>
</tr>
<tr>
<td>SOFECsA</td>
<td>Soil Fertility Consortium for Southern Africa</td>
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<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>SSA</td>
<td>Sub Saharan Africa</td>
</tr>
<tr>
<td>SSA-CP</td>
<td>Sub Saharan Africa Challenge Program</td>
</tr>
<tr>
<td>TVT</td>
<td>Togo’s national television station</td>
</tr>
<tr>
<td>UBOS</td>
<td>Uganda Bureau of Statistics</td>
</tr>
<tr>
<td>UCAD</td>
<td>Cheikh Anta Diop University</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>UDHS</td>
<td>Uganda Demographic and Health Survey</td>
</tr>
<tr>
<td>UFR/SVT</td>
<td>Research Training Unit for the Life and Earth Sciences</td>
</tr>
<tr>
<td>UKJAS</td>
<td>University of Khartoum Journal of Agricultural Sciences</td>
</tr>
<tr>
<td>UNCST</td>
<td>Uganda National Council for Science and Technology</td>
</tr>
<tr>
<td>UNFPA</td>
<td>United Nations Population Fund</td>
</tr>
<tr>
<td>UNICEF</td>
<td>United Nations Children’s Fund</td>
</tr>
<tr>
<td>UPB</td>
<td>Polytechnic University of Bobo-Dioulasso</td>
</tr>
<tr>
<td>USAID</td>
<td>United States Agency for International Development</td>
</tr>
<tr>
<td>UVMD</td>
<td>Unterraced, vegetative, macro contour line with maize-dolicos intercrop</td>
</tr>
<tr>
<td>VAD</td>
<td>Vitamin A deficiency</td>
</tr>
<tr>
<td>VicRes</td>
<td>Lake Victoria Research Initiative</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compounds</td>
</tr>
<tr>
<td>WAP</td>
<td>Weeks after Planting</td>
</tr>
<tr>
<td>WB</td>
<td>Wheat bran</td>
</tr>
<tr>
<td>WCA</td>
<td>West and Central Africa</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
<tr>
<td>WM</td>
<td>Whole maize</td>
</tr>
<tr>
<td>WMC</td>
<td>Wheat Microsatellite Consortium</td>
</tr>
<tr>
<td>WPI</td>
<td>Price index for cereals on the world market</td>
</tr>
<tr>
<td>WUR</td>
<td>Wageningen University and Research centre</td>
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<tr>
<td>WW</td>
<td>World wide</td>
</tr>
<tr>
<td>YPI</td>
<td>Cereal price indices in Yaound?</td>
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