September 2014 Vol. 22 Issue Supplement, s4

ISSN 1021- 9730/2014 (Print)
ISSN 2072-6589/2014 (Online)

African Crop Science Journal

Eighty Fifth Issue Supplement

Internet address:
http://www.acsj.info/
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Editorial Secretariat
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African Crop Science Journal

The Journal of Tropical Crop Science and Production

VOLUME 22 Issue Supplement, s4 **2014**

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This publication was made possible through the support of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)

African Crop Science Journal

The Journal of Tropical Crop Science and Production

Published by the African Crop Science Society

VOLUME 22 (2014)

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The *African Crop Science Journal* was established with the primary objective of providing a forum for presentation and review of research results on Tropical Crop Science that can be readily accessed by researchers and development leaders in Africa and other developing countries, and all those concerned with agricultural development issues in the region. The most important characteristic of the Journal is that it addresses in an integrated manner all aspects of Crop Science and Production.

The Journal publishes original research papers dealing with Crop Agronomy, Production, Genetics and Breeding, Germplasm, Crop Protection, Soil Sciences, Postharvest Systems and Utilisation, Agroforestry, Crop-Animal Interactions, Environmental Issues and Agricultural Information.

The Journal also publishes authoritative reviews on various aspects of Crop Science, Agricultural Development, and the Environment, usually by invitation, and 'Short Communications' dealing with original results not warranting publication as full papers. It has a book review and advertisement sections. To encourage dialogue on topical issues, the Journal has a 'Forum Section' where issues of current contention in crop production, including socioeconomics and rural development, will be discussed. In addition, African Crop Science Journal publishes supplementary issues on emerging themes in crop science and production. Such Issues are marked as "*Issue Supplement*".

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The African Crop Science Society, P. O. Box 7062, Kampala, Uganda

African Crop Science Journal

The Journal of Tropical Crop Science and Production

VOLUME 22

FOREWORD

This Special Issue of the African Crop Science Journal presents some scientific articles presented during the 2nd General Assembly of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) held in Bujumbura, Burundi, between 9 - 13 December 2013. The theme of the Assembly was "Transforming agriculture for Economic Growth in Eastern and Central Africa (ECA)".

Given that the bulk of the sub-region's population resides in rural areas and depends on agriculture for income and sustenance, and given the low levels of productivity growth in the sector, hunger and malnutrition have deepened in ECA in recent years. About 70% of ECA's cropland is in areas with high and medium agricultural potential, which indicates the sub-region's potential to reverse this dire situation.

ASARECA has continued to bring together scientists and other critical stakeholders in the ECA sub-region to generate, share and promote knowledge and innovations to solve the common challenges facing agriculture in the 11 member states of Burundi, DR Congo, Ethiopia, Eritrea, Kenya, Madagascar, Rwanda, Sudan, South Sudan, Tanzania and Uganda. Collectively, ASARECA and its partners work to assist smallholder farmers in the ECA sub-region to practice productive and profitable agriculture. ASARECA initiatives continue to focus on transforming agriculture into a viable market-oriented venture with a strong emphasis on linking smallholder farmers to markets.

The papers presented herein are derived from some research for development projects that were supported by ASARECA during its first Medium Term Operational Plan (MTOP-2008-2013). The articles describe the generation and deployment of cost effective technologies, innovations and management practices besides providing examples of regional policy and farmer empowerment initiatives.

Under its new second MTOP, ASARECA will continue with its role of catalysing cooperation among sub-regional stakeholders in executing its AR4D strategy. In addition, ASARECA envisions itself evolving into a sub-regional learning centre on how to transform agriculture, a think tank, and a knowledge and information hub that will support all aspects of sub-regional agriculture.

ASARECA acknowledges the support provided by the European Union (EU), United States Agency for International Development (USAID), Canadian International Development Agency (CIDA), Swedish International Development Cooperation (SIDA), Department for International Development (DFID), African Development Bank (AfDB), the World Bank and the National Agricultural Research Systems (NARS) of member countries, among others. The support is highly acknowledged.

Dr. Fina Opio
Executive Director
ASARECA

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Text: Should appear in the following order: Title, Authors' names and addresses, Corresponding author's email, Abstract, Key words (not more than 5 and should not be those in the Title), Introduction, Materials and Methods, Results, Discussion, Acknowledgement, References, Tables, Figures, and Figure Legends. Each of the illustrations should be numbered serially as a separate set. Main section headings in the manuscript should be bold, centred and of uppercase letters. Do not underline the title or section headings. Minimise use of scientific names in the Title. Subsections (also bolded) may be included and only the first letter of the subsection should be capitalized. Avoid excessive fragmentation of the paper.

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Title: Should be brief and reflect the main theme of the paper.

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At the 11th African Crop Science Society conference and Annual General Meeting (2013), the Governing Council of the society approved modest Journal publication fees per accepted paper in the order of US$100 for Society members with up-to-date annual subscription payments, and US$150 for non-members. This takes effect from 2014.

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Instructions générales. Les auteurs doivent soumettre leur manuscript au Sécrétariat de la *Revue Africaine des Sciences Agricoles,* au Collège des Sciences Agricoles et Environnementales de l' Université de Makerere, B.P.7062, Kampala, Ouganda. Cette revue ne fait pas payer les frais de mise en page des articles acceptés pour publication. Les articles publiés dans la *Revue Africaine des Sciences Agricoles* doivent être basés sur une recherche novatrice ou une recherche parachevant une étude précédente reproductible. Les articles à publier dans les sections de Revue et Furum devront être dotés d'une pertinence internationale.

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Desmorieux, H. 1992. Le séchage en zone Sub Saharienne une analyse pratique fâce aux réalités géographiques et humaines. Thèse de I'INPL, Nancy. 234p.

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Coût de publication: A la 11ème conférence de la Société Africaine des Sciences Agricoles et la réunion annuelle générale (2013), le Conseil de gestion de la Société a approuvé un coût modeste de publication de US$100 par article accepté pour les membres abonnés de la Société, et US$ 150 pour les non membres. Ceci entre en vigueur depuis 2014.

African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 791 - 798 ISSN 1021-9730/2014 $4.00

RECOVERY OF amiRNA3-PARP1 TRANSGENIC MAIZE PLANTS USING A BINARY VECTOR HAVING THE BIOSAFE *PMI* GENE

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ABSTRACT

Positive plant selectable marker genes are commonly used in plant transformation because they not only enhance the frequency of generation transgenic tissues but are considered biosafe, unlike antibiotic or herbicide resistance genes. In this study, the binary vector pNOV2819-ubiamiRNA3PARP1, harbouring the phosphomannose isomerase (*pmi*) gene was developed and used in recovery of transgenic maize (*Zea mays* L.) plants containing the drought tolerance gene, amiRNA3-PARP1. The pre-amiRNA3-PARP1 and Tnos transgenes were sequentially PCR-cloned upstream the ubiquitine promoter in the Ubi/NC1300 plasmid. The pre-amiRNA3-PARP1 expression cassette was transferred into the *pmi* gene-containing pNOV2819 plasmid to produce the pNOV2819-ubiamiRNA3PARP1 vector. Transgenic IL3 and A188 plants containing pre-amiRNA3-PARP1 were generated through transformation with LBA4404 harbouring the pNOV2819-ubiamiRNA3PARP1 vector. The plants were confirmed transgenic by PCR. It is clear that the developed vectors are effective in recovery of amiRNA3-PARP1 transgenic tissues and plants containing the *pmi* gene, which has been shown to have no negative environmental or health effects.

Key Words: *Agrobacterium* transformation, amiRNA, PMI, *Zea mays*

RÉSUMÉ

Les marqueurs génétiques de sélection positive de plantes sont communément utilisés dans la transformation des plantes parce que, non seulement ils augmentent la fréquence de la génération des tissus transgéniques, mais aussi sont considérés comme biosains, à l'inverse des gènes de résistance aux antibiotiques et herbicides. Dans cette étude, le vecteur binaire pNOV2819-ubiamiRNA3PARP1 portant le gène isomérase phosphomannose (*pmi*) a été développé et utilisé dans le recouvrement transgénique des plantes du maïs (*Zea mays* L.) contenant le gène to tolérance à la sécheresse amiRNA3-PARP1. Les transgènes pre-amiRNA3-PARP1 et Tnos étaient séquentiellement clonés par PCR dans la partie supérieure du promoteur ubiquitine dans le plasmide Ubi/NC1300. L'expression de la cassette de la pré-amiRNA3-PARP1 était transférée dans le gène *pmi* contenant le plasmide pNOV2819 pour produire le vecteur pNOV2819-ubiamiRNA3PARP1. Les plants transgéniques IL3 et A188 contenant le pre-amiRNA3-PARP1 étaient générés à travers la transformation avec LBA4404 portant le vecteur pNOV2819-ubiamiRNA3PARP1. Les plants étaient confirmées transgéniques par PCR. Il est clair que les vecteurs développés sont efficaces dans le recouvrement des tissus transgéniques amiRNA3-PARP1 et les plants contenant le gène *pmi* qui ne présentent aucun effet négatif sur l'environnement et la santé.

Mots Clés: Transformation *Agrobacterium*, amiRNA, PMI, *Zea mays*

INTRODUCTION

A selectable marker gene (SMG) is an essential genetic component of a plant transformation vector. It is useful in identifying plant cells and tissues that take up foreign DNA during genetic transformation. Among the commonly used SMGs are those that code for antibiotic or herbicide resistance. These SMGs have been implicated in reducing the transformation efficiency for many crops. In addition, their use continues to raise environmental and food safety concerns (Miki and McHugh, 2004).

Today, the phosphomannose isomerase (*pmi*) gene is being used as a safer alternative to the antibiotic and herbicide resistance SMGs (Privalle *et al*., 1998; Jaiwal *et al*., 2002). The *pmi* gene was isolated from *E. coli* and has been used to recover transgenic plants at a higher frequency than antibiotic resistance genes (Joersbo *et al*., 1998; Dawson *et al*., 2001). It has been widely used in transformation of monocotyledonous plants, including wheat (Gadaleta *et al*., 2006; Dawson *et al*., 2001), rice (He *et al*., 2004), sorghum (Gao *et al*., 2005) and maize (Negrotto *et al*, 2000; Dawson *et al*., 2001).

The aim of this work was to prepare plant transformation vector containing the amiRNA transgene against maize *PARP1* gene and use it in maize transformation.

MATERIAL AND METHODS

DNA manipulation and cloning was achieved using protocols described by Sambrook *et al*. (1989). Restriction endonucleases and DNA polymerase were purchased exclusively from New England Bio-labs Inc., MA, USA. DNA ligases were procured from Invitrogen Corp. Carlsbad CA, USA. All oligonucleotides for PCR and sequencing were designed using the RealTime Design™ software (Biosearch Technologies), and synthesised in Bioneer Corporation (Korea) through Biosciences Eastern and Central Africa (BecA) Hub (ILRI, Nairobi, Kenya). DNA sequencing was done by the SEGOLI division of the BecA Hub. *Escherichia coli* and *A. tumefaciens* strain LBA4404 cells were made competent using the method of Tu *et al*. (2005) and Xu and Li (2008), respectively. Competent *E. Coli* and LBA4404 cells were transformed by the heat shock and freeze thaw (Raviraja and Sridhar, 2007) method, respectively.

PCR cloning of amiRNA1-PARP1 into Ubi/NC1300. The complete pre-amiRNA3-PARP1 region (414 bp) was amplified from pExamiRNAL2 (Fig. 1) vectors using the amiRNA forward primer (5' tatcacacccgggtccccaaacacacgctcg 3') having the *SmaI* restriction site and the amiRNA reverse primer (5' atacagagctctccccatggcgatgccttaa 3') having the *SacI* restriction site. All reactions were performed in volumes of 100 µl, comprising of ×1 PCR reaction buffer, 0.5 mM dNTPs, 2.5 mM $MgCl_2$ 0.25 M of each primer, 1 U Taq polymerase and 20 ng of plasmid DNA. Amplifications were performed on a Mastercycler vapoprotect (Eppendorf Hamburg, Germany) programmed with, 30 cycles of denaturation at 95 °C for 15 sec °C, annealing at 60 °C for 30 sec and extension at 72 °C for 30 sec. An initial denaturation step at 95 °C for 5 min was performed. PCR products verified by agarose gel electrophoresis were purified using the Qiaquick PCR purification kit (Qiagen, Maryland, USA). PCR products were digested with *SmaI* and *SacI* and ligated into the *SmaI/SacI* site of Ubi/NC1300 plasmid (Fig. 1). The ligation mixture was transformed into competent *E. coli* cells and the positive recombinants harbouring the new Ubi/NC1300-amiRNA3 vector identified by *XbaI* digestion and sequencing.

Cloning of *Tnos* into Ubi/NC1300-amiRNA3 vectors. The full nos terminator sequence (288 bp) was amplified by PCR using the *Tnos* forward primer (5' tatcacagagctcgttcaaacatttggcaa 3') having *SacI* restriction site and Tnos reverse primer (5' atacaactagtgaattcccgatctagtaacatagat 3') having *SpeI* restriction site at their 5' ends. PRESQ101 (Fig. 1) plasmid was used as the template for the PCR reaction. The PCR amplicons were purified and ligated into the *SacI/SpeI* site of Ubi/NC1300-ubiamiRNA3. The ligation mixture was transformed into competent *E. coli* cells and the positive recombinants haboring the new Ubi/NC1300-amiRNA3Tnos vector identified by *HindIII/SpeI* digestion and sequencing.

Construction of pNOV2819-ubiamiRNA3 vector. A *HindIII/SpeI* fragment was removed

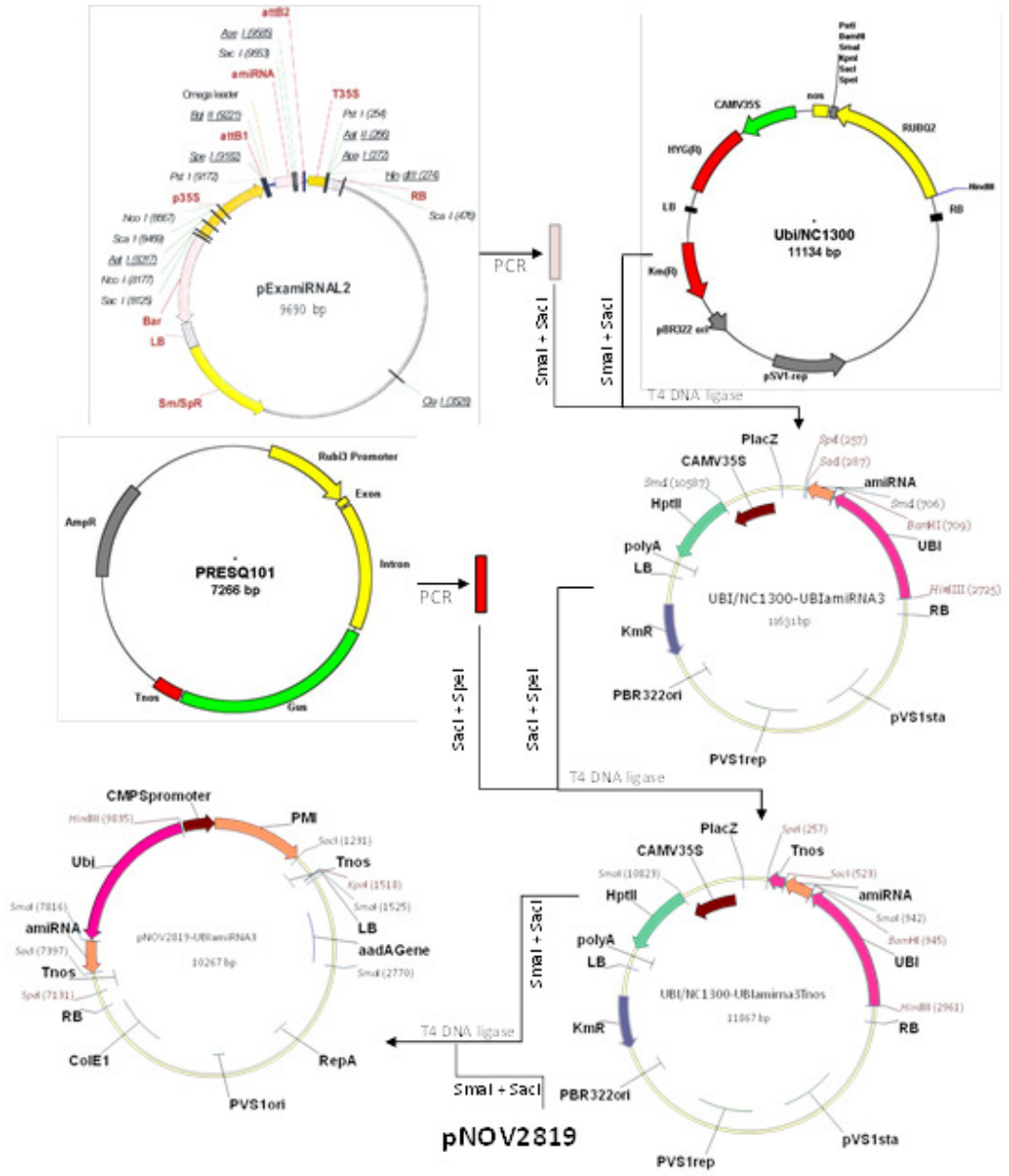

Figure 1. Scheme for construction of pNOV2819-ubamiRNA3 vector.

from Ubi/NC1300-ubiamiRNA3Tnos and ligated into the *HindIII/SpeI* site of pNOV2819 (SYGENTA Biotech Laboratories, North Carolina, USA). Ligation products were transformed into competent *E. coli* cells and positive transformants identified by digestion with *HindIII* and *SpeI* (Fig. 1).

Transformation of *A. tumefaciens* with pNOV2819-ubiamiRNA3 vector. The plant expression vector pNOV2819-ubiamiRNA3 was transformed into competent LBA4404 cells and the recombinant clones identified by PCR using primers specific to amiRNA3-PARP1 gene.

Preparation of PCR reactions and amplification conditions was done as described earlier.

Transformation of maize. LBA4404 harbouring the pNOV2819-ubiamiRNA3 vector was used to transform immature embryos of the inbred lines A188 and IL3. This was achieved using the cocultivation method of Negrotto *et al*. (2000). Transgenic callus tissues were selected on 0.5% mannose. The number of surviving callus was compared with the total number of infected cells to compute the transformation frequency (TF) for each genotype. Putative transgenic plants were regenerated from mannose-resistant tissues. To identify truly transformed plants, DNA was extracted from regenerants using the CTAB method (Saghai-Maroof *et al*., 1984) for PCR analysis. PCR was performed as described earlier using primers specific to the *PMI* gene (PMI-F 5'ctcgctgcatgaccttagtg 3' and PMI-R 5' ttgtaaacacgcgctaaacg 3').

RESULTS

Construction of Ubi/NC1300-ubiamiRNA3 vector. The full-length pre-amiRNA3PARP1 gene of 414 bp (Fig. 2A) was amplified successfully using amiRNA-PARP1-specific primers on pEXamiRNAL2 vector. The pre-amiRNA3-PARP1 gene was ligated onto Ubi/NC1300 vector and positive clones were identified by digestion with *XbaI* (Fig. 2B). *XbaI* released a 450 bp fragment from the recombinant plasmids. However, the band was absent in the control plasmid. The sequence of pre-amiRNA3PARP1 gene was validated by GeneBank database following sequencing of positive clones.

Construction of plant expression UBI/NC1300-ubiamiRNA3Tnos vector. Amplification products (726 bp) were observed only for the recombinant clones. However, PCR reactions for water and Ubi/NC1300-ubiamiRNA3 vector used as negative controls had no observable amplifications (Fig. 3A). Digestion of DNA with *HindIII* and *SpeI* resulted in release of a 2554 bp band from the recombinant clones (Fig. 3B, lane 2 and 3). However, this fragment was absent from the control vector (Ubi/NC1300-ubiamiRNA3), which lacks a cloned *Tnos* gene. Instead, the control vector released a band which was slightly smaller than the one released by the recombinant clones (Fig. 3B, lane 1). One positive clone, whose sequence of the cloned *Tnos* was validated by

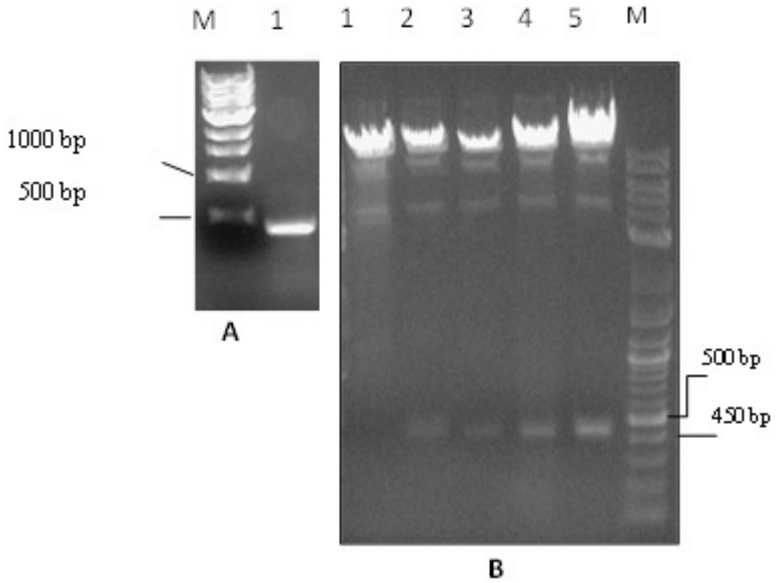

Figure 2. PCR amplification of pre-amiRNA-PARP1 and digestion of Ubi/NC1300-ubiamiRNA3. A: M: 1 Kb DNA ladder; A: 1 amplification of pre-amiRNA-PARP1; B: M: 1 Kb DNA ladder extra plus; B: 1: Digestion of control plasmid (Ubi/NC1300) with*XbaI*; B: 2 – 5: Digestion of Ubi/NC1300-ubiamiRNA3 with *XbaI*.

GeneBank database, was selected for use in development of the final vector, pNOV2819-ubiamiRNA3.

Construction of plant expression pNOV2819-ubiamiRNA3 vector. Results of PCR performed on DNA extracted from six colonies revealed the presence of the expected band (414 bp) in two colonies (Fig. 4A). Digestion of DNA from the PCR positive recombinant clones using *HindIII* and *SpeI* enzymes resulted in the release of the expected 2554 bp fragment from the recombinant plasmids (Fig. 4B, lane 2 and 3)and the control plasmid (Fig. 4B, lane 1).

Identification of recombinant *A. tumefaciens* LBA4404 cells that took up the pNOV2819-ubiamiRNA3 were identified by the presence of a 414 bp band in their PCR profile (Fig. 5).

Identification of transgenic maize plants. Transgenic tissues were recovered at different frequencies. The temperate line A188 had an

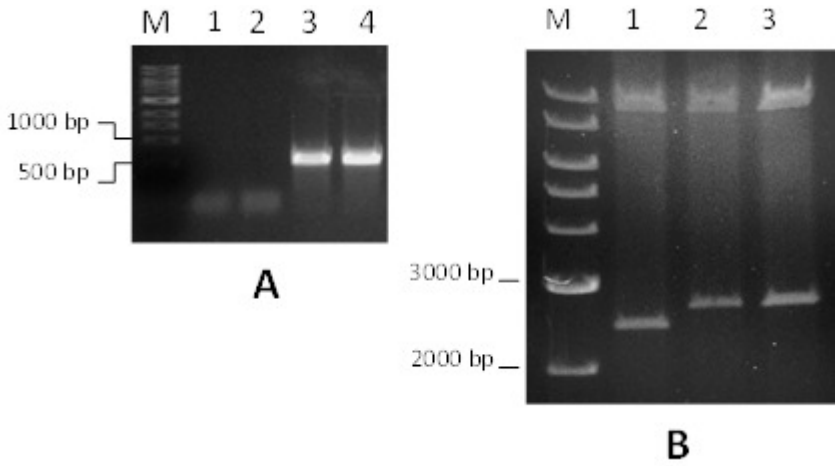

Figure 3. PCR amplification of Tnos and digestion of Ubi/NC1300-ubiamiRNA3Tnos. A: M:1 Kb DNA ladder; A: 1 amplification of pre-amiRNA-PARP1; B: M:1 Kb DNA ladder; B: 1: Digestion of control plasmid (Ubi/NC1300-ubiamiRNA3) with *HindIII* and *SpeI* restriction enzymes; B: 2 – 3: Digestion of Ubi/NC1300-ubiamiRNA3Tnos with *HindIII* and *SpeI* restriction enzymes.

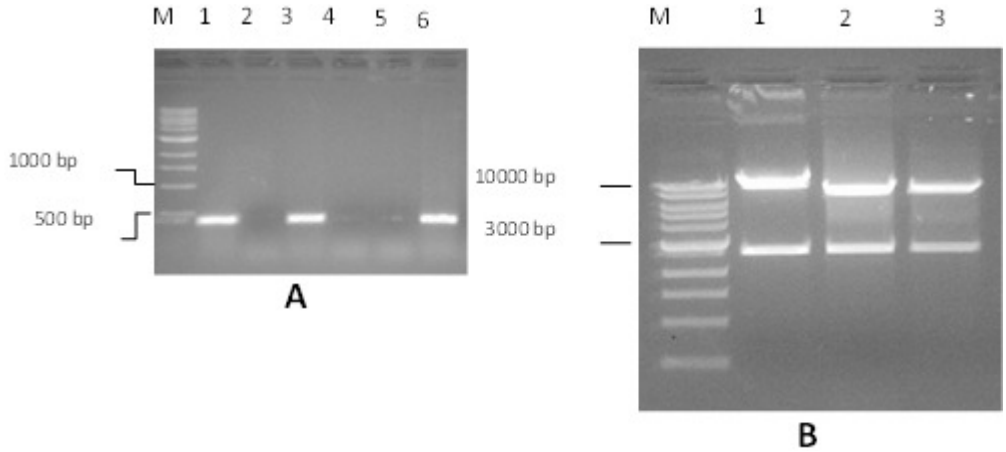

Figure 4. PCR amplification of pre-amiRNA-PARP1and digestion of pNOV2819-ubiamiRNA3. A: M: 1 Kb DNA ladder; A: 1 amplification of pre-amiRNA-PARP1 on 6 selected colonies; B: M: 1 Kb DNA ladder; B: 1: Digestion of control plasmid (Ubi/NC1300-ubiamiRNA3Tnos) with *HindIII* and *SpeI* restriction enzymes; B: 2 – 3: Digestion of pNOV2819-ubiamiRNA3with *HindIII* and *SpeI* restriction enzymes.

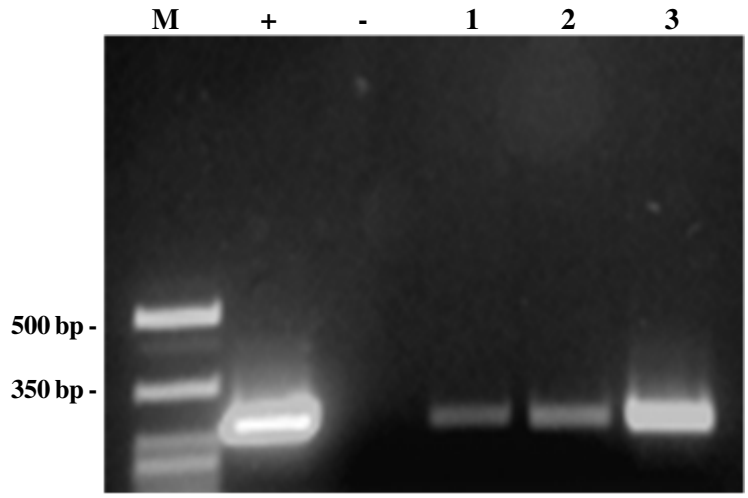

Figure 5. Amplification of the pre-amiRNA-PARP1 gene on plasmid DNA from different *A. tumefaciens* transformants. M: Low molecular weight DNA ladder; +: pNOV2819-ubiamiRNA3 used as positive control; -: Nontemplate control; 1-3: plasmid DNA from three selected *A. tumefaciens* transformants.

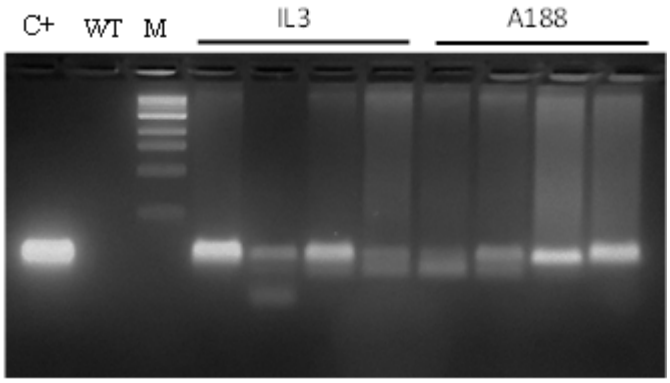

Figure 6. Identification of transgenic PMI plants C+: Positive control (pNOV2819-ubiamiRNA3 plasmid DNA); WT: Negative control (DNA from a non-transgenic plant) M: 1 KB DNA ladder. IL3: DNA from four putative transgenic IL3 plants; A188: DNA from four putative transgenic A188 plants.

average TF of about 3%, while the tropical genotype IL3 had a TF of 4.6%. The IL3 plant number 1 and 3 and the A188 plant number 3 and 4 were identified as transgenic due to the presence of an intense 200 bp amplicon in their PCR profile (Fig. 6).The four transgenic plants were selected for further analyses.

DISCUSSION

In this study, an amiRNA transgene targeting the maize *PARP1* gene was subcloned into pNOV2819 to produce the new binary vector pNOV2819-ubiamiRNA3PARP1. Using *A. tumefaciens* strain LBA4404, the new vector enabled integration of the *pmi* gene into the cells of maize genotypes A188 and IL3, subsequently enabling identification of transgenic tissues on mannose. The use of the *pmi* gene in plant transformation has enabled production of transgenic plants in different species including maize (Negrotto *et al.*, 2000), rice (Lucca *et al.*, 2001) and wheat (Wright *et al.*, 2001). The PMI protein has been found to pose no negative effects on humans or the environment.

Using *pmi*, Negrotto *et al.* (2000) recovered transgenic A188 maize tissues at frequencies of over 30%. Our comparatively lower

transformation frequency (3%) may be attributable to use of PNOV2819 as the vector backbone as opposed to the pNOV117 used in that study. In pNOV2819, the *pmi* gene is under the CMPS promoter which is weaker than the ubiquitine promoter driving the *pmi* gene on pNOV117 (Negrotto *et al.,* 2000). The stronger promoter may enable recovery of transgenic tissues at a higher frequency than the weaker one. In our study, transgenic tissues of IL3 were recovered at a rate of 4.6 %. IL3 has also been transformed using the negative selection gene *bar* (Rasha *et al*., 2013). However, presence of selectable marker genes in the final transgenic product continues to raise biosafety and environmental safety concerns (Jaiwal *et al.,* 2002).

Silencing of the *PARP1* gene is one of the recently developed genetic engineering strategies to enhance drought tolerance in plants. This approach has been shown to be very effective in model plants *A. thaliana* and *B. napus* (De Block *et al*., 2004; Schulz *et al*., 2012; Vanderauwera *et al*., 2007) and, therefore, hold great promise for agronomically important plants such as maize. In this study, we generated plants that had integrated amiRNA3 against maize PARP1 gene in their genome. Analysis of these plants for stable integration and expression of the *PMI* and amiRNA3-PARP1 transgenes is ongoing at the plant transformation laboratory (PTL) at Kenyatta University.

CONCLUSION

This study has generated plant transformation vector bearing an amiRNA targeting the maize PARP1 gene. These vectors are can be used to transform any maize genotype. For the first time, we have demonstrated using the *pmi* gene as the selectable marker gene, that the tropical maize inbred line IL3 is transformable with the amiRNA-PARP1 transgene. This study now paves way for introduction of different amiRNA-PARP1 transgenes into the pNOV2819 backbone for transformation of different tropical maize genotypes.

ACKNOWLEDGEMENT

Professor Mieke Van Lijsebettens (Ghent University, Belgium) provided the pEXamiRNAL2 vector that harbours the amiRNA3-PARP1 gene. Dr. Allan Jalemba (Kenyatta University, Kenya) provided the PRESQ101. This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 799 - 806 ISSN 1021-9730/2014 $4.00

NUTRITIONAL STATUS OF CHILDREN UNDER FIVE YEARS AND ASSOCIATED FACTORS IN MBEERE SOUTH DISTRICT, KENYA

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ABSTRACT

Information on nutritional status of children under five years is an indicator of the nutritional situation in society. Identification of core factors influencing nutrition of this population supports plans to alleviate child malnutrition and its consequences. This study sought to determine the nutritional status of children under five years and associated factors in Mbeere South District in Kenya. A cross-sectional descriptive study was conducted using a structured questionnaire. A total of 144 households was randomly sampled and the nutritional status of one child from each household assessed using anthropometric measurements. Up to 39% of the children were stunted; 7.1% were wasted; and 18.1% underweight. The prevalence of stunting and wasting was significantly higher in boys than in girls (χ =6.765, P =.034) and (χ= 13.053, P = .036), respectively. The individual dietary diversity score showed that the most consumed food group was cereals. Eggs and meat were the least consumed foods. Low diversity scores were recorded for 41.9% of the children (<4 food groups), 35.7% had medium scores (4-5 food groups); while 22.5% had high scores (6- 8 food groups). There was significant association between household size and nutritional status (P =0.047). The findings indicate that malnutrition and dietary diversity are major challenges to good nutrition. Future interventions should focus on improving food access and availability for enhanced diet diversification for the rising population.

Key Words: Boys, dietary diversity, girls, malnutrition

RÉSUMÉ

L'information sur le status nutritionnel des enfants de moins de cinq ans est un indicateur de la situation nutritionnelle dans une société. L'identification des facteurs clés influençant la nutrition de cette population soutient les plans d'éradication de la malnutrition infantile et ses conséquences. Cette étude était menée pour déterminer le statut nutritionnel des enfants de moins de cinq ans et les facteurs associés dans le district de Mbeere Sud au Kenya. Une étude transversale était conduite avec un questionnaire structuré. Un total de 144 ménages étaient aléatoirement échantillonnés et le statut nutritionnel d'un enfant dans chaque ménage évalué par l'utilisation des mesures anthropométriques.Trente neuf pourcent des enfants étaient victimes du nanisme; 7.1% étaient maigres , et 18.1% avaient un poids inférieur à la normale . La prévalence du nanisme et de la maigreur était significativement élevée chez les garçons que chez les filles (c =6.765, P =.034) et (c = 13.053, P = .036), respectivement. Le score de la diversité diététique individuelle a montré que la plupart consommait la nourriture du groupe des céréales. Des scores bas de diversité étaient enregistrés chez 41.9% d'enfants (<4 groupes d'aliments), 35.7% avaient des scores moyens (< 4-5 groupes d'aliments); pendant que 22.5% avaient des scores élevés (< 6- 8 groupes d'aliments). Il y avait une association significative entre la taille des ménages et le statut nutritionnel (P =0.047). Ces résultats indiquent que la malnutrition et la diversité diététique constituent des contraintes

majeurs à une bonne nutrition. Des interventions futures devraient être centrée sur l'amélioration de l'accès et la disponibilité de la nourriture pour une meilleure diversification diététique face à la population croissante.

Mots Clés: Garçons, diversité diététique, filles, malnutrition

INTRODUCTION

Nutritional status of children is an indicator of the level of development and future potential of the community. The nutritional status of infants and children under five years of age is of particular concern since the early years of life are crucial for optimal growth and development (Preschulek *et al*., 1999). Nutritional deficiencies affect long term physical growth and development and may lead to high level of illness and disability in adult life. Moreover, high prevalence of malnutrition jeopardizes future economic growth by reducing the intellectual and physical potential of entire population (Kabubo-Mariara *et al*., 2006).

Undernutrition among children remains common in many parts of the world. According WHO (2011), about 178 million children under five years worldwide are too short for their age group; while 115 million are underweight. The same report showed that stunting rate among children is higher in Africa and Asia than elsewhere. In Kenya, 35% of children under five are stunted, while the proportion severely stunted was 14%; 16% are underweight (low weight-for-age) and 4% are severely underweight (KNBS, 2010).

The primary determinants of malnutrition as conceptualised by several researchers relate to unsatisfactory food intake and/or severe and repeated infections (Rowland *et al*., 1988; Schroeder *et al*., 1994; UNICEF, 1998) . The interactions of these conditions with the nutritional status and overall health of the child; and by extension of the populations in which the child is raised have been shown in the UNICEF Conceptual framework of child survival (UNICEF, 1998). The model characterises the correlates of malnutrition as factors that impair access to food, maternal and childcare, and healthcare. It is these very factors that impact the growth of children. Consequently, the assessment of children's growth is a suitable indicator for investigating the wellbeing of children, as well as for examining the households' access to food, health and care (UNICEF, 1998; de Onis *et al*., 2013).

The objective of this study was, therefore, to evaluate the three common indicators of malnutrition namely stunting, wasting and underweight, among children below the age of five in Mbeere South District (MSD) in Kenya as a basis for formulating appropriate policies and evidence based interventions for reducing the incidence of child malnutrition.

MATERIALS AND METHODS

Study site. The study was conducted in Mbeere South District in the Eastern province of Kenya. The District lies between latitudes 0° 202 and 0° 502 south and longitudes 37° 162 and 37° 562 ; and covers a total area of 1,321.5 Km^2 with a population of 130,185 persons (KNBS, 2010).

Study design and sampling. A cross sectional survey, both descriptive and analytical in nature was carried out using a pretested structured questionnaire. The questionnaire was designed to assess the nutrition status of children and its association with demographic, socio-economic characteristics of the household and dietary diversity of the child. The sampling unit for this study was the household with children aged 0-59 months of age and the respondents were the mothers or the principal caretaker of the index child.

Verbal consent from all caregivers/mothers of the sampled children was sought before administration of the questionnaire. All the information collected during the survey were treated as confidential and used for the purpose of the survey only.

A total of 144 households with children 0-59 months were selected for the study, by the random walk method. Once the interviewers got to the centre of the village, he/she spinned the pencil and followed the direction, enumerating the households on the right side. A child aged 0-59 months was purposively selected for the study

from each of the selected household. There was no target of a particular gender during sampling. Households with more than one child aged 0-59 months, only one child was selected for the assessment randomly by tossing a coin. It was assumed that children in the same household are subjected to the same conditions, hence any selected child could represent the household.

Data collection. The questionnaires comprised mainly of details on household profiles like age, sex, education level and occupation of household members, household size and marital status of the household heads. Data on sources of income and dietary diversity were also collected.

Anthropometric measurements taken for children aged (6-59) months included:

Date of birth. The date of birth for each child was inquired from the caretaker/mother and cross checked from immunisation cards and recorded in months.

Length/height. The length of each child aged 6-24 months was measured lying flat and centrally on measuring boards placed on a hard flat surface on the ground. The length was read to the nearest 0.1 cm (head and feet against the base of the board and foot piece respectively).

The height of children aged above 24 months was measured standing straight on measuring board placed on hard flat surface against a wall with line of sight perpendicular to the horizontal surface. The child's height was measured to the nearest one decimal place.

Weight. The child was put in the weighing pants and was gently lowered on the standardised Salter scale with the strap of the pant in front. The scale was hanged from a secure position; the child's weight read to the nearest one decimal place after the scale needle stabilises.

Data analysis. The Emergency Nutrition Assessment for Standardised Monitoring and Assessment of Relief and Transition (ENA for SMART) was used to compute Z-score (weight-for-age, height-for-age and weight-for-height) according to WHO reference standard (WHO, 2006), taking -2SD as cut-off points (underweight, stunting and wasting). The Statistical Package for Social Scientists (SPSS) version 20 was used to analyse demographic and socio-economic data. Data cleaning was done by running and tabulating all variable frequencies.

Frequencies and cross-tabulation were used to give frequencies, means, standard deviation in descriptive analysis on socio-demographic characteristics of households and nutritional status of study children.

The measure of dietary diversity score of the children was based on simple counts of the number of food groups consumed by the child in the past 24 hour. Eight food groups recommended by FAO (FAO, 2008) for assessing individual dietary diversity was used.

Bi-variate analysis was performed on various selected variables with nutritional indices of the children to determine possible associations.

ENA for SMART was used to convert raw anthropometric data (weight, height and age of the children) into anthropometric Z-score that was used to classify children into levels of nutritional status (stunting, wasting and underweight) Table 1.

RESULTS

Characteristic of study population. The household size ranged from two to eleven people. Age distribution of the household members was highly varied, with children aged between 6-17 years comparatively higher (27.8%). The children under five years comprised of 26.9% of the total population. The ratio of male to female in the study population was approximately 1:1.1. The dependency ratio of the population was 1.02.

The majority of the study population attended or was in primary school (71%). About 23.5% attended secondary school while only 2.0%

TABLE 1. Cut off points for malnutrition used in an under-five children study in Kenya

Indicators	Moderate (GAM)	Severe (SAM)
Wasting	WHZ; <-2 to >-3Z scores	WHZ; below -3Z
Underweight	WAZ; <-2 to >-3Z scores	WAZ; below -3Z
Stunting	HAZ; <-2 to >-3Z scores	HAZ; below -3Z

Source: World Health Organization, 2006

attained levels above this. The main occupation was farming (43.1%). Only a very small proportion (3.7%) of the study population had salaried employment.

One out of every 10 households was female headed. Majority (89.5%) of the household heads were married. Majority (57.7%) of the household heads were farmers. Only a very small proportion (10.6%) of household heads had salaried employment. About 15.5 % were self employed or engaged in small business and 14.1% were casual laborers. The others were either students (0.7%) or had no employment (1.4%). Although the study shows that all the household heads had some formal education, the highest education level attained by majority of the household heads was 5-8 years of primary education (63.2). Only 4.3% attended college.

The main source of income among the study population was sale of crops (42.7%), followed by sale of livestock (27.1%). The mean monthly household income in the study population was US$ 61.3. Majority (52.2%) of the households earned less than US$ 0.7 a day.

Malnutrition among the children. A proportion of 42% of the study children were boys and the rest girls. The mean age of the sampled children was 28.4 months, with the youngest being 0 months old and the oldest 59 months old. Overall, 61% of the children had normal height for their age. The prevalence of stunting among the children was 39%. About 28% of these were moderately malnourished; while the rest (11%) were severely stunted. Up to 92.9% of the children had normal weight for their height. Prevalence of wasting was 7.1%; about 5.5% moderately, while 1.6% was severely wasted. The prevalence of stunting and wasting was significantly higher in boys than in girls (χ =6.765, P =.034; χ = 13.053, P = .036, respectively).

There was no evidence of underweight observed among the children below the age of 6 months. However, for children aged 6-59 months, the prevalence of underweight was 18.1%, of whom 12.6% were moderately underweight while 5.5% were severely underweight. There were more underweight boys than girls, but a Chi-square test on the difference in the prevalence of underweight between the difference gender found no significant difference (P>.05)

There were significant differences in prevalence of malnutrition between age groups (Table 2). Stunting was lowest in the first year of life and highest in second and third years of life; while underweight and wasting was highest in the second year. Prevalence of underweight increased with age from the fourth year of life. No incidence of wasting was observed in the first year of life. Although the differences in prevalence

TABLE 2. Percent prevalence of global and severe malnutrition by age in Mbeere south district in Kenya

Age (months)	WAZ (Under weight)		HAZ (Stunting)		WHZ (Wasting)	
	<-3 z-scoren =12	<-2 z-scoren =23	<-3 z-scoren =14	<-2 z-scoren =49	<-3 z-scoren =2	<-2 z-scoren =9
6-11(13)	0	7.69	7.69	15.4	0	0
12-23(32)	6.25	25	25	43.8	0	18.8
24-35(31)	9.7	9.7	9.7	45.2	3.2	6.5
36-47(27)	0	11.1	0	37.0	0	0
48-59(24)	4.2	25	8.3	37.5	4.1	4.1
Total (127)	9.4	18.1	11.0	38.9	1.5	7.1
1P-value	.048*		.032*		.047*	
2P-value	.577		.030*		.858	

1P = value is pearson chi square significant level between age groups; 2P = value is pearson chi square significant level between girls and boys; * Indicate that the difference between malnutrition levels between age group and different sexes are significant at 0.05 levels of significance

of malnutrition were higher in boys than girls in all the indicators of malnutrition (wasting, stunting and underweight), the difference was significant only in height-for-age z-score (HAZ) (P< .05).

Dietary diversity score. The mean dietary diversity was 4.2 food groups, with a minimum of 2 and a maximum of 8 food groups. Cereals was the most popular food group consumed by children, followed by legumes, nuts and seeds at 97 and 76.8%, respectively. The eggs and meat food group was the least consumed, at 36 and 19.2%, respectively (Fig. 1).

In terms of dietary diversity score, majority of the children (41.9%) had low diversity (<4 food groups), and about 35.7% had medium diversity (4-5 food groups). Only 22.5% accessed high dietary diversity score (6- 8 food groups).

Association of selected variable with child nutrition status. The relationship between nutritional indicators based on wasting, stunting and underweight, and other socio-economic characteristics are shown in Table 3. Significant positive and linear relationships were found between underweight, stunting and wasting among the children of 0-59 months. Negative and significant correlations were observed between children's age and nutritional status based on wasting and underweight. Negative significant relationships was observed between the household size and nutritional status based on stunting and wasting. There were no

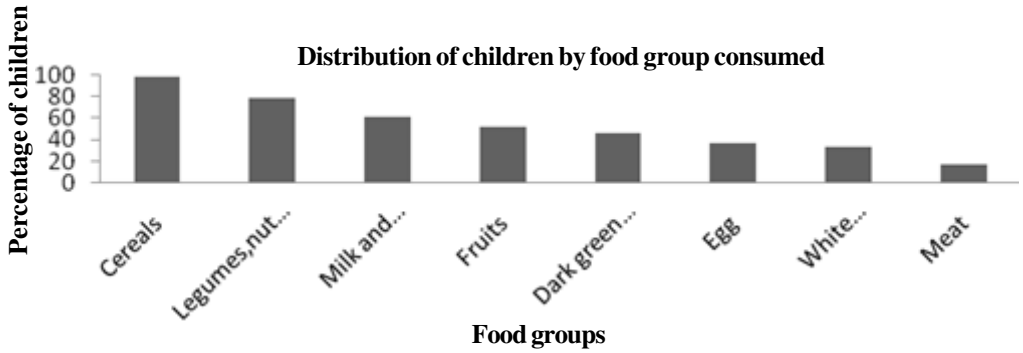

Figure 1. Distribution of children under five years by food group consumed in Kenya.

TABLE 3. Correlation coefficients of selected socio-economic factors and nutrition status among under five years children in Kenya

Variable	WAZ	HAZ	WHZ
	r	r	r
WAZ	1.000	.504*	.828*
HAZ	.504**	1.000	-.047
WHZ	.828**	-.047	1.000
Household size	.611	-.410**	-.402*
Education of household head	-.045	.036	-.052
Gender of household head	-.91	.013	-.013
Age of the child	-.296**	.544	-.243**
Household income	-.592	-.270	.576
Child dietary diversity	-.346	.312	.224

** Correlation significant at 0.01 level (2 tailed). *Correlation significant at 0.05 level (2 tailed); WAZ = weight-for-age z-score, HAZ = height-for-age z-score, WHZ = weight-for-height z-score

significant associations among the three indicators of nutritional, gender and education level of the household head. Similarly, there were no direct significant associations between household income and nutritional indicators. However, there was a significant association ($P<0.05$) between number of food groups consumed and household income.

DISCUSSION

Findings of this study shows that prevalences of underweight (18.1%) and stunting (39%) in Mbeere south district are higher than those reported by the Kenya Demographic Health Survey (KDHS) for national average 16 and 35%, respectively. This means that the situation in this area is worse off than the average area in Kenya.

According WHO classification for assessing severity of malnutrition in a population, prevalence of stunting (39%) was high. Besides, this translates to 39% stunted children who are unlikely to grow to their full potential both physically and mentally. The process of becoming stunted, due to restricted nutrient supply and/or frequent infection, is a common cause of both short stature and structural and functional damage to the brain, resulting in delay in the development of cognitive functions as well as permanent cognitive impairments (Kar *et al*., 2008; Kathryn *et al*., 2011).

The observation that the prevalence of stunting in the first year of life is low is similar to that from the finding of survey conducted earlier in Mbeere District (KNBS, 2009b) and Makueni (Macharia *et al*., 2005); whereby the prevalence of stunting was highest among children 12-35 months. This could be attributed to poor weaning and complementary feeding practices resulting into inadequate energy and protein intake. The poor feeding practices may be due to either lack of knowledge by the mother or lack of adequate food.

The negative and significant relationship observed between children's age and nutritional status based on stunting and underweight could be explained by the fact that as the child grows older he/she becomes more dependent and accesses different food than the younger infant who depends on what is provided by the caregiver/mother (Meme, 1996). However, in this study the prevalence of wasting and underweight seem to increase after the 48 months of age. This is probably due to increased physiological activities of the child at this age, which may necessitate more nutrient intake to support growth and development. Children at this age are outside homes either in school or playing, failing to feed regularly to replenish their energy.

The finding that prevalence of stunting and wasting was higher in male than female children concurs with that of national prevalence indicated in Kenya Demographic Health survey (KNBS, 2010). Other studies are required to explain the relationship between sex and nutritional status, which is an important phenomenon as far as understanding malnutrition is concerned.

The negative significant relationships among household size and stunting, and wasting could be explained by the fact that the family meal is distributed among large numbers of household members resulting to inadequate diet for an extended period eventually causing chronic malnutrition (Macharia *et al.*, 2005).

Contrary to other studies (Onyango *et al*.,1998; Ruel, 2002), this study did not find significant association between nutritional status and dietary diversity. Thus, malnutrition in this area might be caused by other factors other than just having a diversified diet. Additional studies are required to explain the cooking method and caloric adequacy of the complementary foods consumed by children in the study area. The high consumption of food items from mainly cereals observed in this study only confirms that the diets of the children were predominantly based on starchy staples. Besides lacking adequate nutrients, it is also possible that the quantity of carbohydrates obtained from these cereals group was still not adequate to meet the macronutrient needs of the children. From personal observations, the diets of children below two years mainly comprised of starchy staple (mashed banana and potatoes). While the intake of energy is important in diet, other nutrient such as vitamins, proteins and minerals are also necessary for healthy living. Moving from a monotonous diet to one containing a more diverse range of foods has been shown to increase intake of

energy as well as micronutrients in developing countries (Gina *et al*., 2007).

Although legumes, nuts and seeds were the second most popular food groups after cereals, the benefit from consumption of these food groups was not evident in determining nutritional status in this study probably because other factors like quality of the diet, quantity of food consumed and utilisation by the body are also determinant factors.

The lack of relationships between the nutritional status and gender of the household head as well as their education level could be attributed to the fact that the overwhelming majority of the household heads were male and also similar education level to impact difference in nutritional status.

CONCLUSION

The malnutrition rate among the children under five years in Mbeere South District of Kenya is high, clearly confirming that malnutrition is still a wide spread health problem. Diversity and quality of the meals of particularly children below 3 years is poor. Less than 25% of the children consume highly diversified; while over 40% consume poorly diversified diets. Future interventions should focus on improving food access and availability for enhanced diet diversification for the rising population.

ACKNOWLEDGEMENT

The authors thank the Director, Kenya Agricultural Researh Institute (KARI) for supporting the implementation of this work. This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 807 - 818 ISSN 1021-9730/2014 $4.00

ANALYSIS AND MAPPING OF CLIMATE CHANGE RISK AND VULNERABILITY IN CENTRAL RIFT VALLEY OF ETHIOPIA

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ABSTRACT

There is growing demand for spatially explicit information among stakeholders across public and private institutions regarding vulnerability to climate change at the local scale. This study was conducted over 16 districts in Central Rift Valley (CRV) of Ethiopia, to determine the degree of climate risk and the relative vulnerability of the districts, to climate change and, thereby identify vulnerable hotspots. A biophysical and socio-economic indicator based integrated vulnerability assessment technique was used to map climate change vulnerability. Indicators were generated and analysed under three components of vulnerability, namely exposure, sensitivity and adaptive capacity; and finally aggregated into a single vulnerability index. The values of all indicators were normalised by considering their functional relationship with vulnerability, and expert judgment was then used to assign weights to all indicators. Aggregate vulnerability index (VI) was finally determined from the weighted sum of all indicators and mapped over the 16 districts. Selti, Dodotana-Sire and Tiyo districts had relatively high vulnerability to climate change; while Arsinegele, Adamitulu-Jido-Kombolcha and Dugda-Bora were the least vulnerable. The rest of the districts had medium vulnerability to changing climate. This study shows that vulnerability mapping is crucial in determining the varying degrees of vulnerability of different localities, and generating information that can help researchers, policy makers, private and public institutions in formulating site-specific adaptation strategies and prioritising adaptation investments to the most vulnerable hotspots.

Key Words: Socio-economic indicators, vulnerability index

RÉSUMÉ

Il ya une demande sans cesse croissante parmi les partenaires à travers les institutions publiques et privées, de l'information spatiale explicite concernant la vulnérabilité au changement climatique à l'échelle locale. Cette étude était conduite sur 16 districts de la Vallée du Rift Central (VRC) en Ethiopie, pour déterminer le degré de risque climatique et la vulnérabilité relative de ces districts au changement climatique et delà, identifier les sites les plus vulnérables. Une technique d'évaluation du degré de vulnerabilité basé sur un indicateur intégrant les aspects biophysiques et socio-économiques était utilisée pour établir la carte de vulnérabilité au changements climatique. Les indicateurs étaient générés et analysés sous trois composantes de vulnérabilité : exposition, sensitivité et capacité adaptive; et finalement agrégés en un seul indice de vulnérabilité. Les valeurs de tous les indicateurs étaient normalisées en considérant leur relation fonctionnelle avec la vulnérabilité, et ensuite, un jugement expert était utilisé pour leur assigner un poids. L'indice de vulnérabilité cumulative (VI) était finalement déterminé de la somme du poids de tous les indicateurs et cartographié sur l'étendue de seize districts. Les districts de Selti, Dodotana-Sire et Tiyo avaient relativement une vulnérabilité élevée au changements climatique, pendant que Arsinegele, Adamitulu-Jido-Kombolcha et Dugda-Bora étaient les districts les moins vulnérables. Le reste des districts présentaient une vulnérabilité moyenne au changement climatique. Cette étude montre que la cartographie de la vulnérabilité est cruciale dans la détermination des divers niveaux de vulnérabilité des différentes localités et la génération de l'information pouvant aider les chercheurs, les décideurs politiques, les institutions privées et

publiques dans la formulation des stratégies spécifiques d'adaptation et à la formulation des priorités d'investissement pour renforcer l'adaptation des sites les plus vulnérables.

Mots Clés: Indicateur socio-économique, indice de vulnérabilité

INTRODUCTION

Climate change is one of the current issues that severely impact all climate sensitive sectors like agriculture. The manifestation of climate change such as rising temperatures, increasingly erratic rainfall, and more frequent and severe floods and droughts have grave consequences on the livelihood security of smallholder farming communities, making them more vulnerable. Agriculture plays a great role in the livelihood of rural communities in many African countries. Most such countries are, however, predicted to be among the globe's most vulnerable to climatic changes (Schlenker and Lobell, 2010; Samson *et al*., 2011; Morand *et al*., 2012). Muller *et al*. (2011) noted that the negative consequences of climate change are anticipated overall for Africa where over 95 % of the farmers subsist on rain-fed agriculture. In Ethiopia, agriculture is the dominant sector contributing around 50% of the Gross Domestic Product (GDP) and 85% of total employment and livelihoods. It is also the major source of food for the population and, hence, the prime contributor to food security (CEEPA, 2006).

Climate Resilient Green Economy (CRGE, 2011) noted that climate change has the potential to hold back economic progress, or reverse the gains made in Ethiopia's development and could exacerbate social and economic problems. It is heavily dependent on rainfall, with irrigation accounting for less than 1% of the country's total cultivated land. Crop production is dominated by small scale subsistence farmers (about 8 million households) who practice more traditional farming, accounting for 95% of the total area under crop and more than 90% of the total agricultural output (CSA, 2011). Vulnerable agricultural systems are most prevalent in arid, semi-arid, and dry sub-humid regions of the developing world, home to half of the world's currently malnourished populations (Jon, 2009). The most vulnerable households are those with assets and livelihoods exposed and sensitive to climatic risks, and who have weak risk management capacity (Heltberg *et al*., 2009).

Assessment and mapping of the vulnerability to climate change is the base for the development of site specific adaptation options that reduce the risks associated with climate change. Several researchers have noted that vulnerability mapping including exposure, sensitivity, and adaptive capacity, has become a central tool for communicating with policy makers and local stakeholders as well as visualising climate change impacts on the landscape to more effectively support risk management and spatial planning (Eakin and Luers, 2006; Preston *et al*., 2011; López-Carr *et al*., 2014). Vulnerability assessment describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. The level of vulnerability of different areas to climate change is determined by both socioeconomic and environmental factors. The socioeconomic factors include the level of technological development, infrastructure and institutional linkage (Kelly and Adger 2000; McCarthy *et al*., 2001); while the environmental attributes are climatic conditions, quality of soil, and availability of water for irrigation (O'Brien *et al*., 2004). The variations of these socioeconomic and environmental factors across different social groups are responsible for the differences in their levels of vulnerability and coping capacities to climate change.

Ethiopia is highly heterogeneous in elevation, climate, agricultural production, cultural practices and other socio-economic factors. The degrees therefore of vulnerabilities of different localities and farming systems vary accordingly. Capturing this variation in assessing vulnerability of the sector is essential for laying the bases for developing and prioritising different adaptation responses for different vulnerable groups.

The aim of this study was to determine the degree of climate risk and the relative vulnerability of the farming areas of Central Rift Valley of

Ethiopia to climate change by developing district level vulnerability maps that identify the most vulnerable hotspots.

MATERIALS AND METHODS

Description of the study sites. A study was conducted in sixteen selected districts in Central Rift Valley (CRV) of Ethiopia located between longitudes 38° 12'- 39° 60' E and latitudes 6° 58'- 8° 47' N. The districts are Dugda Bora, Adamitulu-Jido-Kombolcha, Arsinegele, Dodotana-Sire, Ziway Dugda, Hitosa, Degeluna Tijo, Tiyo, Munessa, Bekoji, Gedeb, Kofele, Sodo, Meskanena Mareko, Selti and Lanfero. The altitude of the study area ranges from 1396 to 4216 m above sea level. The area is predominantly characterised by semi-arid and sub-humid climate.

Data used

Selection of vulnerability indicators. This study was undertaken based on the definition of vulnerability of the Intergovernmental Panel on Climate Change (IPCC), where a region's vulnerability to climate change and variability is described by three components, namely exposure, sensitivity and adaptive capacity (IPCC, 2001). The indicator selection was also made based on the three components of vulnerability. In this study, vulnerability indicator approach is integrated, therefore, the selected indicators represent both the biophysical conditions of the farming regions and the socio-economic conditions of the farmers. The selection of indicators was done after extensive review of previous reports; in particular, we drew from TERI (2003), O'Brien *et al*. (2004), Temesgen *et al*. (2008) and Gbetibouo and Ringler (2009). After identifying the vulnerability indicators, 17 biophysical and socioeconomic vulnerability indicators that reflect the three vulnerability components (Exposure, Sensitivity and Adaptive capacity) were selected and used in this study (Table 1).

Data sources. Data on the selected indicators and parameters used to derive them were taken from various sources. Both primary and secondary data were used in this study. Indicators under the sensitivity and adaptive capacity component (Table 1) were extracted from a CD-ROM prepared by International Food Policy Research Institute (IFPRI); while statistically downscaled and gridded climate change projection data (rainfall and temperature) having 0.5 by 0.5 resolution used to derive indicators related to future change in climate were extracted from the Downscaled General Circulation Model (GCM) Data Portal of Climate Change Agriculture and Food Security (CCAFS) Research Programme (http://www.ccafs-climate.org/spatial_downscaling/).

Gridded data on Standardised Precipitation Index (SPI) (Mckee et al., 1993), which is the most widely used index for quantifying drought, was extracted from IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/) and used to derive drought frequency indicator. An administrative map showing the boundary of the study districts was obtained from the Central Statistical Agency (CSA) of Ethiopia.

Data analysis. Selected indicators were computed from primary data as follows:

(a) Drought frequency indicator. Climate risk was quantified in terms of drought events. Mckee *et al*. (1993) noted that SPI is the most widely used index for quantifying the frequency of drought events. Indicators in exposure components of vulnerability were quantified using gridded SPI data obtained from IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/). Thirty three (1970-2002) years' gridded seasonal SPI data having 0.5 by 0.5 degree resolution were extracted in the form of XY table from TS2 dataset, and based on SPI value less than -1.5 (Mckee *et al*.,1993), drought frequency analysis was done for each grid and the value was interpolated using Kriging interpolation techniques (Spherical semivariogram/Covariance model) in ArcGIS 9.3 version environment, and classified to represent the spatial trends of drought frequency. The drought frequency value of each district was also extracted using majority rule method for vulnerability analysis.

TABLE 1. List of identified indicators and their relationship with vulnerability by vulnerability components in Ethiopia

Vulnerability components	Component indicators (weight)	Indicators (weight)	Description of indicators	Relationship with vulnerability
Exposure	Exposure indicators (1)	Frequency of drought (0.4)	Number of drought events from 1970-2000	Increasing
		Change in rainfall (0.4)	% change (base period compared to 2050s)	Increasing
		Change in mean temperature (0.2)	change in ^{0}C (base period compared to 2050s)	Increasing
Sensitivity	Human sensitivity (0.3)	Rural population density (0.2)	Rural population/km^2	Increasing
		Dependency ratio (0.1)	Percentage of unemployment	Increasing
	Livelihood sensitivity (0.7)	Proportion of Household fully engaged in Agriculture (0.3)	Agricultural household heads	Increasing
		Crop diversification index (0.2)	Percentage of area under a major crops	Increasing
		Access to water sources (0.1)	Percentage of population to proximity to water source	Decreasing
		Topography (0.1)	Percentage of sloppy area	Increasing
Adaptive capacity	Socio-economic assets (0.7)	Literacy rate (0.2)	Proportion of agricultural population aged 15 years and older who can read and write	Decreasing
		Farm organization (0.1)	Percentage of farmers utilizing advisory services	Decreasing
		Access to credit (0.1)	Percentage of farmers utilizing credit service	Decreasing
		Crop productivity (0.15)	Amount of Yield per hectares for major crops	Decreasing
		Farm asset (0.15)	Total value of farm asset	Decreasing
	Infrastructural assets (0.3)	Access to market (0.2)	All weather road density	Decreasing
		Land area under smallholder farmers (0.1)	Percentage of total land area	Increasing

(b) Change in rainfall and temperature. Projected change in rainfall (% change) and temperature (absolute change) were analysed using historical empirical data (1980-2012) from worldclim (http://www.worldclim.org/) as base period and ensemble of four downscaled GCMs (CGCM3, HADGEM, MK3 and ECHAM5) data of 2050s (2040-2069) under A1B emission scenario from CCAFS (www.ccafs-climate.org/spatial_ downscaling/), using the Delta method as future projection. A Delta value of each grid was generated that quantify the possible changes of rainfall and temperature.

Vulnerability index. Vulnerability to climate change was analysed using an integrated vulnerability assessment approach using diverse set of biophysical and the socioeconomic indicators listed in Table 1 that reflect the three vulnerability components; exposure, sensitivity and adaptive capacity.

The identified indicators have different units and scales, and to use them for assessment they were normalised using the methodology used in United Nations Development Programme (UNDP)'s Human Development Index (HDI) (UNDP, 2006). The first step was to determine the functional relationship of all the indicators with vulnerability, i.e. vulnerability increases with increase (decrease) in the value of the indicators (Table 1). Then, standardised indicator values, which are free from the units and that lie between 0 and 1 were determined using the Equations 1 and 2. Equation 1 was used when the increase in the indicator was hypothesized to increase vulnerability; and Equation 2 when the increase in the indicator was hypothesized to decrease vulnerability (Table 1).

$$Ini, j = (Iaci,j - Ijmin)/(Ijmax - Ijmin) \quad \text{Equation 1}$$

$$In = (Ijmax - Iaci,j)/(Ijmax - Ijmin) \quad \text{Equation 2}$$

Where:

i and j are indicators and districts respectively, Ini,j= normalised i^{th} indicator for the j^{th} district, Iac=actual value of the i^{th} indicator of the j^{th} district before normalisation; Ijmin and Ijmax=minimum and maximum value of the i^{th} indicator when compared among all the districts, respectively.

After normalising, expert judgment (Moss *et al*., 2001; Brooks *et al*., 2005) was used to assign weights to all the normalised indicators. Then, sub-indices of vulnerability were calculated for each district using weighted sum of indicator values under each of the exposure, sensitivity and adaptive capacity components of vulnerability. The aggregate vulnerability index was also determined by summing weighted indicator values to produce a single number, which can be used to compare the 16 districts. The sub- and aggregate index values of vulnerability were then categorised into high, low and medium classes, whereby the medium level of vulnerability was defined as an index within one standard deviation unit of the whole districts index, meanwhile high and low level were greater than and less than 1 standard deviation unit above or below the whole districts index mean, respectively. Finally, a GIS tool was used to map both the sub- and aggregate indices of vulnerability.

RESULTS

Frequency of drought. Climate risk quantified in terms of drought frequency revealed that all the districts experienced drought ranging from 2 to 5 times within 33 years (Fig. 1). Among the worst hit districts, which experienced the highest frequency of drought (5 times in 33 years), were Adamitulu-Jido-Kombolcha, Dugda Bora, Ziway Dugda, Dodotana-Sire and Tiyo districts. Gizachew (2012) also confirmed that Adamitulu-Jido-kombolcha and Ziway dugda districts had the highest probability of severe drought occurrence with 46 to 76% severe severity level in East Shoa zone of Ethiopia. Bekoji, Gedeb, Kofele and Lanfaro districts experienced the lowest drought frequencies of 2 to 3 times in 33 years. The remaining districts experienced drought 4 times in 33 years. This result was used as a proxy indicator for exposure to future climate change in vulnerability analysis.

Change in rainfall and temperatures. A change in rainfall and mean temperature in CRV by 2050

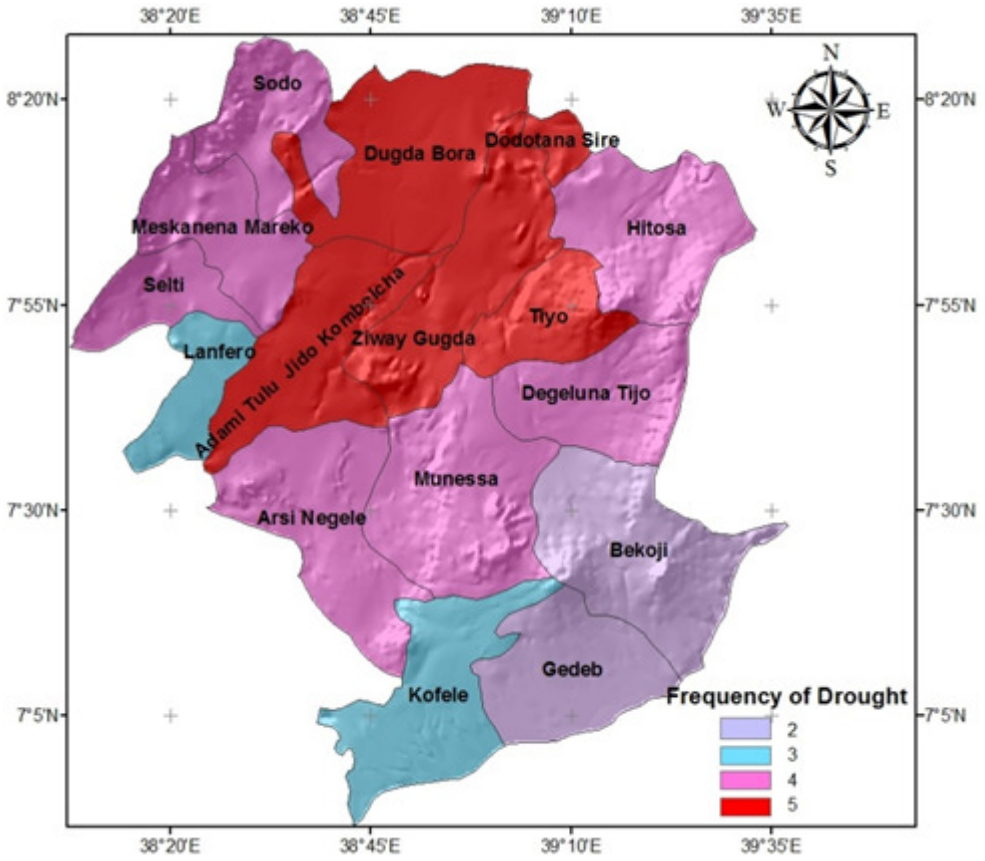

Figure 1. Drought frequency map of Central Rift Valley of Ethiopia.

was predicted from the future climate projection. The delta values overlaid over the study area vary substantially from district to district. For rainfall, a relatively high positive percentage change of around 8.6 was determined for districts of Hitosa, Munesa and Tiyo; while the highest reduction of rainfall around -11.3% was predicted for districts of Arsinegele, Gedeb and Kofele when compared with the base period (Fig. 2). In the case of temperature, the change varied between 3.5 ^{0}C at parts of Dodotana-Sire and Arsinegele districts and -1.1 ^{0}C at parts of Hitosa, Munesa, and Tiyo districts. This result was also used as a proxy indicator for exposure to future climate change in vulnerability analysis.

Analysis of vulnerability using vulnerability components

Exposure index. The exposure index related to the frequency of climate hazards results indicated that Dugda Bora and Dodotana-Sire districts are highly prone to drought given their projected future change in temperature and rainfall, while Kofele, Bekoji and Gedeb districts were relatively less prone (Fig. 3). The remaining districts had moderate risk of exposure to climate hazards.

Sensitivity index. Sensitivity index measures the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001). Results from the sensitivity analyses revealed that Hitosa and Tiyo districts were highly sensitive to the adverse impacts of climate change due to high human environmental interactions (Fig. 4) caused by combined effects of high population density and small ratio of land holdings, and high dependency on rain-fed cropping system. The least sensitive districts were Dugda Bora, Adamitulu-Jido Kombolcha and Arsinegele districts.

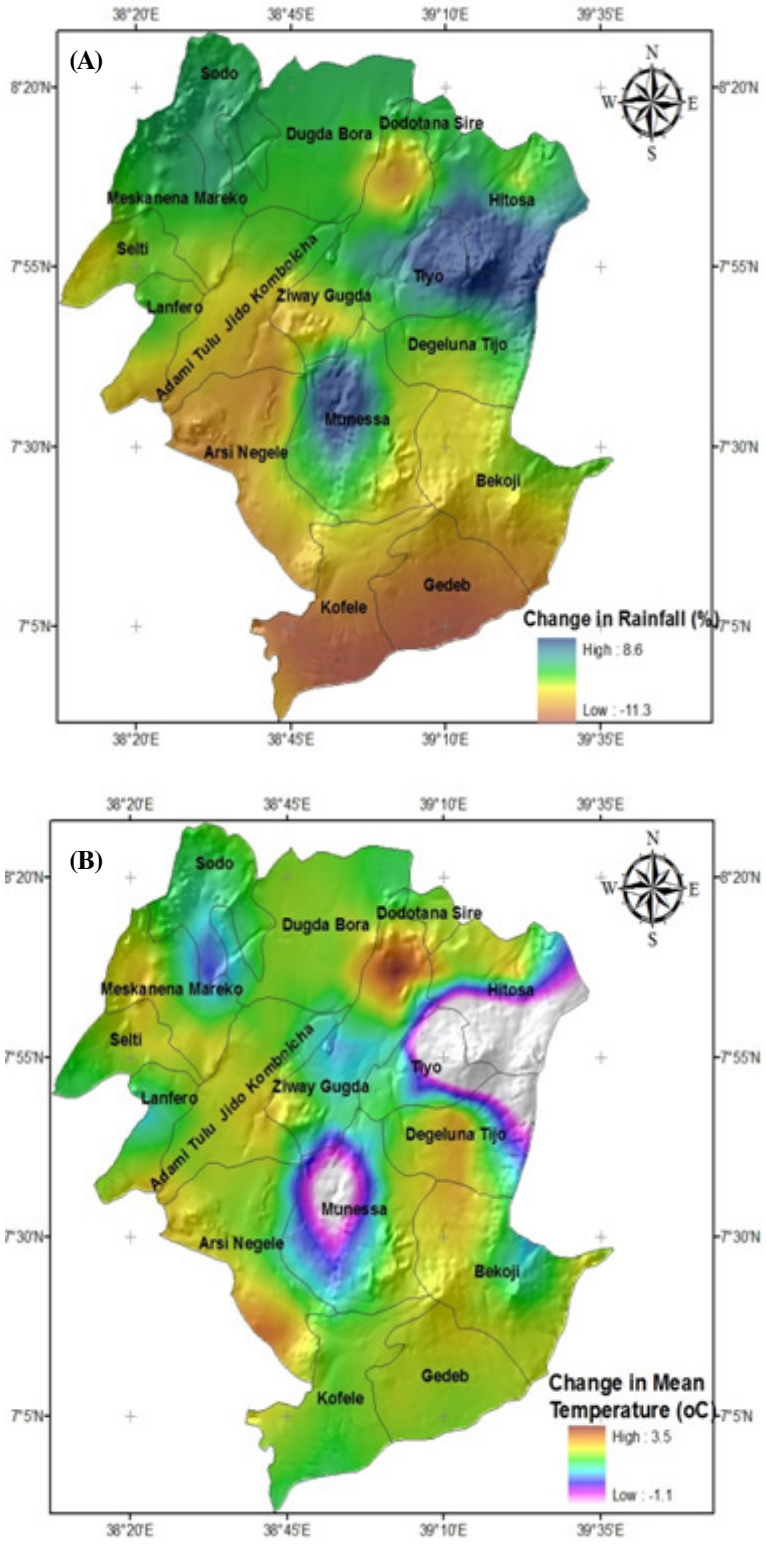

Figure 2. Projected change in rainfall and mean temperature in the Central Rift Valley of Ethiopia a period of 2050s (2040-2069).

Figure 3. Vulnerability sub-indices map for the Central Rift Valley of Ethiopia: Exposure index.

Adaptive capacity index. Adaptive capacity index measures the ability of a given system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001). The majority of the districts had medium level of adaptive capacity that could avert the negative consequence of climate change. Munessa and Lanfaro districts had relatively high adaptive capacity compared to the rest (Fig. 5). This was mainly due to the combined effect of high level of literacy, crop productivity, farm assets and use of credit and advisory services. Arsinegele, Meskanena Mareko and Hitosa districts had relatively low adaptive capacity, while the rest of the districts had medium level adaptive capacity.

Aggregate vulnerability index. The overall vulnerability index map, which is a composite of the three sub-indices map (Exposure, Sensitivity and Adaptive capacity) revealed that Selti, Dodotana-Sire and Tiyo districts were relatively highly vulnerable to the impact of climate change (Fig. 6); while Arsinegele, Adamitulu-Jido-Kombolcha and Dugda Bora districts were the least vulnerable. The rest of districts were under medium level of vulnerability to the impact of climate change.

DISCUSSION

Even though vulnerability assessments is the major task for studying climate change impact and developing site specific adaptation options, so far limited studies (only at large scale such as regional level) have been conducted in Ethiopia (NMA, 2007; Temesgen *et al*., 2008). The result obtained from this study is based on district levels, which is relatively at small scale level. This is one of the limitations to compare the result obtained from this study with those of other research works.

Vulnerability to climate change was analysed by generating vulnerability indices from 17 biophysical and socioeconomic vulnerability

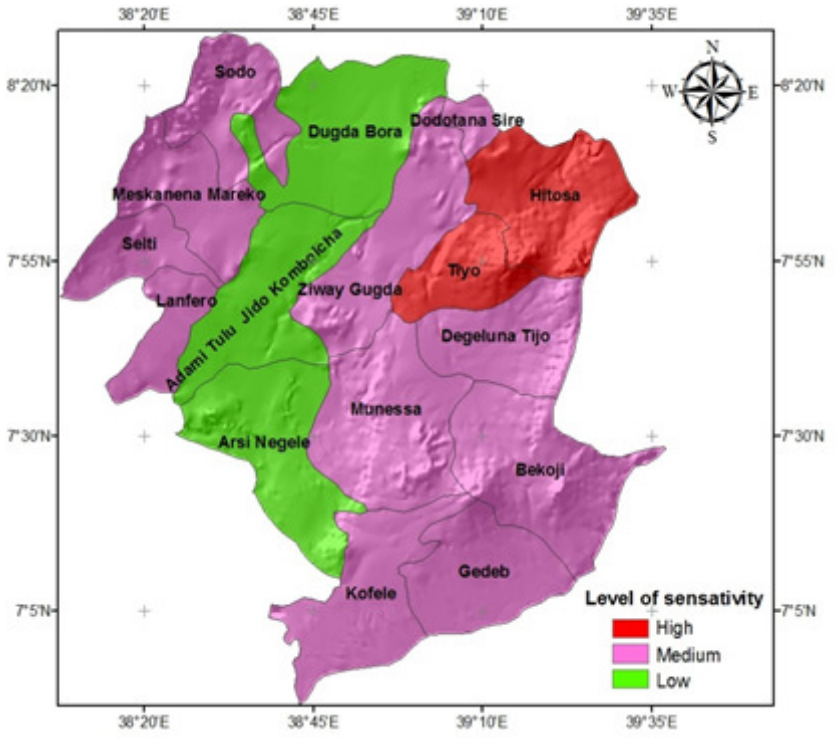

Figure 4. Vulnerability sub-indices map of the Central Rift Valley of Ethiopia: Sensitivity index.

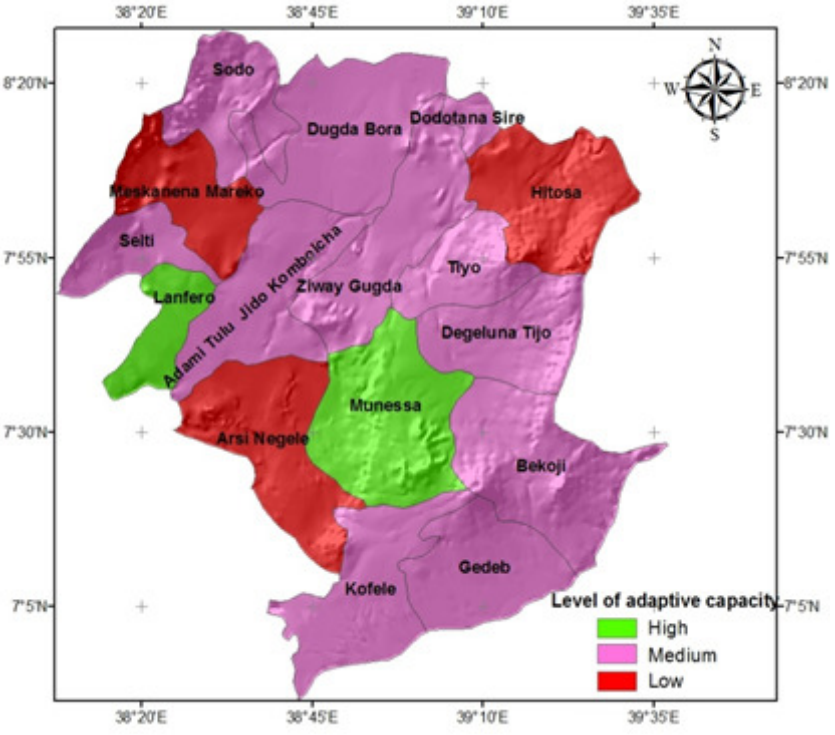

Figure 5. Vulnerability sub-indices map of the Central Rift Valley of Ethiopia: Adaptive capacity index.

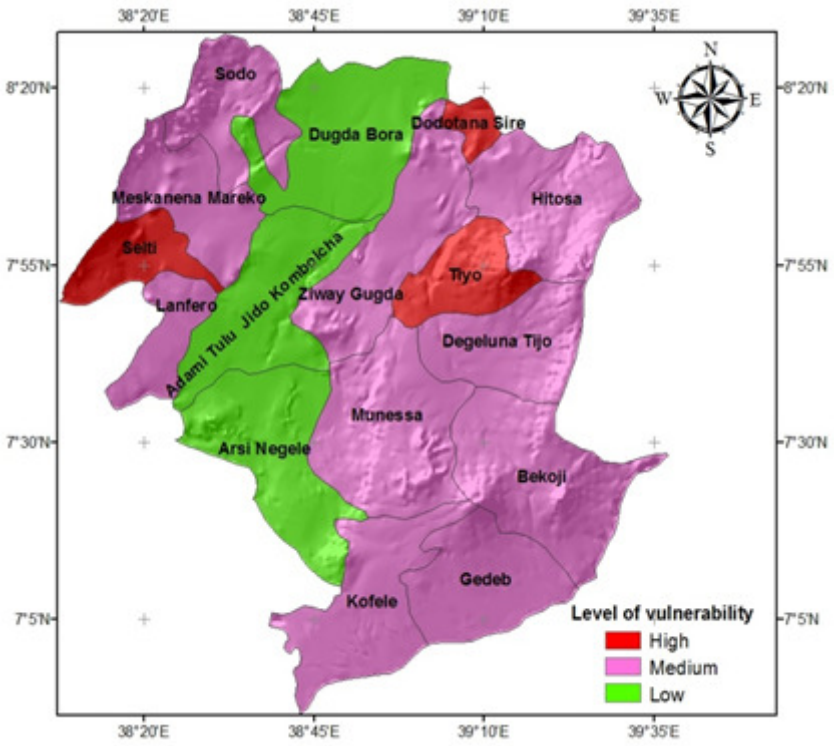

Figure 6. Aggregate vulnerability index map of the Central Rift Valley of Ethiopia.

indicators that reflect the three vulnerability components: Exposure, Sensitivity and Adaptive capacity; and comparing these indices across 16 districts, to produce vulnerability maps. Based on the result, relative vulnerability of districts within CRV to climate change varies spatially and vulnerable hotspot districts were identified as the result of their differences on exposure, sensitivity and adaptive capacity to climate change. Therefore, districts require site specific adaptation options based on their level of vulnerability to climate change.

Vulnerability mapping helps to target vulnerable hotspots and recommend appropriate interventions. This also helps to generate baseline information that helps researchers to conduct further site specific impact and adaptation studies, based on such identification of risk levels within relatively large geographical area. The knowledge of vulnerability to climate change can also assist decision makers in recommending the existing adaptation measures and prioritising resource allocation for specific areas, as well as determining investments for adaptation measures to future impacts of climate change.

Detailed biophysical impacts of climate change on the different sub-sectors of agriculture (crop, livestock, forestry, etc) should further be studied using ex-ante approach through system simulation models like APSIM and DSSAT for development of site specific adaptation options. The results of district scale level vulnerability analysis are believed to be important for decision makers and a good starting point for different impact and adaptation study. However, it is recommended that detailed assessment of vulnerability analysis at the smallest geographical unit, "Kebele", or household level and then at national level can be done using more diverse indicators for further refinement of the result of this study.

ACKNOWLEDGMENT

The authors acknowledge East shewa, Arsi, West Arsi and Gurage zones agricultural and rural

development offices and their respective District offices, International Food Policy Research Institute (IFPRI), National Meteorology Agency (NMA), Central Statistical Agency (CSA), and CCAFS for their cooperation in providing all necessary information. Melkassa Agricultural Research Center (MARC) based Biometrics, GIS and Agrometerology (BGA) support process researchers are also acknowledged. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 819 - 828 ISSN 1021-9730/2014 $4.00

KENYAN PURPLE TEA ANTHOCYANINS ABILITY TO CROSS THE BLOOD BRAIN BARRIER REINFORCING BRAIN ANTIOXIDANT CAPACITY IN MICE

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ABSTRACT

Studies on antioxidants as neuroprotective agents have been hampered by the impermeability of the blood brain barrier (BBB) to many compounds. However, previous studies have shown that a group of tea (*Camellia sinensis*) flavonoids, the catechins, are brain permeable and neuroprotective. Despite this remarkable observation, there exists no data on the bioavailability and pharmacological benefits of tea anthocyanins (ACNs) in the brain tissue. This study investigated the ability of Kenyan purple tea ACNs to cross the BBB and boost the brain antioxidant capacity. Mice were orally administered with purified and characterised Kenyan purple tea ACNs or a combination of Kenyan purple tea ACN's and coenzyme-Q_{10}, at a dose of 200 mg kg^{-1} body weight in an experiment that lasted for 15 days. Twenty four hours post the last dosage of antioxidants, CO_2 was used to euthenise the mice. Then the brain was excised and used for various biochemical analyses. Kenyan purple tea ACNs significantly ($P<0.05$) raised brain Glutathione (GSH) levels, implying a boost in brain antioxidant capacity. Notably, ACN metabolites were detected in brain tissue of ACN fed mice. This is the first demonstration that Kenyan purple tea ACNs can cross the BBB, reinforcing the brain's antioxidant capacity. Hence, there is need to study ACNs as suitable candidates for dietary supplements that could support antioxidant capacity in the brain and have potential to provide neuroprotection in neurodegenerative conditions.

Key Words: Coenzyme-Q_{10}, Glutathione, neuroprotective

RÉSUMÉ

Les études sur les antioxydants comme agents neuroprotecteurs ont été handicapées par l'imperméabilité de la barrière de sang du cerveau (BBB) à plusieurs produits. Par ailleurs, les études antérieurs ont montré qu'un groupe de flavonoïdes du thé (*Camellia sinensis*) , les catéchines, permettent la perméabilité du cerveau et protègent les nerfs. Malgré cette observation importante, il n'ya pas de données sur la biodisponibilité et les vertus pharmacologiques des anthocyanines du thé (ACNs) dans le tissue du cerveau. Cette étude a évalué l'aptitude des anthocyanines du thé pourpre du Kenya de traverser le BBB et améliorer la capacité antioxydante du cerveau. Des rats étaient oralement administrés des anthocianines du thé pourpre purifiés et caractérisés ou une combinaison des ACNs avec le coenzyme-Q_{10}, à une dose de 200 mg kg^{-1} de poids vif dans un essai d'une durée de 15 jours. Vingt quatre heures après le dernier dosage d'antioxydants, le CO_2 était utilisé pour euthanasier les rats. Ensuite, le cerveau était excisé et soumis à diverses analyses biochimiques. Les ACNs ont augmenté significativement ($P<0.05$) les niveaux du Glutathione (GSH) du cerveau,,ce qui implique une amélioration de la capacité antioxydante du cerveau. Remarquablement, les métabolites ACN étaient détectés dans le tissu des rats nourris aux ACNs. Ceci est la première démonstration que les anthocyanines (ACNs) du thé pourpre Kenyan peuvent franchir la barrière hémato-encéphalique (BHE), renforçant ainsi la capacité antioxydante du cerveau.

Ainsi, le besoin s'impose de les étudier comme des candidats appropriés pour les aliments de supplément qui pourraient renforcer la capacité antioxydante dans le cerveau et avoir le potentiel d'offrir la neuroprotection dans les conditions neurodégénératrices.

Mots Clés: Coenzyme-Q_{10}, Glutathione, neuroprotecteur

INTRODUCTION

Tea (*Camellia sinensis*), an evergreen plant native to China, is one of the most commonly consumed beverages in the world; processed from the young tender leaves of the plant (Cabrera *et al.,* 2003). The chemical composition of tea is complex but includes polyphenols, amino acids, carbohydrates, proteins, chlorophyll, volatile compounds, minerals, trace elements and alkaloids such as caffeine, theophylline and theobromine. Among these, polyphenols constitute the main bioactive molecules in tea (Cabrera *et al.,* 2003).

For centuries, the Chinese have used tea beverage to treat a myriad of diseases (Sharangi, 2009). This pharmacological value of tea heavily relies on its antioxidative properties known to surpass that of major antioxidants such as vitamins C and E (Rice-Evans *et al.,* 1995) and other synthetic antioxidants such as butylated hydroxyl anisole (BHA) and butylated hydroxytoluene (BHT) (Chen and Wan, 1994). The ability of tea to scavenge for free radicals is associated with the possession of a phenolic hydroxyl group attached to the flavan-3-ol structure of these compounds (Amie *et al.,* 2003). However, the importance of polyphenols in enhancing resistance to oxidative stress goes beyond simple radical scavenging activity. It is also due to amplified activity of most detoxifying enzymes such as glutathione peroxidase (GPx) and glutathione reductase (GR) (Mandel *et al.,* 2006). Indeed, as a result of their free radical quenching strengths, tea polyphenols have widely been credited with therapeutic action against free radical mediated diseases (Amie *et al.,* 2003).

Over the last few years, numerous epidemiological and clinical investigations have aroused increased interests in the use of tea polyphenols as neuroprotective agents. This is because previous studies have shown phytochemicals present in tea such as epigallocatechin gallate (EGCG) and epicatechin (EC) metabolites formed after oral ingestion of EC by rats, can cross the blood brain barrier protecting nerve cells from reactive oxygen species (ROS)-induced cell death (Mandel *et al.,* 2006). Other neuroprotective properties associated with tea polyphenols include preventing loss of dopaminergic neurons and preservation of striatal levels of dopamine, decreased expression of neuronal nitric oxide synthase (nNOS), inhibition of pro-apoptotic genes and protection against beta-amyloid induced neurotoxicity (Zaveri, 2006). This strongly suggests that tea polyphenols have potential application in the treatment of neurodegenerative disorders such as Alzheimer's and Parkinson's disease.

However, compared to other flavonoid groups from tea such as the catechins, little is known about the bioavailability and pharmacological benefits of tea anthocyanins (ACN). This is, despite the fact that anthocyanins from other sources have been associated with a broad spectrum of health benefits including cardiovascular, neurological, urinary tract and ocular protection, as well as anti-carcinogenic, anti-diabetic, anti-aging, antioxidant and anti-inflammatory properties (Bagchi *et al.,* 2004).

It has been widely established that isolated individual antioxidants do not explain the observed health benefits of diets, implying that interactions between antioxidants may yield positive synergistic effects (Chu *et al.,* 2002). Indeed, synergistic effects of various ACNs have been demonstrated in black-current and wine grapes (Hosseini-Beheshti *et al.,* 2012). Therefore, the health benefits of a diet rich in phytochemicals is attributed to the complex mixture of phytochemicals present in it, an observation which clearly suggests that to improve their nutrition and health, consumers should take antioxidants from diverse sources. However, only

a very limited number of studies have investigated combinations of purified ACN extracts with other chemical components of food.

Intracellular synthesis that occurs in the inner mitochondrial membrane via the mevalonate pathway, is the major source of Co-Q_{10}, although small amounts can be obtained from the diet (Mancuso *et al.,* 2010). Co-Q_{10} is an essential cofactor involved in mitochondrial oxidative phosphorylation and when reduced, it is a powerful antioxidant that prevents oxidative damage by free radicals including oxidation of lipids within the mitochondrial membrane (Matthews *et al.,* 1998). More importantly, Co-Q_{10} crosses the BBB exerting a multitude of neuroprotective effects in the brain and protecting against pathophysiology associated with neurodegenerative disorders (Matthews *et al.,* 1998), hence the inclusion of this nutraceutical in this study.

This study aimed at evaluating the synergistic, additive or antagonistic types of interactions manifested by purified tea anthocyanin extracts and co-enzyme Q_{10} (Co-Q_{10}). Co-Q_{10}, or ubiquinone, is an endogenously synthesized lipid, which shuttles electrons from complexes I and II to complex III (ubiquinol cytochrome c oxidase) of the electron transport chain.

MATERIALS AND METHODS

Tea samples. Purple tea used to extract ACNs was obtained from the Tea Research Foundation of Kenya, Timbilil Estate in Kericho (latitude 0 °22'S, longitude 35°21'E, altitude 2180 m.a.s.l). ACNs were extracted from the purple tea variety TRFK 306. Young tender shoots comprising of two leaves plus a bud were harvested, dried using a microwave and pulverised with a grinder into fine powder.

Extraction, purification and lyophilisation of anthocyanins. Extraction and purification of tea ACNs were carried out as described elsewhere (Kerio *et al.,* 2012). Prior to the lyophilisation of ACNs extract, methanol and formic acid were removed using a rotary evaporator at 35ºC under vacuum and the residue was reconstituted with distilled water. Pre-freezing of the extract was done before being placed on the drying accessory. A 200 ml sample of the ACN extract was each placed in dehydration flasks and rapidly frozen by spinning the round bottom flasks in a dry ice-acetone bath. Temperature and pressure of the lyophiliser were allowed to reach appropriate levels of -40 ºC and $100x10^{-3}$ M Bar, respectively before freeze drying process was initiated. Lyophilisation was done using a Modulyo freeze dryer (Edwards, England) producing a free flowing powder that was weighed and stored in airtight containers at room temperature until use.

HPLC analysis of anthocyanins. Qualitative and quantitative analyses of the tea extract and anthocyanin profiles of purple tea variety TRFK/306 were carried out in triplicates by high performance liquid chromatography (HPLC) as described elsewhere (Kerio *et al.,* 2012).

Experimental animals. All experimental protocols and procedures involving use of mice as experimental animals adhered to rules and regulations approved by Institutional Animal Care and Use Committee (IACUC) of the Trypanosomiasis Research Centre of Kenya Agricultural Research Institute (KARI-TRC) Muguga, Kenya and Egerton University as well as the National Regulations of the Kenya Veterinary Association. A total of 15, eight-week old female adult healthy Swiss white mice, weighing between 21-30 g, were obtained from the TRC breeding colony and used in all experiments. The animals were housed in standard mice cages at a temperature of 21-28 °C. They were provided with *ad libitum* access to water and standard mice cubes (Unga Feeds Ltd Kenya), with wood-chippings provided as bedding material. All mice were treated with 0.02 ml of Ivermectin (Ivermectin®, Anupco, Suffolk, England) injected subcutaneously to each mouse to eradicate endoparasites and ectoparasites infestation.

After two weeks of acclimatisation, the mice were randomly selected and divided into two groups of five animals each. Appropriate controls were used for this experiment. Group one was supplemented with Kenyan purple tea ACNs; while group 2 was supplemented with a combination of Kenyan purple tea ACNs and Co-Q_{10} . Note that we did not have a group on Co-Q_{10}

alone because the antioxidant abilities of Co-Q_{10} are well known and this study was focused on determining if Co-Q_{10} will boost the beneficial effects of ACNs.

The test antioxidants were administered orally at a dosage of 200 mg kg^{-1} body weight for fourteen days, after every second day using a gavage needle. Twenty four hours after the last dosage of antioxidants; carbon dioxide was used to euthanize the mice after which the brain was excised, snap frozen in dry ice and stored in liquid nitrogen until analysis.

Packed cell volume (PCV) and body weight. At one week interval, blood was taken from each mouse by tail snip into 100 ìl microhaematocrit capillary tubes for PCV determination (Woo *et al.,* 1970). After blood collection, the capillary tubes were sealed with plasticin at one end and centrifuged in a haematocrit centrifuge (Hawksley H England) at 10,000 revolutions per minute (RPM) for 5 minutes. PCV was then read using a micro-haematocrit reader and expressed as a percentage of the total blood volume. Body weight of each mouse was determined every two days using the analytical electronic balance (Mettler PM34, DoltaRange®).

Brain sample preparation. Snap-frozen whole brains were homogenised on ice water (4 ºC) in 0.5ml of 0.25 M sucrose, 5 mM Hepes-Tris, pH 7.4, with protease inhibitor cocktail to a final concentration of 10% (w/v). The homogenates were aliquoted into 1.5 ml microfuge tubes to avoid repeated freeze-thaw process and stored in liquid nitrogen until analysis

Glutathione assay. Glutathione assay was performed as described in a previous experiment (Rahman *et al.,* 2007), with slight modifications. A volume of 50 µl of brain homogenates were mixed with 50 µl solution containing sulphosalicylic acid (5% w/v) and 0.25 mM ethylene diamine tetra-acetic acid (EDTA) and the mixture centrifuged at 8000x*g* for 10 minutes at 4 ºC. A volume of 200 µmol l^{-1} of GSH standard solution was prepared in 0.5% sulphosalicylic acid (SSA) and serial dilutions made using the same solution (0.5% SSA) to final concentrations of 100, 50, 25, 12.5, 6.25, 3.13 and 1.56 µmol l^{-1}. Ellman's reagent (5,5'-Dithiobis (2-nitrobenzoic acid (DTNB)) was prepared by dissolving in 0.1 M potassium phosphate buffer with 5 mM EDTA disodium salt, pH 7.5 (KPE buffer) to a final concentration of 0.6 mg ml^{-1}. A volume of 25 µl of each standard were loaded on a 96-well microtitre plate to wells B–H in column 1, 2 and 3 followed by 25 µl of the sample to the remaining wells in triplicate. To each well, 100 µl of freshly prepared DTNB was then added and the absorbance measured at 405nm at intervals of 30 seconds using a multi-detection microtitre plate reader (Bio-Tek Synergy HT).

HPLC for detection of anthocyanins. A volume of 600 µl methanol/formic acid (99/1) was mixed with 600 µl brain homogenate in a 1.5 ml microfuge tube and the mixture centrifuged at a speed of 5000 g for 10 minutes. One millilitre of the supernatant was then pipetted into a separate tube and HPLC analysis of the samples carried out as described in the earlier section, "High-performance liquid chromatography analysis of anthocyanins".

Data analysis. Data were analysed using Prism Graph pad version 5.0 and at a $P<0.05$. Significance of difference between means for PCV and glutathione was determined by one way ANOVA and Tukey post hoc test was performed to evaluate differences among group means.

RESULTS

Purple tea anthocyanin profile. Following lyophilisation of the anthocyanin extracts, a free flowing powder that was bright red in colour, with a characteristic smell of fresh berries was produced. ACN profiling of Kenyan purple tea revealed presence of anthocyanidins; cyanidin, peonidin, pelargonidin, delphinidin and malvidin (Fig. 1). The anthocyanidins profile revealed cyanidin as the most abundant (1755.60 µg ml); while delphinidin was the least (122.85 µg ml^{-1}) abundant (Table 1).

Retention time

Anthocyanin in brain tissue. ACN metabolites, vividly absent from animals not supplemented

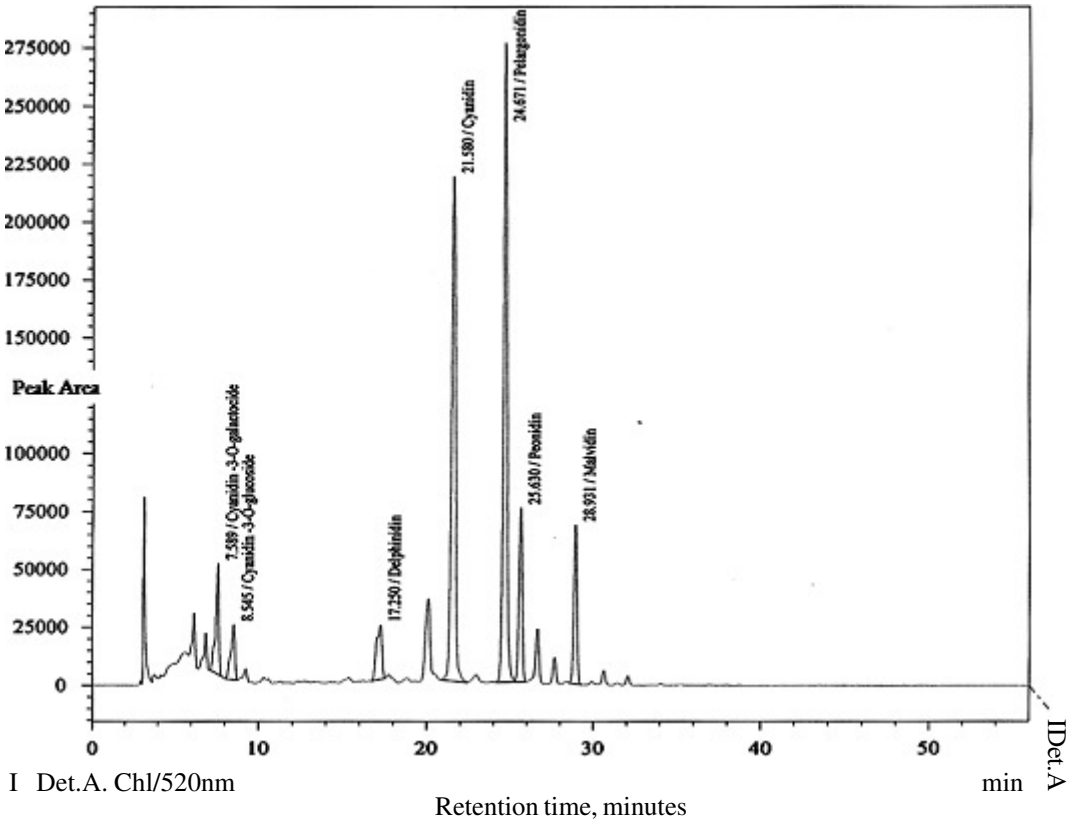

Figure 1. A representative HPLC chromatogram of un-aerated (green) tea from a Kenyan purple tea variety clone TRFK 306.

TABLE 1. Concentration of anthocyanins in non-aerated (green) tea derived from Kenyan purple leaf colored variety TRFK 306 by HPLC

Individual anthocyanins/ anthocyanidins	Concentrations (µg ml^{-1})
Cyanidin-3-*O*-Galactoside	139.25
Cyanidin-3-*O*-Glucoside	50.26
Delphinidin	122.85
Cyanidin	1755.60
Pelargonidin	840.08
Peonidin	371.36
Malvidin	304.83
Total anthocyanin content	3584.23

with ACNs and having very close retention times to individual intact anthocyanins (Table 2), were detected in brain tissue of animals from the various anthocyanins groups (Fig. 2).

Tea anthocyanins and coenzyme-Q_{10} in mice

Clinical symptoms and survival. Animals supplemented with ACNs and Co-Q_{10} were marked with hyperactivity from the onset of Co-Q_{10} supplementation to the last day of the experiment. No clinical signs were detectable in the ACNs only groups, signifying that the tea polyphenols were well tolerated in the experimental animals. One animal supplemented with both test antioxidants died 9 days post start of antioxidant administration.

Packed cell volume and body weight. PCV levels and body weight baseline data are presented in Table 3. There was a gradual increase in PCV levels of the untreated animals throughout the experiment rising from 55.2± 0.49 to 58.4± 2.50%. Experimental animals supplemented with ACNs only and ACNs and Co-Q_{10} had a rather steady

TABLE 2. Retention times in minutes of the detected metabolites against intact individual anthocyanins

Chromatogram B- Retention times in minutes of the detected metabolites	Possible metabolites of anthocyanin
23.321	Cyanidin-21.580Pelargonidin-24.671
25.227	Pelargonidin-24.671Peonidin-25.630
27.114	Malvidin-28.931
Chromatogram C- Retention times in minutes of the detected metabolites	Possible metabolites of anthocyanin
15.334	Delphinidin-17.250
21.272	Cyanidin-21.580
28.287	Malvidin-28.931

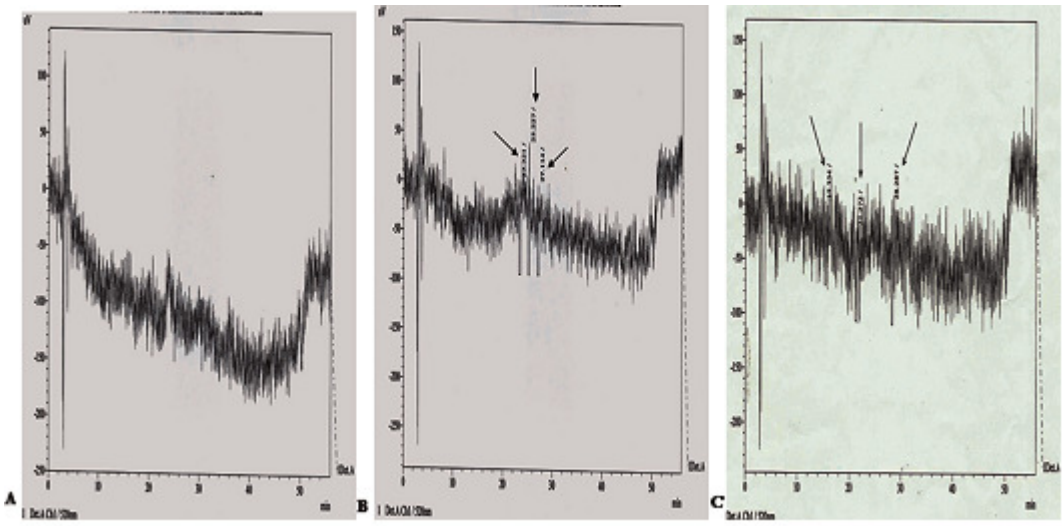

Figure 2. Representative HPLC chromatogram of brain homogenates from animal not supplemented with antioxidants (A), animal supplemented with ACN's and Co-Q_{10} (B) and animal supplemented with ACN's only (C). Chromatograms B and C show presence of possible ACN's metabolites in the brain tissue indicated by arrows.

increase in PCV, rising from 53.4± 1.03 and 53.4± 1.36%, three days prior to antioxidant administration to 58.6± 1.08 and 59.25± 2.03% on the sixth day after the start of antioxidant administration, respectively. This was followed by a steady decrease in PCV levels to the last day of the experiment, reaching 53.2± 1.93 and 55± 0.71% in ACNs only and ACNs and Co-Q_{10} groups, respectively. However, these fluctuations did not portray a statistical significant difference ($P>0.05$) between the different groups analysed. Mice receiving both antioxidants showed a significant decrease in mean body weight changes during the experimental period ($P<0.05$) (Fig. 3). The decrease in weight commenced immediately after the start of antioxidant administration, falling from 26.76±0.77 to 23.30±1.67g by the seventh day post start of antioxidant administration (DPSAA) after which a marginal increase was observed reaching 23.45±1.82 g. Animals supplemented with ACNs lost weight consistently from the first DPSAA to the last day of the experiment, dropping from 27.88±1.60 to 25.76±1.69 g. Untreated animals registered an unsteady, but gradual increase in mean body weight rising from 24.64±0.59 to 26.3±0.50 g by the end of the experimental period. However, no significant differences in mean body

TABLE 3. Changes in PCV levels of mice supplemented with ACNs, ACNs and Co-Q_{10} or water only

Days post start of antioxidant administration	PCV levels in %		
	Controls	ACNs	ACNs and Co-Q_{10}
-3	55.2 ±0.49	53.4±1.03	53.40±1.36
6	57.4±0.51	58.6±1.08	59.25±2.03
12	58.4±2.50	53.2±1.93	55.00±0.71

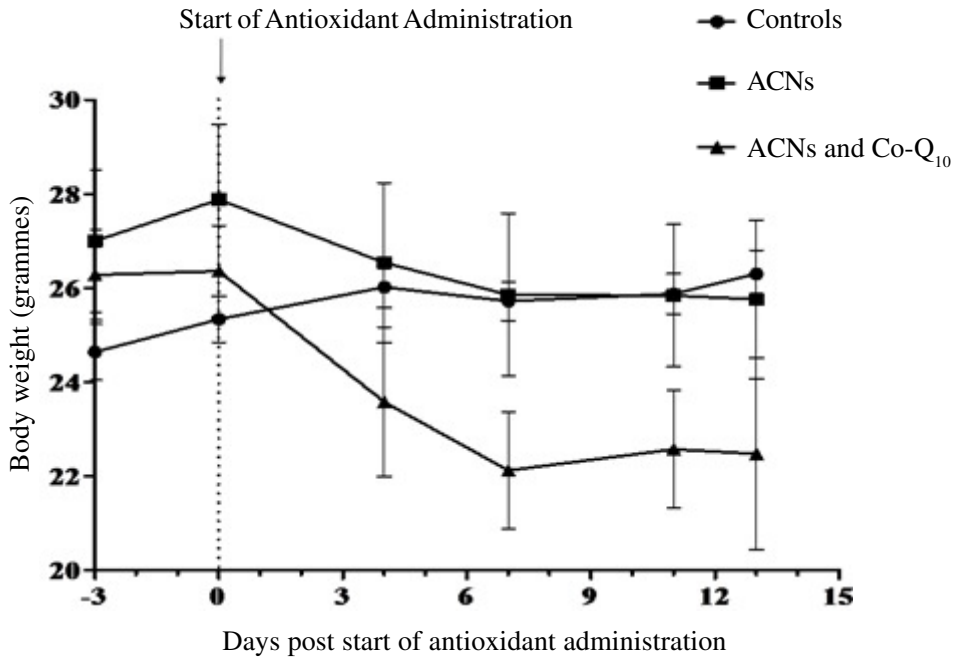

Figure 3. Changes in body weight of mice supplemented with ACNs, ACNs and Co-Q_{10} or water only.

weight were recorded between untreated animals and animals supplemented with ACNs (P>0.05).

Anthocyanins and Co-Q_{10} *versus* glutathione levels. The level of GSH in brain tissue of mice supplemented with either one or both antioxidant supplements is presented in Figure 4. Supplementing experimental animals with Kenyan purple tea ACNs significantly boosted the levels of endogenous total GSH levels in the brain tissue (2.22±0.18 µM) compared with the controls (1.27±0.12 µM) (P=0.0006). However, when both test antioxidants were provided, there was a decline in total GSH levels to amounts below even the level recorded in healthy animals not supplemented with antioxidants (0.97± 0.06 µM).

DISCUSSION

Polyphenols and other phytochemicals in plants must cross the BBB to be able to exert their beneficial effects in the central nervous system (CNS). Otherwise, the multitude of health benefits associated with these flavonoids, such as strong antioxidant and anti-inflammatory properties, would be excluded from the brain and the CNS in general. Our research clearly demonstrates that ACNs from the Kenyan purple tea cross the BBB and exert physiological effects by boosting antioxidant capacity in the brain. The presence of ACNs in this pivotal organ was confirmed by the detection of ACN metabolites in the ACN fed animals. These metabolites were absent in

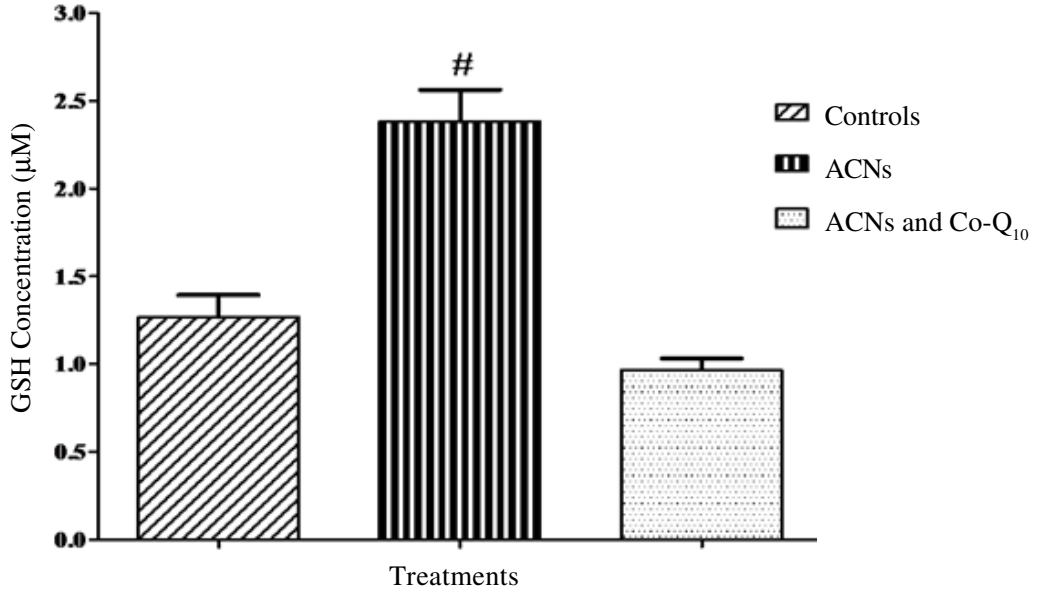

Figure 4. Total brain GSH levels in mice supplemented with ACNs, ACNs and Co-Q_{10} or water only. #P<0.05, statistically significant versus untreated group.

the placebo group that was not fed the purple tea. However, we were not able to detect intact ACNs from the brain homogenates of the ACN fed mice. Considering that approximately two-thirds of ACNs are highly biotransformed and end up as methylated and glucuronidated metabolites (Kay, 2006), absence of such intact ACN's in the brain homogenates of our ACN fed mice was not surprising.

Our results also indicate that oral intake of tea ACNs markedly increases brain GSH levels. Indeed, ACNs from a wide array of sources have been shown in several instances to up-regulate endogenous antioxidant levels. A previous study working with the same variety of purple tea reported an increase in cellular GSH content in cells exposed to ACNs (Kerio *et al.,* 2011). Red mixed berry juice rich in ACNs has also been shown to decrease oxidative DNA damage, increase GSH levels and glutathione status in healthy human volunteers (Weisel *et al.,* 2006). The mechanisms by which ACNs are thought to exert these effects include quenching of ROS, chelating of metals known to participate in reactions that result in the vicious formation of reactive moieties and by the activation of antioxidant response element (ARE) upstream of genes that are involved in antioxidation and detoxification (Shih *et al.,* 2007).

Our results on PCV, body weight and brain glutathione strongly suggest negative interactions between Kenyan purple tea ACNs and Co-Q_{10}. An antagonistic effect between the two antioxidants was unexpected as it was thought that the nutraceuticals would have a more pronounced synergistic effect in combination rather than in isolation. However, ACNs and other substances known to lower cholesterol levels or prevent its absorption are expected to have adverse effects on non sterol compounds such as Co-Q_{10} (Bliznakov *et al.,* 1998). The negative interactions have also been observed while employing other lipid lowering substances such as HMG-CoA competitive inhibitors known as statins (Bliznakov *et al.,* 1998). Indeed, several authors have reported the ability of Co-Q_{10} to reverse the detrimental side effects associated with statins including muscle myopathy and rhabdomyolysis (Langsjoen and Langsjoen, 2003). Further studies will be necessary to determine whether indeed purple tea ACNs could nullify the beneficial effects of Co-Q_{10} supplements or vice versa.

CONCLUSION

Data from our study provide compelling evidence that Kenyan purple tea ACNs are able to cross the BBB and exert their physiological effects in this organ by up-regulating endogenous antioxidant reserves. We, therefore, recommend the study of this nutraceutical as a suitable candidate for consideration as dietary supplements to modulate conditions associated with oxidative stress in the brain such as Alzheimer's and Parkinson's disease, amyotrophic lateral sclerosis (ALS) and multiple sclerosis.

ACKNOWLEDGEMENT

We thank the National Commission for Science and Technology (NACOSTI) in Kenya, the Tea Research Foundation of Kenya and Egerton University for funding this work. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 829 - 836 ISSN 1021-9730/2014 $4.00

PROPERTIES OF EXTRUDATES FROM SORGHUM VARIETIES

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ABSTRACT

Extrusion cooking is a modern high-temperature short-time (HTST) processing technology, which is becoming popular in certain industries because it offers several advantages over other types of cooking processes. The objective of this study was to evaluate the extrusion performance of sorghum (*Sorghum bicolor*) varieties commonly grown in Uganda. Four varieties of sorghum namely, Seso1, Epuripur, Seso3 and Eyera were extruded with and without defatted soy-flour. Physical-chemical properties of the extrudates including, lateral expansion, bulk density, hardness, water absorption index, water solubility index, as well as proximate composition were determined. The extrudates exhibited 240-300% lateral expansion and 0.067-0.095 g cm^{-3} bulk density. The water absorption index was 6.4-7.9 g g^{-1} compared to 1.9-2.3 g g^{-1} of the control; while the water solubility index was 6.5-13% compared to 3.4-5.0%% of the control. Extrusion of all the varieties reduced the peak and final viscosity of the extrudates. There were no varietal differences with respect to lateral expansion, bulk density and hardness. However, the water absorption index for the varieties increased in the order, Eyera, Seso 3, Seso 1 and Epuripur; while the water solubility index for the varieties increased in the order, Seso 1, Seso 3, Eyera and Epuripur. Defatted soybean flour had no effect on the extrudate properties. The results suggest that the four sorghum varieties in this study can be used in the production of extruded puffed snacks, breakfast cereals and other food products.

Key Words: Bulk density, extrusion cooking, sorghum, soy-flour

RÉSUMÉ

La cuisson-extrusion est une technologie moderne de cuisson rapide à haute température qui devient de plus en plus populaire dans certaines industries parce qu'elle offre plusieurs avantages face à d'autres procédés de cuisson. L'objectif de cette étude était d'évaluer la performance de l'extrusion des variétés du sorgho (*Sorghum bicolor*) communément cultivées en Ouganda. Quatre variétés du sorgho dont Seso1, Epuripur, Seso3 et Eyera étaient extrudées avec et sans farine du soja dégraissée. Les propriétés physico-chimiques de l'extrudant incluant l'expansion latérale, la densité volumique, la dureté, l'indice d'absorption d'eau ainsi que la composition chimique étaient déterminées. Les extrudants ont manifesté 240-300% de l'expansion latérale et 0.067-0.095 g cm^{-3} de la densité volumique. L'indice d'absorption d'eau était de 6.4-7.9 g g^{-1} en comparaison avec 1.9-2.3 g g^{-1} dans le contrôle, pendant que l'indice de solubilité dans l'eau était de 6.5-13% contre 3.4-5.0% dans le contrôle. L'extrusion de toute les variétés a réduit l'apogée et la viscosité finale des extrudants. Il n'y avait pas de différences significatives entre les variétés au niveau de l'expansion latérale, la densité volumique et la dureté. Par ailleurs, l'indice d'absorption d'eau pour les variétés a augmenté dans l'ordre pour les variétés Eyera, Seso 3, Seso 1 et Epuripur; pendant que l'indice de solubilité dans l'eau pour les variétés a augmenté dans l'ordre pour les variétés Seso 1, Seso 3, Eyera et Epuripur. La farine degraissée de soja n'avait aucun effet sur les propriétés de l'extrudant. Ces résultats suggèrent que toutes les quatre variétés de sorgho dans cette étude peuvent être utilisées dans la production des collations , céréales pour petit déjeuner et autres produits alimentaires.

Mots Clés: Densité volumique, extrusion de cuisson, sorgho, farine de soja

INTRODUCTION

Extrusion cooking is a modern high-temperature short-time (HTST) processing technology, which is becoming popular in certain industries because it offers several advantages over other types of cooking processes, such as faster processing times and significant reduction in energy consumed, which consequently results in lower prices for the final products (Branèiæ *et al.,* 2006). The products of extrusion are important in the food and feed industries today. An extruder represents a very complex bioreactor in which, various types of food raw materials with different moisture contents and viscosities are treated, under high temperatures, short residence times, high pressures and very strong shear forces (Branèiæ *et al.,* 2006).

Extrusion typically involves mixing, mass kneading, heating, shearing, and lastly forcing the food material through a die appropriately designed to form and dry an expanded product under rapid fall in pressure (Akdogan, 1999). The extrudate formed has characteristic properties that are very different from the starting raw materials (Cai *et al.,* 1995).

Sorghum (*Sorghum bicolor* L. Moench) is major food and cash crop in Africa (Rohrbach, 2003; Ebiyau *et al*., 2005) with over 90 million people directly dependant on it in the east and central Africa region alone. However, in most of the communities that depend on sorghum, little or no value addition processing is done on this crop. The little processing that is done involves milling, malting and fermentation with rudimentary traditional technologies to produce, flours, traditional alcoholic and non-alcoholic beverages and pre-ferments. Extrusion is a relatively new technology in Africa that is not widely used.

Nonetheless, extrusion technology provides more opportunities for producing and marketing new value added products from soghum. Early research done on extrusion of sorghum showed both successes and challenges (Anderson *et al*., 1969; Pelembe *et al*., 2002). As such, most of the work done on sorghum extrusion has been on sorghum composites. On the other hand, sorghum breeding programmes have continued to release high yielding elite sorghum varieties. However, such elite varieties have not been evaluated for extrusion purposes. The objective of this work was to evaluate the extrusion performance of sorghum varieties commonly grown in Uganda for products like breakfast cereals and snack foods.

MATERIALS AND METHODS

Samples and sample treatment. One hundred kg each, of four sorghum varieties namely, Epuripur, SESO 3 SESO1 (improved varieties) and Eyera (local variety) were obtained from National Semi-Arid Resources Research Institute (NaSARRI), in Uganda. The samples were manually cleaned and sorted to get rid of chaff, foreign matter and any broken, shriveled and/or moulded grains. Defatted soy-flour packed in sealed polyethylene bags was obtained from a local supplier (SESACO Uganda Ltd).

The sorghum grain varieties were individually milled into flour using a commercial hammer mill. The flour from each sorghum variety was then individually mixed with defatted soy-flour at 0, 3 and 6% (w/w) proportions. The control samples were un-extruded flours from the respective sorghum varieties to which no soy-flour was added. Treatment samples were identified by sorghum variety name and level of defatted soy flour added.

Extrusion process. Prior to extrusion, 30 kg of the mixed flour were individually thoroughly mixed with 3% potable tap-water (w/w) in order to condition the flour for proper extrusion. Extrusion was done in a co-rotatory intermeshing twin screw extruder, at temperatures: 60 °C (heater area I), 130 °C (heater area II) and 150 °C (heater area III); Screw frequency: 35Hz; Filler frequency: 30Hz and Cutter frequency: 50Hz. The residence time for sorghum flour samples in the extruder was about 5 seconds. Preliminary experiments (results not shown) exhibited these conditions as the optimum extrusion conditions for sorghum. Extrudates were collected, dried and packaged in polyethylene bags, and kept for further analysis. All treatments were extruded in triplicates and each analysis was done in duplicate.

Laboratory analyses

Diameter of extrudates. Ten extrudates were selected at random from each of the triplicate extrudate samples. Using a vernier caliper, the diameter of the extrudates was measured at three positions along the length of each of the selected samples. The average of the 3 x 10 readings was taken as the extrudate diameter for subsequent statistical analysis.

Lateral expansion of extrudates. The ratio of diameter of extrudates to the diameter of die was taken as a measure of lateral expansion of the extrudates (Ibanoglu *et al*., 2006). The percent Lateral Expansion (LE) was calculated using the mean of the measured diameters with the following equation:

$$LE = \frac{\text{Diameter of extrudate - Diameter of extruder}}{\text{Diameter of extruder die}} \times 100$$

Bulk density of extrudates. Bulk density (BD) measured in g cm^{-3} (Stojceska *et al*., 2008) was calculated using:

$$BD = \frac{4 \times m}{\pi \times d^2 \times L}$$

Where:

m = mass (g), L = length (cm) and d = diameter (cm) of extrudates.

Hardness of extrudates. Hardness of the sorghum grains was determined using a penetrometer (AFG series, T.W.L Force Systems, Stubbington, United Kingdom). The probe was attached onto the penetrometer and then the gauge fitted onto the strand. The penetrometer was allowed to stabilise for 20 minutes and it was then zeroed by pressing the reset button. Each sample was placed in between the probe and the stand using a lever. The probe was then gently lowered to press against the sorghum extrudate and the reading on the gauge was recorded in degrees and then converted to mm (1° = 0.01 mm) using a conversion table supplied with the instrument. The higher the measured degrees the softer the sample.

Water Absorption Index (WAI) and Water Solubility Index (WSI). WAI and WSI were determined using the method developed for cereals (Stojceska *et al*., 2008; Yagci and Gogus, 2008). The extrudate samples were ground into a fine flour and suspended in water at room temperature (approximately 25 °C) for 30 minutes, and gently stirred during the period. The samples in water were centrifuged at 6000 rpm for 10 minutes. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. WAI and WSI were calculated using the following formulae:

$$WAI\ (g/g) = \frac{\text{Weight of wet gel - Dry weight of extrudate}}{\text{Dry weight of extrudate}}$$

$$WSI\ (\%) = \frac{\text{Weight of dry solid in the supernatant}}{\text{Dry weight of extrudate}} \times 100$$

Determination of proximate composition

Moisture content. Moisture content was determined using the method recommended by AOAC (1996). About 2 g of sample was taken onto a preconditioned Petri-dish and dried in a hot air oven at 100 °C for about 18 hours. The dry sample was cooled in a dessicator for about 30 minutes and reweighed. The loss in weight was taken as moisture content of the sample and calculated as percentage of the total.

Crude fat analysis. The fatty material or crude fat in foods was determined by extraction of the dried food with Petroleum ether. The Soxhlet extraction method was used as described by AOAC (1996). About 3 g of the sample was mixed with about 40 ml of extraction solvent (Petroleum Ether) The extracted oil was weighed and

expressed as a percent of the original sample weight.

Dietary fibre. Fibre was determined using the method described by Kirk and Sawyer (1991). About 1 g of the oven dried sample was taken for analysis. Total fiber content was weighed and expressed as a percent of the original sample weight

Ash content. Ash content was determined by the method described by AOAC (1996). About 3 g of the sample were taken for analysis. The ash extract expressed as a percent of the original sample weight

Crude protein. The Kjeldahl technique was used as described by Kirk and Sawyer (1991) for crude protein determination. About 0.2 g were measured from each sample for analysis. Protein content was calculated using the cereals' nitrogen conversion factor of 6.25.

Data analysis. Data were subjected to Analysis of variance (ANOVA) using the Statistical Package for Social Scientists (SPSS) computer software. Where significant differences were detected, the Least Significant Difference method was used to separate the means at $P < 0.05$.

RESULTS AND DISCUSSION

Physical properties of extrudate. Table 1 shows the physical properties of sorghum extrudates with and without soy-flour. Lateral expansion of extrudates ranged from about 240 in Eyera to 300% in Epuripur. However, there was no significant difference ($P>0.05$) among the expansion rates of extrudates from the different sorghum varieties. The expansion rates obtained in this work were higher than the 175-189% reported by Zamre *et al*. (2012) for sorghum based extruded products. This difference can be attributed to differences in varieties. According to Chinnaswamy and Hanna (1988), higher starch contents favour

TABLE 1. Physical properties of extrudates of four commonly grown sorghum varieties obtained from germplasm in Uganda

Sample	Diameter (cm)	Lateral expansion (%)	Bulk density (g cm^{-3})	Hardness (mm)
Seso1 + 0% Soy	1.58 (0.05)	284.11 (11.06)	0.077 (0.00)	1.78 (0.23)
Seso1 + 3% soy	1.61 (0.08)	292.60 (20.18)	0.078 (0.00)	1.84 (0.71)
Seso1 + 6% soy	1.47 (0.03)	256.76 (16.76)	0.090 (0.00)	1.78 (0.31)
LSD (0.05)	0.10	27.18	0.01	0.08
Epuripur + 0% Soy	1.55 (0.16)	275.91 (11.95)	0.069 (0.01)	1.42 (0.29)
Epuripur + 3% soy	1.46 (0.13)	255.47 (20.68)	0.073 (0.01)	1.74 (0.54)
Epuripur + 6% soy	1.65 (0.12)	301.22 (28.08)	0.067 (0.01)	1.04 (0.32)
LSD (0.05)	0.27	46.7	0.008	0.81
Seso3 + 0% soy	1.58 (0.06)	283.94 (9.81)	0.083 (0.01)	1.44 (0.35)
Seso3 + 3% soy	1.52 (0.06)	270.07 (9.64)	0.085 (0.00)	1.24 (0.43)
Seso3 + 6% soy	1.44 (0.05)	249.88 (7.46)	0.095 (0.01)	1.04 (0.41)
LSD (0.05)	0.07	18.20	0.009	0.5
Eyera + 0% soy	1.54 (0.05)	273.72 (9.42)	0.079 (0.01)	1.48 (0.53)
Eyera + 3% soy	1.47 (0.04)	256.94 (5.13)	0.081 (0.01)	1.34 (0.67)
Eyera + 6% soy	1.40 (0.14)	239.66 (3.07)	0.085 (0.01)	1.82 (0.25)
LSD (0.05)	0.17	17.00	0.008	0.46

Values in parenthesis ( ) are the standard deviation of the mean

expansion of extrudates. The expansion recorded in this study seems to be higher due to starch content for the varieties tested in this study compared to those in literature. Other factors that could have contributed to the difference include formulation and extrusion conditions such as initial moisture content of the feed, the barrel and die temperatures, screw speed and feed rate.

Addition of defatted soy-flour at 6% decreased lateral expansion and increased bulk density in Seso1 Seso3 and Eyera ($P<0.05$). A similar trend of decreasing expansion was reported in sorghum extrudates containing increasing amounts of cowpea flour (Pelembe *et al.,* 2002). Chinnaswamy and Hanna (1988) noted that the expanded volume of cereal flour decreases with increasing amounts of protein and lipid; but increases with starch content. Although addition of soy-flour is nutritionally desirable since it increases the protein content of the extrudates, its reduction of the expansion is detrimental for products like puffed snacks that are sold by volume.

The hardness recorded for extrudates in this work (Table 1) suggests that the extrudates were in the lower intermediate and brittle range, which is desirable for puffed snack food. Both sorghum variety and addition of soy-flour had no significant effect on hardness of the extrudates. Hardness of a product is closely correlated with bite forces during mastication of any food (Mioche and Payron, 1995). The lower intermediate and brittle range suggests that the consumer would use relatively low force to crunch and bite the extrudates. This implies high desirability for puffed sorghum snack foods.

Table 2 presents the WAI and WSI of sorghums extruded with and without soy-flour. The extrudates had WAI and WSI 2-3 times higher than the control flour, implying that the extrudates would easily absorb moisture and get solublised. With respect to storage, these results suggest that the extrudates would have to be packed and stored in air tight packages to avoid moisture absorption to maintain the brittle texture. Anderson *et al*. (1969) reported a similar increase in WAI and WSI for sorghum extrudates obtained from varieties of Texas-Oklahoma areas in The USA. The higher WAI and WSI of the extrudates than the control flour was possibly due to the dextrinisation and depolymerisation of starch at extrustion temperatures, reducing molecular weight of amylose and amylopectin chains (Anderson *et al*., 1969; Gujska and Khan, 1990; Balandran-Quintana *et al*., 1998). Soy-flour reduced WAI in Seso1 and Eyera varieties, suggesting a soy-flour-sorghum variety interaction, which can be taken advantage of should a processor require a product with lower WAI.

TABLE 2. Water absorption index and water solubility index of extrudates from four commonly grown sorghum varieties obtained from the germplasm in Uganda

Sample	Water absorption index (g g^{-1})	Water solubility index (%)
Seso1 CTRL	1.87 (0.06)	3.86 (0.29)
Seso1 + 0% soy	7.14 (0.17)	7.53 (0.85)
Seso1 + 3% soy	7.03 (0.19)	7.24 (0.53)
Seso1 + 6% soy	6.65 (0.16)	6.48 (0.07)
LSD (0.05)	0.36	0.73
Epuripur CTRL	2.03 (0.12)	4.02 (0.21)
Epuripur + 0% soy	7.16 (0.88)	11.91 (1.41)
Epuripur + 3% soy	7.90 (0.23)	11.03 (0.42)
Epuripur + 6% soy	7.42 (0.28)	12.23 (1.27)
LSD (0.05)	0.94	1.50
Seso3 CTRL	2.14 (0.16)	3.36 (0.22)
Seso3 + 0% soy	7.35 (0.33)	7.68 (0.89)
Seso3 + 3% soy	7.36 (0.08)	8.84 (0.60)
Seso3 + 6% soy	7.20 (0.27)	9.10 (0.68)
LSD (0.05)	0.37	1.45
Eyera CTRL	2.28 (0.17)	5.11 (0.34)
Eyera + 0% soy	7.87 (0.34)	11.75 (0.95)
Eyera + 3% soy	6.57 (0.36)	11.26 (0.63)
Eyera + 6% soy	6.39 (0.34)	13.70 (2.20)
LSD (0.05)	1.50	2.51

Values in parenthesis ( ) are the standard deviation of the mean

Proximate composition of extrudates. Table 3 shows the proximate composition of sorghum extrudates, with and without soy-flour. Extrusion resulted in decreased moisture, fat and fiber contents of the extrudates. The decrease in

TABLE 3. Proximate composition of the extrudates and control flour samples of sorghum varieties obtained from Uganda

Sample	Moisture (%)	Crude fat (%)	Dietary fiber (%)	Ash (%)	Protein (%)
Seso1 CTRL	10.88 (0.29)	3.75 (0.03)	5.18 (0.01)	1.51 (0.06)	8.79 (0.69)
Seso1 + 0% soy	4.36 (0.11)	1.14 (0.09)	2.78 (0.37)	1.86 (0.06)	10.47 (0.81)
Seso1 + 3% soy	4.56 (0.34)	1.25 (0.19)	2.44 (0.04)	2.00 (0.13)	13.50 (0.04)
Seso1 + 6% soy	4.51 (1.47)	1.41 (0.17)	2.85 (1.12)	2.23 (0.19)	18.04 (0.42)
LSD (0.05)	1.20	0.96	1.10	0.34	1.60
Epuripur CTRL	13.90 (0.38)	3.80 (0.11)	8.16 (0.37)	1.68 (0.12)	11.11 (0.06)
Epuripur + 0% soy	5.36 (0.71)	1.39 (0.06)	2.43 (0.40)	2.66 (0.50)	13.40 (0.11)
Epuripur + 3% soy	5.13 (0.46)	1.42 (0.11)	2.31 (0.17)	2.66 (0.05)	16.67 (1.12)
Epuripur + 6% soy	5.38 (0.40)	1.25 (0.03)	2.88 (0.38)	2.26 (0.02)	19.57 (0.20)
LSD (0.05)	1.36	0.50	1.20	0.89	2.25
Seso3 CTRL	10.66 (0.01)	3.30 (0.21)	9.30 (0.07)	1.88 (0.10)	9.54 (0.40)
Seso3 + 0% soy	5.49 (0.36)	0.75 (0.01)	6.00 (0.30)	1.67 (0.12)	12.57 (0.10)
Seso3 + 3% soy	5.20 (0.31)	0.79 (0.35)	5.75 (0.48)	1.91 (0.05)	15.68 (1.84)
Seso3 + 6% soy	4.91 (1.00)	1.21 (0.52)	5.45 (0.74)	1.97 (0.15)	19.18 (1.20)
LSD (0.05)	1.07	0.58	0.92	0.73	2.94
Eyera CTRL	10.22 (0.43)	3.17 (0.15)	8.83 (0.83)	1.81 (0.29)	8.98 (0.01)
Eyera + 0% soy	5.17 (0.43)	0.83 (0.02)	6.38 (0.05)	1.93 (0.12)	10.49 (0.45)
Eyera + 3% soy	4.72 (1.23)	0.91 (0.03)	6.33 (0.75)	2.17 (0.11)	12.60 (0.44)
Eyera + 6% soy	5.52 (1.54)	0.80 (0.13)	7.24 (0.57)	2.40 (0.41)	18.29 (1.65)
LSD 0.05	2.30	0.94	1.13	0.95	1.10

Values in parenthesis ( ) are the standard deviation of the mean

moisture content is expected since the extrudates are released from a high pressure and temperature to a low pressure and temperature zone resulting in product expansion and easy evaporation of moisture. The composition of the sorghum samples was in agreement with that of other researchers (Dendy, 1995), suggesting that while there may be soil and climatic variations, the nutrient composition of the sorghums remained fairly the same.

The reduction in fat and fibre contents could be attributed to high shear, pressure and temperature conditions of extrusion resulting in breakdown of fibre and lipid polymeraisation, and interaction with other nutrient components (Belitz *et al*., 2009). Addition of soy-flour increased the protein content of extrudates; but had no effect on other nutrient components. This was expected since soy-flour contained more protein than the sorghum. Pelembe *et al*. (2002) reported similar increases in protein content of sorghum composite flours with increasing cowpea content. It is, thus, possible to increase the protein content of extruded cereal products to meet specific consumer nutrient needs. However, as stated earlier increasing protein content may have undesirable effects on other physic-chemical properties of extrudates, especially products that are sold by volume.

CONCLUSION

Extrusion provides the basis for use of sorghum in value added food products hitherto dominated by other cereals. Interactions between variety, soy-flour content and extrusion occur for some properties suggesting that different product formulations may behave differently when

subjected to extrusion. Thus, use of sorghums in extruded products would require testing the extrusion performance of different formulations so as to achieve the desired nutritional and product quality properties.

ACKNOWLEDGEMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 837 - 846 ISSN 1021-9730/2014 $4.00

ANTIOXIDANT, ANTIMICROBIAL AND SYNERGISTIC ACTIVITIES OF TEA POLYPHENOLS

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ABSTRACT

Microbial resistance to antibiotics has become an increasing global problem and there is a need to find out novel potent antimicrobial agents with alternative modes of action as accessories to antibiotic therapy. This study investigated the antioxidant, antimicrobial and synergistic properties of tea polyphenols. The tea germplasm from Kenya, China and Japan that are grown in Kenya were characterised for their biochemical profiles. The total phenolic content, theaflavins and thearubigins content of different tea products used in this study were determined spectrophotometrically according to Folin-Ciocalteus and flavognost methods, respectively. The individual catechin contents were characterised by high performance liquid chromatography (HPLC) and identified according to their HPLC retention times, elution order and comparison with authentic standards. The antioxidant activity of tea polyphenols was determined spectrophotometrically on its ability to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical. The agar disc diffusion method was used to screen for antimicrobial and synergistic activities of the tea liquors. Black, green, purple coloured leaf and white (silvery tips) tea products differed significantly in the levels of total polyphenols, total catechins, catechins fractions, theaflavins and thearubigins ($P<0.05$). Green, purple coloured leaf (aerated) and black tea from terminal buds and white tea products analysed in this study exhibited slightly higher antioxidant activity than black tea. The different types of tea products exhibited significant influence on the inhibition zone diameters against bacteria and fungi exposed to the tea extracts. Methicillin and penicillinase resistant *S. aureus* ATCC 25923, *C. albicans* ATCC 90028 and a clinical isolate of *C. neoformans* were more susceptible to all tea extracts than *E. coli* and *S. typhi*. There was synergism between most tea extracts and penicillin G against methicillin and penicillinase resistant *S. aureus* ATTC 25923.

Key Words: Catechins, methicillin, penicillinase, theaflavins

RÉSUMÉ

La résistance microbienne aux antibiotiques est devenue un problème épineux au niveau global et il est nécessaire d'identifier d'autres agents antimicrobiens efficaces avec des modes alternatifs d'action pour appuyer la thérapie antibiotique. Cette étude était menée sur les antioxydants et les propriétés antimicrobiennes et synergétiques des polyphénols du thé. Les germoplasmes de thé en provenance du Kenya, de la Chine et du Japon cultivés au Kenya ont fait l'objet d'une caractérisation de leurs profiles biochimiques. La teneur phénolique totale ainsi que les théaflavines et les théarubigines dans les différents produits de thé utilisés dans cette étude étaient déterminée par spectrophotométrie respectivement sur base des méthodes dites de Folin-Ciocalteus et flavognost. Les teneurs individuelles en catéchine étaient caractérisées par chromatographie liquide à haute performance (HPLC) et identifiées sur base de leurs temps de rétention de HPLC, de l'ordre d'élution en comparaison avec les

standards normaux. L'activité antioxydante des polyphénols de thé était déterminée par spectrophotométrie sur base de sa capacité à capter le radical 2,2-diphenyl-1-picrylhydrazyl (DPPH). La méthode de diffusion sur disque d'agar était utilisée pour tester les activités microbiennes et synergétiques des extraits du thé. Les feuilles de thé de couleurs noir, verte, pourpre et les extraits du thé blanc différaient significativement du point de vue niveaux de polyphénols totaux, des catéchines totales, des fractions de catéchines, des théaflavines et des théarubigines ($P<0.05$). Les feuilles de couleurs verte et pourpre ainsi que les thés noirs issues des bourgeons terminaux et extraits du thé blanc analysés dans cette étude ont montré une activité antioxydante légèrement supérieure à celle du thé noir. Les différents types d'extraits de thé ont montré une influence significative sur les diamètres des zones de contamination une fois exposés à des bactéries ou des champignons. *Staphylococus aureus* ATCC 25923, *C. albicans* ATCC 90028 et un isolant clinique de *C. Neoformans* résistants à la méthicilline et à la pénicillinase étaient les plus susceptibles à tous les extraits de thé en comparaison avec *E. coli* et *S. typhi*. Il y avait un synergisme entre la plupart d'extraits de thé et la pénicilline G contre *S. aureus* ATTC 25923 résistant à la méthicilline et à la pénicillinase.

Mots Clés: Catechines, méthicilline, pénicillinase, théaflavines

INTRODUCTION

Black tea (*Camellia sinensis*) which is a major source of theaflavins and thearubigins has been shown to have antibacterial properties both *in vivo* and *in vitro* (Bandyopadhyayet *et al.,* 2005). Theaflavin-3, 3'-digillate has antifungal activity against *Candida albicans* and *Cryptococcus neoformans* in a dose and contact time-dependent manner (Okubo *et al.,* 1991). There is also growing evidence that indicates that catechin components of green tea have antibacterial activity (Yam *et al.,* 1997).

Apart from its antimicrobial properties, green tea is known to exhibit synergistic activity with antibiotics against some enteric pathogens (Tiwari *et al.,* 2005). Tea polyphenols synergistically enhance the antimicrobial activity of antimicrobial agents used against methicillin resistant *Staphylococcus aureus* (Hu *et al.,* 2002).

Despite the valuable data generated so far from green tea, little information has been generated from black tea. The objective of this study was to investigate the relationship between biochemical profiles of different types of tea products processed from different tea germplasm grown in Kenya and antioxidant, antimicrobial and synergistic properties on bacteria and fungi resistant to antibiotics.

MATERIALS AND METHODS

Test microorganisms and tea samples. The test bacteria of American Type Culture Collection (ATCC) were sourced from the Kenya Medical Research Institute Centre for Respiratory Research (KEMRI-CRDR) at Nairobi and included methicillin and penicillinase resistant *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, *Candida albicans* ATCC 90028 and clinical isolates of *Salmonella typhi* and *Cryptococcus neoformans.*

The tea samples were sourced from the Tea Research Foundation of Kenya (TRFK), Timbilil Estate, Kericho (latitude 0^{O} 22'S, longitude 35^{O} 21'E, altitude 2180 masl) and processed at the TRFK miniature factory as described by Karori *et al.* (2007).

Estimation of total polyphenols and biochemical profiling of the tea extracts. The Folin-Ciocalteu phenol reagent method was used to determine total polyphenols in the tea extracts, according to ISO (BS ISO 14502-1: 2005(E)). A modified high performance liquid chromatography procedure was used to assay for the tea catechins (Zuo *et al.,* 2002).

Analysis of total theaflavins and thearubigins content. Black, green, purple and white teas were also assayed for total theaflavins (TF) using the flavognost method of Hilton and Palmer-Jones (1973).

Total thearubigins (TRs) were determined in the tea samples using the method of Roberts and Smith (1961).

Antioxidant activity of tea and freeze drying of tea liquors. The stable 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) was used for

determination of free radical scavenging of tea extracts using a modified method of Brand-Williams *et al.* (1995). Tea liquors derived from the processed tea samples were freeze dried according to the method described by Turkmen *et al.* (2009).

Antimicrobial assays. The agar disc diffusion method was used to screen for antimicrobial activities of the tea liquors, according to the National Committee of Clinical and Laboratory Standards (NCLSI, 2012).

Statistical analysis. Data were subjected to analysis of variance using SAS software Version 9.1. The Least Significant Difference (LSD) procedure was used to separate differences among the treatment means.

RESULTS

Total tea polyphenols. Black, green and white tea products processed from the test germplasm differed significantly (P<0.05) in total polyphenols (Table 1). Green teas processed from Kenyan germplasm were higher in total polyphenols, with levels ranging from 20.2 to 24.4% compared to green teas processed from the Chinese and the Japanese germplasm, which ranged from 16.7 to 18.5%, respectively. Cultivar TRFK 6/8, a high black tea quality Kenyan clone exhibited the highest total polyphenol content of 24.4 and 19.3% in green and black processed teas, respectively. The purple leaf coloured cultivars, TRFK 306/3, TRFK 73/1 and TRFK K-purple, produced non-aerated teas that were not significantly different (P>0.05) in total polyphenol content. Black teas, processed only from the terminal leaf buds were significantly (P<0.05) higher in total polyphenol content than black teas processed from the youngest two leaves and bud. White teas processed from plucked shoots of the two cultivars AHP S15/10 and TRFK 301/5 were not significantly (P>0.05) different in total polyphenol content from conventional green teas.

Total catechin content. The total catechins data of green, black, white tea products processed from 11 tea cultivars are presented in Table 1. The data revealed that the tea cultivars that produced the different tea products significantly differed in total catechin content. There were significant differences (P<0.05) in total catechin levels between processed black teas, green teas, white and purple leaf coloured teas. Non-aerated (green) teas contained significantly higher amounts of total catechins than aerated (black) teas. Green teas from Kenyan cultivars were significantly higher in total catechin content than those from Chinese and Japanese cultivars. White teas processed from the Kenyan cultivars, TRFK 301/5 and AHP S15/10, had the highest levels of total catechins at 22.8 and 22.3%, respectively. Among the Kenyan purple coloured leaf tea cultivars, the highest catechin content was recorded in the non-aerated tea products from clones TRFK 73/1 with 16.1% and TRFK 306/3 with 11.9%.

Total theaflavins (TFs) and total thearubigins (TRs) levels. There was no significant difference (P<0.05) in total TRs levels for the Kenyan, Chinese and Japanese green teas. This was also exhibited by Kenyan black tea and black tea buds. Black tea had the highest levels of total TFs and total TRs, which ranged from 1.1 to 1.7% and 14.6 to 17.2%, respectively (Table 1). Black tea from the popular high black tea quality clone TRFK 6/8 had the highest TFs and the lowest content of TRs among the black tea products. White tea had the lowest TFs compared to green, black and aerated and unaerated teas from the purple coloured leaf clones. TRs were particularly low in white teas processed from cultivars AHP S15/10 and TRFK 301/5.

Antioxidant activity. There was no significant difference (P>0.05) in the antioxidant activity among the different types of tea products (Table 1). However, antioxidant activity was marginally higher among the green teas processed from Kenyan germplasm, as well as the white teas from Kenyan clones. There was no significant difference in the antioxidant capacity between Kenyan black teas and green teas processed from cultivars Hanlu and Yabukita, from China and Japan, respectively. Purple coloured leaf (unaerated) manufactured from clone TRFK 306/3, which is rich in anthocyanins and clone TRFK

TABLE 1. Percent total polyphenols, total theaflavins, total thearubigins and antioxidant activity of processed tea products from different tea germplasm grown in same environment in Kenya

Tea samples	TP%	TC%	TFs%	TRs%	AA%
Black tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	18.8	5.22	1.1	15.5	72.7
BBK 35	17.5	4.95	1.3	16.2	73.4
TRFK 303/577	17.4	5.41	1.5	15.4	72.4
TRFK 6/8	19.3	6.36	1.7	14.6	73.3
Purple leaf coloured cultivars					
TRFK K-Purple	16.2	3.22	1.3	17.2	72.3
TRFK 306/3	18.7	6.18	1.3	15.7	73.7
TRFK 73/1	16.3	5.22	1.5	15.6	73.3
Mean	17.7	5.22	1.4	17.9	73.0
Black tea products from buds of Kenyan germplasm					
AHP S15/10	17.2	9.06	1.4	13.1	73.8
TRFK 301/5	19.0	10.84	1.1	10.4	73.7
Mean	18.1	9.95	1.4	11.7	73.8
Green tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	20.2	17.46	0.4	7.7	73.5
BBK 35	20.9	19.65	0.4	6.8	73.3
TRFK 303/577	22.8	19.96	0.4	8.7	74.0
TRFK 6/8	24.4	17.63	0.5	9.3	74.2
Purple leaf coloured cultivars					
TRFK K-Purple	19.7	12.34	0.6	10.2	74.1
TRFK 306/3	22.2	11.92	0.4	11.2	74.5
TRFK 73/1	21.5	16.10	0.4	8.8	73.9
Mean	21.7	16.44	0.5	8.9	73.9
Green tea products from germplasm of other sources					
Hanlu st. 830 (China)	18.5	13.98	0.3	9.6	73.3
Yabukita st. 536 (Japan)	16.7	10.68	0.2	9.8	72.8
Mean	17.6	12.33	0.3	9.7	73.0
White tea products from Kenyan germplasm					
AHP S15/10	22.0	22.29	0.1	0.8	74.1
TRFK 301/5	25.2	22.79	0.1	0.9	74.1
C V %	3.8	16.16	17.6	6.6	0.9
LSD (P<0.05)	0.7	0.76	0.5	0.8	0.5

TP = total polyphenols; TC = totalcatechins; TFs = total theaflavins; TRs = total thearubigins

6/8 processed as green tea had a high DPPH radical scavenging activity, with a mean value of 74.5 and 74.2%, respectively; followed by white teas from clones AHP S15/10 and TRFK 301/5 with 74.3 and 74.1%, respectively.

Antimicrobial activity. Methicillin and penicillinase resistant *S. aureus* ATCC 25923 was susceptible to the tea extracts (Table 2). Black teas from clones TRFK 6/8, AHP S15/10 and BBK 35 had no significant difference in inhibitory activity with the green teas processed from leaf of Kenyan cultivars. There was also no significant difference in inhibitory activity between the Kenyan black tea products with tea processed as black tea products from the terminal buds and some of the Kenyan, Chinese and Japanese green teas studied.

Escherichia coli ATCC 25922 was inhibited weakly by black tea and black tea from the buds (Table 2). There was no significant difference (P>0.05) in inhibitory effect of black tea and black tea buds. This was also exhibited by green and purple tea extracts processed from Kenyan tea cultivars, Chinese and Japanese green tea extracts. White tea extracts processed from clone TRFK 301/5 exhibited the highest inhibitory effect with a zone of inhibition.

The clinical isolate of *S. typhi* was inhibited by the majority of tea extracts (Table 2). Black tea extracts did not differ significantly (P>0.05) in the inhibitory effects with green tea extracts. Processed Kenyan black tea buds had no inhibitory effects while white tea extracts processed from clones AHP S15/10 and TRFK 301/5 had the highest inhibitory effects compared to all the teas studied.

There was no significant difference (P>0.05) in the antifungal activity of Kenyan black tea and purple coloured leaf (aerated) tea extracts with the Chinese and Japanese green tea extracts against *C. albicans* ATCC 90028 (Fig. 1). Unaerated tea from purple leaf coloured and white tea extracts did not differ significantly in antifungal activity with black tea extracts against *C. albicans* ATCC 90028. Generally, different tea extracts had antifungal activity against *C. albicans* ATCC 90028.

A clinical isolate of *C. neoformans* was inhibited by all the different types of tea extracts (Fig. 1). White tea extracts from the Kenyan tea cultivars exhibited the highest antifungal activity against *C. neoformans* compared with black tea, black tea buds, green tea and aerated and unaerated tea extracts from the purple leaf

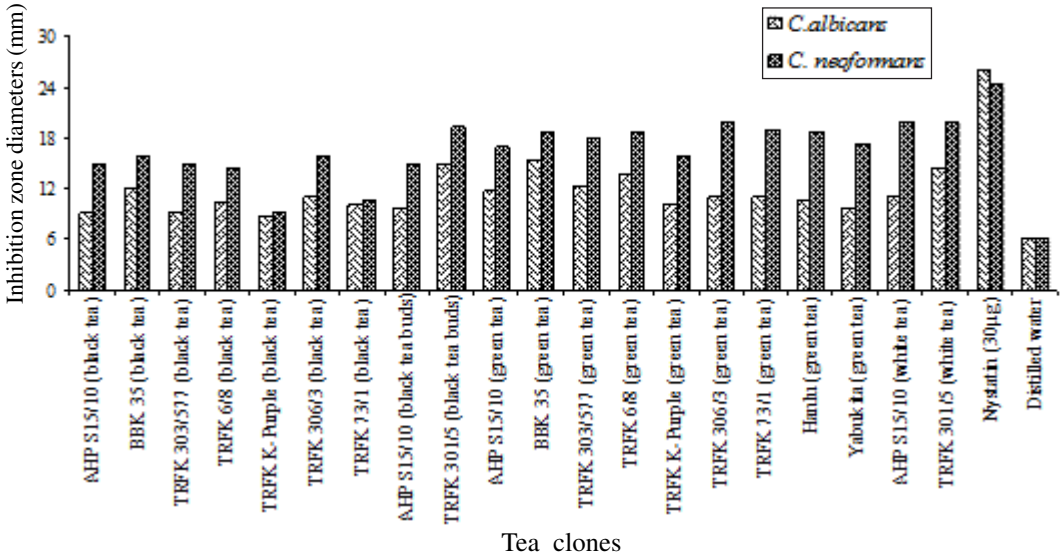

Figure 1. Variation in antifungal activity among different types of Kenya tea extracts.

TABLE 2. Antibacterial, synergistic, antagonistic and additive effects of tea liquors and antibiotics against methicillin and penicillinase resistant *S. aureus* ATCC 25923, *E. coli* ATCC 25922 and a clinical isolate *S. typhi* determined by zones of inhibition (mm)

Tea sample	Tea alone (1 mg ml^{-1})	Gentamicin + tea	Tetracycline + tea	Penicillin G + tea	Ampicillin + tea
Black tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	16.0[6.0](8.0)	12.3[6.0](7.0)	12.0[6.0](7.0)	18.7[6.0](11.3)	12.0[6.0](8.3)
BBK 35	16.0[6.0](7.0)	12.7[6.0](6.0)	13.0[6.0](7.7)	19.3[6.0](7.0)	12.7[6.0](7.0)
TRFK 303/577	14.0[6.0](9.3)	8.0[6.0](8.3)	8.0[7.0](6.3)	12.3[7.3](8.3)	12.0[7.3](8.3)
TRFK 6/8	16.3[6.0](7.7)	14.3[6.0](7.7)	16.0[6.0](8.3)	18.0[6.0](9.0)	8.7[6.0](8.0)
Purple leaf coloured cultivars					
TRFK K-Purple	13.7[6.0](6.0)	7.3[6.0](6.0)	8.0[6.0](6.0)	17.3[6.0](6.0)	9.0[6.0](6.0)
TRFK 306/3	14.0[6.0](6.0)	14.0[6.0](6.0)	14.7[6.0](6.0)	16.3[6.0](6.0)	11.3[6.0](6.0)
TRFK 73/1	14.3[7.0](6.0)	11.0[6.0](6.0)	10.0[6.0](6.0)	18.0[6.0](6.0)	8.0[6.0](6.0)
Mean	14.9[6.2](7.1)	11.4[6.0](6.7)	11.7[6.1](6.8)	17.2[6.2](7.7)	10.5[6.2](7.1)
Black tea products from buds of Kenyan germplasm					
AHP S15/10	13.7[6.0](6.0)	12.7[6.0](7.0)	12.3[6.0](6.0)	18.0[6.0](6.0)	11.3[6.0](6.0)
TRFK 301/5	14.3[7.3](6.0)	11.3[6.0](6.0)	14.0[7.0](6.0)	18.7[10.0](6.0)	9.7[8.3](6.0)
Mean	14.0[6.7](6.0)	12.0[6.0](6.5)	13.2[6.5](6.0)	18.3[8.0](6.0)	10.5[7.2](6.0)
Green tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	16.7[7.0](6.0)	9.3[7.0](6.0)	14.0[7.0](6.0)	18.0[8.3](6.0)	11.0[6.0](6.0)
BBK 35	22.0[8.7](8.0)	11.7[7.3](6.0)	14.0[7.0](7.0)	16.7[8.3](11.3)	9.3[7.0](7.0)
TRFK 303/577	19.0[8.0](7.0)	10.3[7.0](6.0)	12.0[8.0](7.0)	18.7[7.3](10.0)	7.7[7.3](9.0)
TRFK 6/8	21.0[8.0](7.3)	8.0[6.0](6.0)	6.0[7.0](7.0)	21.0[6.0](11.0)	8.0[8.3](10.3)

TABLE 2. Contd.

Tea sample	Tea alone (1 mg ml^{-1})	Gentamicin + tea	Tetracycline + tea	Penicillin G + tea	Ampicillin + tea
Purple leaf coloured cultivars					
TRFK K-Purple	18.0[7.7](6.0)	12.7[6.0](6.0)	8.0[6.0](6.0)	23.0[7.3](6.0)	11.0[6.0](6.0)
TRFK 306/3	17.0[7.0](7.7)	13.3[7.0](6.0)	12.0[7.0](7.0)	17.0[7.3](8.3)	11.0[7.3](7.3)
TRFK 73/1	13.3[7.0](7.0)	13.0[6.0](7.0)	13.7[7.0](7.7)	18.0[7.7](10.3)	11.7[7.0](12.3)
Mean	18.1[7.6](7.0)	11.2[6.6](6.1)	11.4[7.0](6.8)	18.9[7.5](9.0)	9.9[7.0](8.3)
Green tea products from germplasm of other sources					
Hanlu st. 831 (China)	14.7[7.0](7.3)	16.0[6.0](8.3)	17.0[7.0](6.0)	22.0[7.0](7.3)	13.0[7.7](7.3)
Yabukita st. 536 (Japan)	16.0[7.0](8.0)	13.0[7.0](7.0)	12.7[7.0](7.0)	19.0[7.3](8.3)	12.0[7.7](7.0)
Mean	15.3[7.0](7.7)	14.5[6.5](7.7)	14.8[7.0](6.5)	20.5[7.2](7.8)	12.5[7.7](7.2)
White tea products from Kenyan germplasm					
AHP S15/10	18.0[7.0](25.0)	10.7[6.0](6.0)	15.0[7.3](7.3)	20.3[8.0](19.0)	9.3[7.0](8.3)
TRFK 301/5	22.0[11.0](12.3)	11.3[6.3](7.0)	13.7[7.0](7.0)	17.0[7.0](16.0)	9.0[7.0](8.0)
Mean	20.0[9.0](18.7)	11.0[6.2](6.5)	14.3[7.2](7.2)	18.7[7.5](17.5)	9.2[7.0](8.2)
Distilled water	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)
Chloramphenicol (0.60µg/ml)	32.0[20](23)				
Antibiotics alone (µg ml-1)					
Gentamicin 1.96		18.0[8.0](8.0)			
Tetracycline 1.96			19.0[9.0](9.0)		
Penicillin G 1.96 [250] (125)				14.0[8.0](10.0)	
Ampicillin 1.96 [62.5] (15.64)					18.0[8.0](7.0)

CV% = 2.24 [3.27] (3.72); LSD (P<0.05) = 0.24 [0.16] (0.22); Parentheses [x] = *E. coli*; brackets (x) = *S. typhi*

coloured clone. Black tea extracts gave the lowest inhibitory activity.

Synergistic effects of tea liquors and antibiotics

Methicillin and penicillinase resistant *Staphylococcus aureus* ATCC 25923. There was a marked increase in the inhibition zone diameters in tea extracts combined with penicillin G against methicillin and penicillinase resistant *S. aureus* ATCC 25923, except for black tea processed from clones TRFK 303/577 and TRFK 306/3 (Table 2).

***Escherichia coli* ATCC 25922.** A combination of black, green (Kenyan, Chinese or Japanese) tea extracts with gentamicin and tetracycline did not significantly differ ($P>0.05$) with tea extracts, gentamicin or tetracycline alone (Table 2). Synergism was only observed in black tea processed from the buds of clone TRFK 301/5 with penicillin G. Similarly, there was no significant difference in combinations of tea extracts with penicillin G and ampicillin.

Clinical isolate of *S. typhi*. There was a significant difference in the inhibitory effects of black tea extracts combined with gentamicin, compared with black tea extracts alone (Table 2). Thus, black tea extracts did not synergise with gentamicin. This was also exhibited by black tea buds and green tea from the Kenyan, Chinese and Japanese cultivars, except white tea. Black tea processed from terminal buds had no inhibitory effects even in combination with tetracycline, penicillin G and ampicillin. Green teas also did not differ significantly ($P>0.05$) when the tea extracts were combined with tetracycline compared to tea extracts alone.

DISCUSSION

Kenyan teas were rich in total polyphenols comparable with the teas processed from Chinese and Japanese germplasm. This is in agreement with results from previously reported studies by Wachira and Kamunya (2005) and Karori *et al.* (2007). The general trend among the samples assayed showed that non-aerated tea had higher total polyphenol content than aerated tea from the same sample.

The variation in the polyphenolic composition of the different tea products is ascribed to the different process methods applied particularly the leaf maceration and auto-oxidation steps during manufacturing. During black tea manufacture, the gallocatechins are first oxidised and dimerised to theaflavins and thearubigins because of their high oxidation potential and high concentration in leaves (Mahanta and Hemanta, 1992).

Several other factors have been discovered to influence the polyphenol content of a tea product. These include genotype, geographical origin, soil composition, harvesting time, post-harvest treatment and physical structure of the leaves (Lin *et al.,* 2003).

The total catechins content in white and green tea products were significantly higher than those of aerated tea products from the same clones. The findings of this study corroborated with those of Karori *et al.* (2007), who found that green teas had significantly higher catechin content than black teas. The enzymatic oxidation of catechins located in the vacuole is as a result of polymerisation of flavan-3-ol monomers to form TFs and TRs, which are compounds that have an influence on the quality of black tea (Owuor and Obanda, 2001). In this study, aerated tea products had lower amounts of individual catechins due to the formation of TFs and TRs.

There was high radical scavenging activity on DPPH by both the black and green teas. The antioxidant activity of the ordinary green teas is mainly attributed to the presence of high levels of bioactive catechins that have the ability to donate hydrogen ions to stabilise the free radicals. The high antioxidative effect of polyphenols in both white and green Kenyan teas is due to the presence of phenolic hydroxyl groups in their structures that make them potent free radical scavengers (Amie *et al.,* 2003). This explains why radical scavenging was high in the gallocatechins, including epigallocatechins gallate and epigallocatechin (Zhu *et al.,* 2001).

The results on the antibacterial and antifungal activity indicated that the green tea products, as well as tea from the purple leaf coloured (unaerated) cultivar, and white tea products processed from Kenyan tea cultivars, expressed the highest antimicrobial activities; while black

tea and black tea processed from terminal tea buds, had lower inhibitory activity. This may indicate that the presence of the hydroxyl moieties at 3', 4', and 5' on the B ring in the catechin and epicatechin molecules is a major factor that contributed to inhibitory activity of both green, unaerated tea from the purple leaf coloured clone and white tea. This is in agreement with a study reported by Nance *et al.* (2006) that antimicrobial activity of catechins is predominantly as a result of the gallic moiety and hydroxyl group member. The highest antimicrobial activity also corresponded to the highest total polyphenols content and to antioxidant activity.

The findings of this study also indicate that the antimicrobial effects of assayed tea extracts differed depending on the concentration and type of the extract; from black, green, purple leaf coloured and white teas and also the type of test organism; bacteria or fungi. The conclusion by Taguri *et al.* (2006) that antimicrobial potency of polyphenols is dependent upon bacterial species, is consistent with the findings of this study, which showed that, while the tea extract was active against the Gram-positive bacteria, methicillin and penicillinase resistant *S. aureus* ATCC 25923, it did not affect the activity of *E. coli* ATCC 25922 and the clinical isolate of *S. typhi*.

The antibacterial results of this study showed a marked increase in the inhibition zone diameters on combination of tea extract with penicillin G. This is in agreement with results of other researchers (Zhao *et al.,* 2001; Hu *et al.,* 2002) who reported enhanced effect of Japanese tea on inhibitory activities with β-lactams antibiotics against methicillin resistant *S. aureus* ATCC 25923. Synergistic inhibition by tea extracts and the antibiotics could be attributed to the presence of dual binding sites on the bacterial surface for antibiotic and tea extract (Tiwari *et al.,* 2005).

The tea extracts and penicillin G synergistically inhibited the growth of methicillin and penicillinase resistant *S. aureus* ATCC 25923 possibly because they attack the same site which is the peptidoglycan on the cell wall (Zhao *et al.,* 2001). The tea extracts-induced damage of the bacterial cell wall and the possible interference with its biosynthesis through direct binding with peptidoglycan may be the major reasons for the synergism against methicillin resistant *S. aureus* ATCC 25923.

CONCLUSION

Green and white Kenyan tea products are rich in catechins while black tea products are rich in TFs and TRs. Despite the above differences, the black tea products are potent in their *in vitro* antioxidant properties. Therefore, it is concluded that teas are a great source of antioxidants. Tea extracts can be used in management of bacterial and fungal infections caused by methicillin and penicillinase resistant *S. aureus* ATCC 25923, *C. albicans* and *C. noeformans*, respectively. The concomitant administration of tea extracts and antibiotics may not impair antibacterial activity of penicillin G.

ACKNOWLEDGEMENT

The Tea Research Foundation of Kenya (TRFK) funded this work. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 847 - 858 ISSN 1021-9730/2014 $4.00

GEOGRAPHIC INFORMATION SYSTEMS FOR ASSESSMENT OF CLIMATE CHANGE EFFECTS ON TEFF IN ETHIOPIA

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ABSTRACT

The value of Geographic Information Systems (GIS) for assessing climate change impacts on crop productivity cannot be over-emphasised. This study evaluated a GIS based methodology for teff (Eragrostis *tef*) production in Ethiopia. We examined the spatial implications of climate change on areas suitable for teff, and estimated the effects of altered environments on teff's productivity. There was a non-linear relationship between suitability indices, the output of spatial analysis and teff yield data collected from diverse ecological zones. This served as the basis for country-wide crop yield analysis for both current and future climate scenarios. To complement this effort, a socio-economic survey was carried with a thrust of understanding the agricultural activities in the study area. With the current climatic conditions, 87.7% of Ethiopia is suitable for teff. On the other hand, approximately 67.7% of Ethiopia is expected to be suitable for teff production by 2050. Suitability index (SI) and the actual crop yield data showed a strong positive correlation (r = 74%). There is a predicted severe drop in teff yield (-0.46 t ha^{-1}) by the year 2050. Based on the current area under teff in Ethiopia, this equals an overall reduction in national production of about 1,190,784.12 t, equivalent to a loss of US$ 651 million to farmers. The results indicate that crop yield varied significantly as a function of climatic variation and that the model is applicable in assessing the impact of climate change on crop productivity at various levels taking into consideration spatial variability of climate.

Key Words: Climate change, suitability index, teff

RÉSUMÉ

On ne saurait trop insister sur la valeur des Systèmes d'Information Géographiques (SIG) pour l'évaluation d'impacts des changements climatiques sur les rendements des cultures. Cette étude a été menée pour évaluer en utilisant le SIG la production du teff (Eragrostis *tef*) en Ethiopie. L'investigation a porté sur les implications spatiales du changement climatique sur les zones favorables à la culture du teff en Ethiopie et l'estimation des effets des changements environementaux sur la productivité du teff. L'étude a révélé une relation non linéaire entre les indices de convenance et les résultats de l'analyse spatiale et des rendements de la culture de teff dans différentes zones agro-écologiques. Ceci a servi de base à l'analyse des rendements des cultures dans tout le pays pour le présent et les futurs scenarios de changement climatique. En complément à cet effort, une enquête socioéconomique était conduite pour comprendre le déroulement des activités agricoles dans la zone d'étude. Sous les conditions climatiques actuelles, 87.7% de l'Ethiopie convient pour le teff. D'autre part, il est prédit qu'environ 67.7% de l'Ethiopie seront encore faborable à la culture du teff en 2050. L'indice de convenance et les données de rendements actuels ont montré une forte corrélation positive (r = 74%). Par ailleurs, une diminution sensible de rendement du teff (-0.46 t ha^{-1}) a été prédite pour l'an 2050. Sur base de la superficie actuelle sous culture de teff en Ethiopie, cette chute de rendement correspond à une réduction de la production nationale d'environ 1.190.784,12 t équivalents à une perte de 651 millions de dollars pour les producteurs. Ces résultats indiquent que les rendements des cultures ont varié significativement en fonction de la variation climatique et que

le modèle est applicable dans le cas de l'évaluation de l'impact du changement climatique sur la productivité des cultures à différents niveaux considérant les variabilités spatiales du climat.

Mots Clés: Changement climatique, indice de convenance, teff

INTRODUCTION

The impact of rising temperatures on rainfall distribution patterns in Africa remains far less certain (IPCC, 2007). To date, it remains largely unclear what the likely extent of staple crop yield changes are and the impacts on local food security that could be anticipated given the expected changes in rainfall patterns and temperature. Several studies confirm that temperatures will rise and rainfall will increase in some places, while in others, rainfall will decrease (Rosenzweig *et al.,* 1993). However, there is general agreement among scientists that food crops are sensitive to the changing climate. Climate models predict an acceleration of recent warming in Africa, with associated changes in rainfall and the frequency of extreme events. However, studies of climate change impacts on crops in Africa show conflicting results and uncertainties, mainly relating to the methods used (Jones and Thornton, 2003; Schlenker and Lobell, 2010; Lobell *et al.,* 2011; Kelbore, 2012; Müller, 2013). A recent study using data from long term maize trials in Africa, combined with daily weather data showed a nonlinear relationship between warming and yields. Each degree day spent above 30 ^{0}C reduced the final yield by 1% under optimal rain-fed conditions (Lobell *et al.,* 2011*)*.

Crop modelling requires detailed knowledge of many variables including climate, soil, land cover, crop requirements, water availability and on-farm management practices, which vary widely in space and time. The net effect of the variability of the factors is fluctuations and uncertainty in predicted agricultural output. In this study, we estimate suitable growing areas for teff using bioclimatic variables and teff yield data collected in the field and also generate crop yield maps for both current and future climatic conditions. We show two methodologies on use of geographical information systems (GIS) in assessing climate change impacts on the productivity of teff (Eragrostis *tef*), a major staple crop in the horn of Africa. The first method examined the spatial implications of climate change on the areas suitable for teff production. The second estimated the effects of climate change on teff production.

METHODS

The study area. The study focused on three teff growing geographic locations in Ethiopia, namely, Gimbichu, Bora (Dugda) and Minjar (Shenkora). Being in the northern hemisphere of the globe, Ethiopia generally experiences four seasons, namely: "*Kiremt*" (main rainy season, June-August), "*Tsedey*" ("spring" season, September-November), "*Bega*" (dry and sunny, December-February), and "*Belg*" (light rains, March-May). All yield data were collected during the main season. Climate variability in the country is high mainly due to the wide altitude range (Gamachu, 1988). The windward areas in the highlands receive relief rainfall, but the leeward areas and surrounding lowlands are in the rain shadow and are very arid. The districts selected for the socio-economic survey, i.e. Bora, Minjar and Gimbichu, represent three climatic zones Kolla, Weina Dega and Dega, respectively. They differ in elevation, rainfall and minimum, and maximum temperatures to a large extent determine the kind of crops grown, and potential yield.

Assessment of geographic shifts, current and potential distributions. Passport data which contained a total of 1441 geo-referenced data points, which included germplasm collections and herbarium specimens, were collected from the gene bank of the Institute of Biodiversity Conservation and the Ethiopian National Herbarium at the Addis Ababa University. Teff geographic range was modeled to determine the crop's suitable areas in Ethiopia. All base maps were obtained from DIVA GIS (www.diva-gis.org) with a reference scale of 1:10000. The methodology used in developing suitability indices is based on DIVA GIS Version 5.2 developed by Hijmans (2003).

Environmental data consisted of climate surfaces for present (1950-2010) and projected future conditions (~2050) obtained from WorldClim. For present climate, Worldclim climate surfaces (Hijmans, 2003) were used because of their high spatial resolution (1 km) and global extent. Future climate data were obtained from a number of global climate models (GCMs) with differing greenhouse gas emission scenarios, model characteristics and spatial resolutions. Data from Govindasamy *et al*. (2003) were used because they had the highest spatial resolution (50 km) based on the CCM3 model, with concentration of CO_2 in the atmosphere of 600 ppm (two times that of pre-industrial conditions).

We used Bioclim model as implemented by Busby (1991) in DIVA-GIS (www.diva-gis.org). Climate variables in the Worldclim dataset have the potential to be correlated with one another (e.g. maximum and minimum temperature). Many correlated variables can lead to statistical bias and model over-prediction. For this reason, the number of variables was minimised by selecting only those which were deemed biologically relevant to the crop. In this study, annual mean temperature, mean monthly temperatures, annual precipitation, precipitation seasonality, temperature seasonality and mean diurnal range of temperature were used.

Geographic ranges under current and future conditions for the crop were mapped in order to identify the broad spatial patterns of the impact of climate change and by what suitability index. While there are other techniques for species distribution modeling, DIVA GIS was used as it does not create response curves that may cause erratic behaviours (Hijman and Graham, 2006; Segurado and Araújo, 2004). BIOCLIM (Nix, 1986) is a commonly used modeling programme which relates climatic parameters (i.e. temperature, precipitation, moisture, etc.) to species presence data to predict areas within which an organism can survive (Beaumont *et al*., 2005). The model was run in DIVA-GIS and the output was transformed into presence/absence by assigning presence to the areas where scores were within 2.5 - 97.5 percentile range. The scores per pixel were then treated as the suitability indices.

Assessment of crop yield losses. We analysed teff yield data collected from District Offices of Agriculture and the Central Statistical Agency in Ethiopia for the 2010/11 Meher season (Table 1). Yield points were converted into shape files and overlaid on the suitability grids (from the BIOCLIM model), which had various indices. The environmental conditions where the yield points were overlaid were grouped according to the various suitability indices. Bioclimatic variables for each of the 23 yield data points were extracted from the climatic datasets using DIVA-GIS software. Each point included average minimum and maximum temperature, and average monthly precipitation. Mean annual rainfall and mean monthly temperatures were calculated from temperature and precipitation variables. This enabled the yield value to be directly correlated with the suitability index value. Two variables were extracted from the relationship, yield and suitability index. It was assumed that with all other factors held constant, the amount of yield produced by a particular crop would be approximately the same given the same climatic condition. The assumption was borrowed from Bioclim model as implemented in DIVA-GIS (Busby, 1991). The relationship between suitability index and teff yield was calculated using a simple linear regression (Equation 1). The yield and suitability index were used to predict teff yield distribution maps.

$$y = a + bx \quad \text{..... Equation 1}$$

Where:

a = 0.576 (intercept), b = 0.003 (slope), x = suitability index and y = yield (t ha^{-1})

Socio-economic study. A socio-economic survey was carried out to understand the agricultural activities in the study districts, climatic changes observed, impacts of the changes as perceived by farmers, challenges faced and what farmers are doing and planning to do to mitigate negative effects of the changes in general and climate change in particular. Our sampling strategy was based on minimising the sample error and

TABLE 1. Yield in relation to suitability indices (SI), mean temperature and average rainfall

Longitude (DD)	Latitude (DD)	Yield (t ha^{-1})	Mean temperature (°C)	Average rainfall (mm)	SI value
38.5	9.0666656	1.3	15.49	202.75	198
38.716667	8.8166656	2	17.98	175	307
39.133331	9.6000004	0.925	15.39	172.75	111
40.200001	7.8499999	0.608	22.49	94	111
38.733334	14.116666	0.808	18.19	139	50
37.166664	7.5333328	0.522	16.29	217.5	79
38.200001	10.45	1.16	15.42	223.5	130
38.283333	10.5	1.16	17.46	209	199
38.133331	10.166666	1.16	15.9	210	199
38.966667	8.7333326	2.4	18.64	165.5	333
37.099998	9.5666656	0.947	14.65	312	37
37.849998	7.5500002	0.933	15.74	150.25	91
36.833332	7.666666	0.936	18.71	232.5	64
39.150002	9.8833332	1.6	15.54	176.25	160
39.416664	8.9333334	2.2	20.6	149.25	251
36.450001	11.333333	0.889	22.8	332	51
39.549999	12.416666	0.959	23.9375	97.25	56
37.700001	7.0666661	0.648	18.8125	173	72
37.483334	11.266666	0.87	16.85	296.5	93
40.783333	8.8999996	1.4	21.4	133	108
37.849998	8.9833326	1.121	16.95	179.5	291
38.200001	9.083333	1.2	15.625	198	224
38.950001	8.2833328	1	20.225	137.5	257

assuming maximum variability in the population of teff farmers. We assume a ±5% level of precision and 95% statistical confidence level.

The number of all farm holders in Ethiopia is about 12,208,970. Average cultivated land per holder is about 1.81 ha, while the average land size for cultivation of teff per holder is 0.76 ha (42.16%) of total cultivated land (CSA, 2010). The number of teff farm holders was estimated to be 5,630,440. Using the Cochran formula (Cochran, 1963) for calculating sample sizes, and assuming maximum variability (P=0.5), a 95% confidence level and ±5% precision, the sample size was calculated using Equations 2 and 3. Applying the same formula to smaller population sizes e.g. 3,289,473 or 1,380,000, resulted in the same sample size of about 400 farmers.

$$n_{0=}Z^2pq\ /\ e^2 \quad \text{..... Equation 2}$$

Where:

n_o = the sample size; z^2 = the absisca of the normal curve that cuts off an area at the tails (1 – equals the desired confidence level, e.g., 95%); e = the desired level of precision; p = the estimated proportion of an attribute that is present in the Teff farmer population, and q = 1-p. The value for Z is derived from statistical tables which contain an area under the normal curve.

$$n_0 = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 385 \text{ farmers}$$

..... Equation 2.1

A simplified formula for proportions is provided by Yamane (1967):

$$n = N/1 + N(e)^2 \quad \text{..... Equation 3}$$

Where:

N = the assumed population size, and e = the level of precision.

$$n = \frac{5{,}059{,}200}{1+5{,}059{,}200\,(0.05)2} = 400 \text{ farmers}$$

..... Equation 3

In the study, however, the general principles of this formula were followed but the sample size had to be reduced to 300 due to cost implications.

The interview approach selected for this study was that of structured interviews, though the questionnaire did contain some elements of semi-structured questions. Structured interviews have the advantage of allowing for statistical analysis of the data collected and making general comparisons. Stratified random sampling procedure was employed to select peasant associations and farmers households. From each district, ten peasant associations were randomly selected, and from each peasant association, ten farmers' households were again randomly selected. A total of 100 respondents from each of the three districts participated in the survey resulting in 300 respondents in total. The data were analysed using SPSS software.

A study was carried out to assess the extent to which climate change is likely to affect food security, socio-economic lifestyles and agricultural practices. The study was carried out using available secondary data, particularly agricultural statistics, agronomic data, policy documents and food security statistics. This information highlights the consequences of climate change scenarios on teff yields, production, and socio-economic risk. Potential impacts of climate change on teff yield were projected using a global model, which is an integrated ecological-economic modeling framework encompassing climate scenarios, agro-ecological zoning information, as well as socio-economic drivers.

The biophysical results were fed into an economic analysis to assess how climate impacts may interact with alternative development pathways, and key trends expected over this century for food demand and production. The approach connects the relevant biophysical and socio-economic variables within a unified and coherent framework to produce a national assessment of teff production and food security under climate change. Projected changes in yield were calculated using the data of area, production and yield of teff for private peasant holdings during the main (Meher) season of 2009/2010 using sample surveys compiled by the Central Statistics Agency (CSA) in 2010. Simple calculation were then used to evaluate consequent changes in national teff production and teff prices. The annual teff grain production projection estimate was calculated by reducing the total loss based on the projected estimate of 0.46 t ha^{-1} from the total current gross teff grain production. The subsequent computations were based on the statistics presented by CSA (2010).

RESULTS

Geographic shifts and impacts on yields. The model showed the species having a future climatic suitable area of a minimum annual precipitation of 600 mm and a maximum of 1900 mm. The minimum annual temperature will be 14.9 ^{0}C, while the maximum will be 26.8 ^{0}C. By 2050, 67.7% of Ethiopia land area will be suitable for the crop. High suitability index shifted from Shewa to Amhara. Areas around South Gonder, East Gojam and South Wollo were predicted to be very suitable for the species in future.

Teff will lose an average 236,976.65 km² or 24% of climatic suitable area (Fig. 2). It is predicted that the species will only be restricted in the higher altitudes. Oromia areas will lose most of its suitable area. There is a pattern of the species shifting from South-East to North-West towards the higher elevations of the Northern Ethiopia. Crop suitability areas at the lower altitudes will be affected. Suitability increased at altitudes between 1200 – 2500 meters.

The analysis of climate change effects on teff yield revealed that there is a relationship (R^2=0.74) between the suitability index (SI) and teff yield (Fig. 1). The first image in Figure 4 reveals the current prediction of teff yield using climate surfaces for present (1950-2010), the 2nd image shows the predicted yield map by the year 2050 using projected future conditions. Applying Equation 1 on the predicted current suitability index grid, a drop of 0.46 t ha^{-1} was predicted in the areas marked in red (Fig. 4). Minimal increase in teff production of about 0.14 t ha^{-1} in the areas marked in blue was predicted but was negligible.

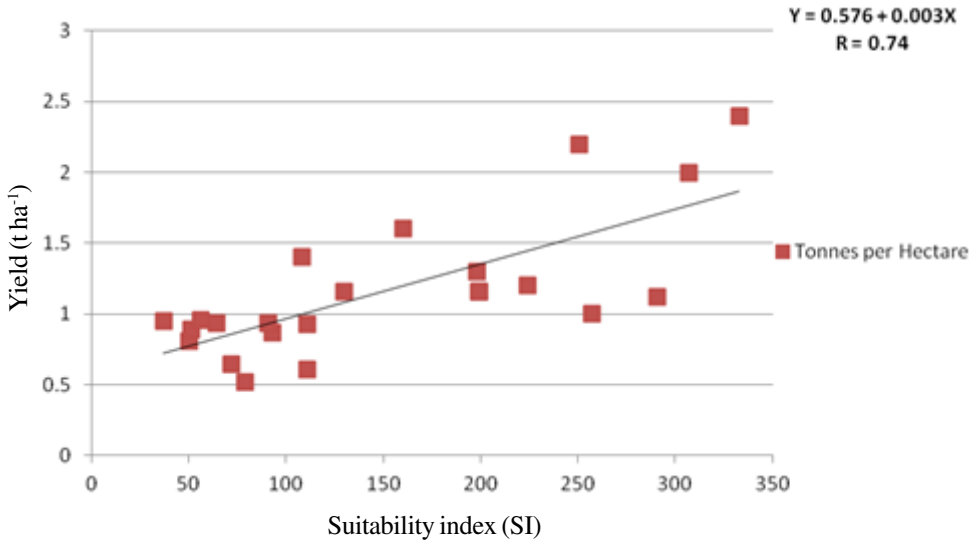

Figure 1. Scatter plot of yield versus suitability index values.

Droughts and crop production. In Bora, out of 100 respondents 43, reported reduction in teff yield. On average, over the last half decade, respondents experienced 2.5 serious droughts resulting in crop failures (Table 2). In Gimbichu only one respondent reported to have missed out on one harvest due to drought. In Minjar, out of 85 respondents, 61% reported yield reduction. Sorghum was the only cereal in Bora reported to be grown by fewer farmers than 5 to 10 years ago. There was a drop from 36 to 10% of the respondents growing sorghum. Surprisingly, despite the high risk of crop failure in maize during droughts in Bora, respondents did not shift to growing other cereals. In Minjar, there was a slight decrease in the number of respondents growing maize (from 30 to 23%), which could well be due to the high crop failure risk of maize, combined with the possibility of the shift to growing other crops. Crop failures due to drought were found to be most frequent in Bora, and least frequent (absent) in Gimbichu. Water availability seemed to have decreased as reported by 81% of the respondents. Related to rainfall is the start and length of the growing season, which according to 97% of respondents had become shorter than it was before. Temperature in general increased according to 99% of the respondents. The number of hot days in a year increased as well as the occurrence of heat waves according to 97% of the respondents.

Environmental and climatic changes. The respondents reported changes in rainfall and temperature over the last 7 years (Table 3). Bora was reportedly drier and hotter than 7 years ago (i.e. around 2003/2004). Bora experienced a decrease in the amount of rain per year (Table 3). The number of dry months in a year increased according to 98% of the respondents, though the occurrence of droughts seems to be constant.

Socio-economic implications. Based on biophysical data input in an economic analysis to project a national assessment of teff production and food security under climate change, and to evaluate consequent changes in national teff production, the model revealed large losses. Considering the current acreage and production level, the overall reduction in national production was estimated at 1,190,784.12 t. This is equivalent to an economic loss of US$ 650,961,954 to farmers using farm gate prices. At the national level, the economic loss due to teff grain yield reduction was estimated to be US$ 730, 347, 581 per year.

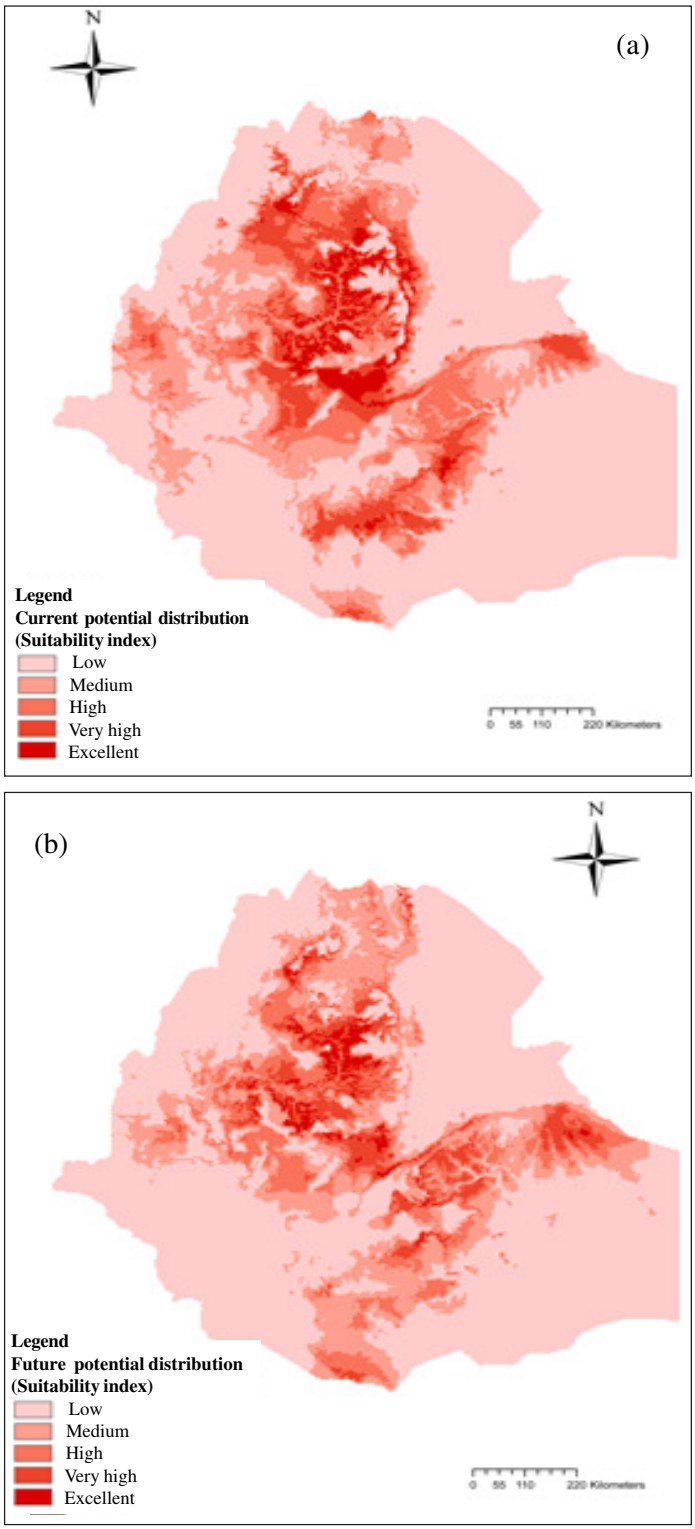

Figure 2. Predicted suitability index grids for teff in Ethiopia; current (a) with passport data overlaid and future (b). Suitability grids were calculated using climate surfaces for present (1950-2010) and projected future conditions (~2050).

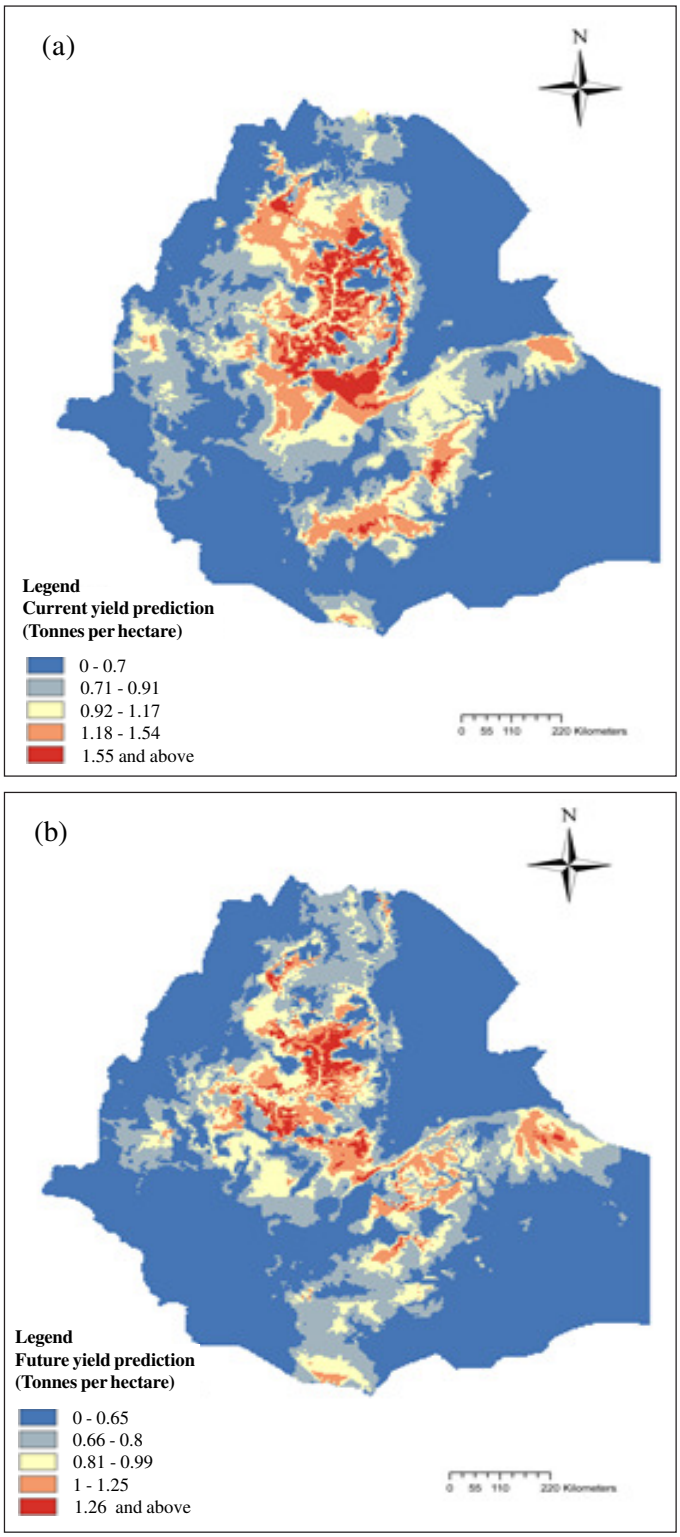

Figure 3. Current (a) and future (b) predicted teff yield distribution maps in Ethiopia. Yield was calculated by applying Equation 2 on the predicted current suitability index grid.

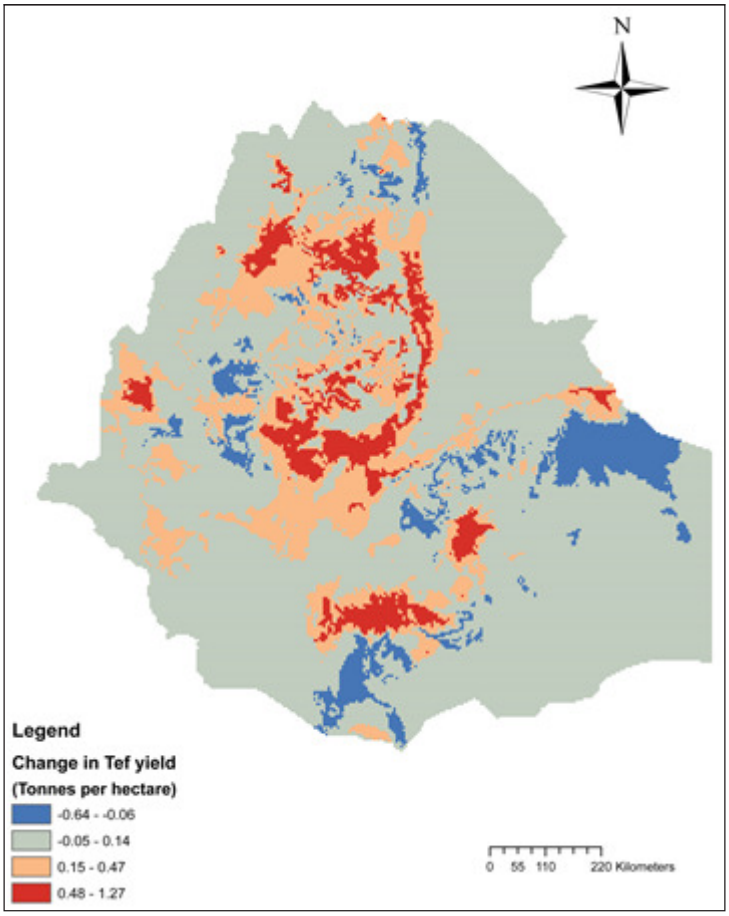

Figure 4. The predicted change in yield by the year 2050 using projected future conditions (~2050) and the current scenarios for teff in Ethiopia.

TABLE 2. Cereal crop failures due to drought in the three districts in Ethiopia over the past 5 years (2005-2010)

Site	Average number of crop failures due to drought during last 5 yrs	Specified crop failure for respondents who lost crops to droughts*				
		Teff	Barley	Wheat	Maize	Sorghum
Bora	2.5 (n=100)	43	20	68	96	22
Gimbichu	0.0 (n=1)	0	0	1	0	0
Minjar	1.4 (n=85)	61	59	89	34	31

* Frequency percentage of respondents (n)

DISCUSSION

From the study it was clear that Bora is dry and hot, with low teff yield. Strategies to improve yields have not been successful. Rainfall has decreased and is more erratic; droughts have become more common as have floods. Temperatures have increased, and there are more hot days than before. In Gimbichu and Minjar, a similar pattern of change in rainfall and

TABLE 3. Change in rainfall and temperature over the past 7 yrs (2003-2010) as perceived by respondents in the three districts in Ethiopia

Climate variables	Bora*				Gimbichu*				Minjar*			
	n	+/-	+	-	n	+/-	+	-	n	+/-	+	-
Amount of rain	100			100	99	6	35	59	100	7	13	80
Frequency of rain showers	100			100	97	4	35	61	100	10	8	82
Distribution of rainfall in the year	100			100	97	15	19	66	99	9	8	83
Number of dry months in a year	100		98	2	89	39	52	9	94	6	61	33
Occurence of droughts	100	52	25	23	73	47	14	40	78	50	22	28
Occurence of floods	100	22	68	10	76	43	36	21	81	74	5	21
Water availability	100	19		81	96	2	25	73	100	16	28	56
Water stress	100	18	81	1	95	1	49	49	98	18	34	48
Length of the growing season	100	3		97	85	28	34	36	97	14	8	77
Temperature	100		99	1	98	7	80	13	98	5	81	14
Number of hot days	100		98	2	94	14	74	12	95	6	80	14
Occurence of heat waves	100	3	97	0	75	48	41	11	83	60	30	10

* Frequency in percentage of respondents (n) i.e. +/- (no change), + (increase), - (decrease)

temperature can be seen, though far less extreme than in Bora. Climatic conditions are thought to have changed the least in Gimbichu.

The model confirmed future teff distribution changes and yields reductions due to climatic changes. There will be an average loss of approximately 24% of the current suitable area for teff by 2050. With a change in the species climatic envelope, teff will only be suitable in areas with temperatures of up to 27 °C and a low of 15 °C in 2050, but this has been compensated with increased rainfall of up to 1900 mm from a low of 600 mm. The model also predicted a complete loss of suitable areas at latitude between 6°N – 8°N and a gain at latitudes between 9°N – 11°N, but restricted to 36°E – 39.4°E longitudes.

The slight change of species distribution to Eastern Ethiopia conforms to the predicted future increase of rainfall amounts of between 1250 - 1800 mm from the current low of 950 - 1000 mm around longitude 39°E and latitude 7°N up north. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long term climate trends very difficult to predict (Chen *et al*., 2004). A careful assessment of the predicted yield distribution maps indicates that the suitability index developed in the study correlates positively with the yield data collected in the various agro ecological zones. This means that changes in temperature, rainfall and seasonality in Ethiopia directly affect the distribution and yield of teff, a conclusion made by Kelbore (2012) and Evangelista *et al*. (2013) in previous research.

Based on predicted loss of 0.46 t ha^{-1}, the supply of teff grain will further diminish by 1,190,784.12 t from the current level of 3,179,743 t. The prices are expected to increase as the supply of teff grain decreases.

Currently the production of teff is not commensurate with the national demand for the grain. There is already a huge deficit between the production and the national demand, and this will be exacerbated by climate change effects. It is, therefore, understandable that as long as the production of teff decreases against a rising demand due to the fast growing population, there will be unprecedented price increase on teff grain. Being a major staple crop, teff is very important for national food security in Ethiopia. A threat to the crop's area suitable for cultivation due to climate change is a direct threat to food security. If teff production in Ethiopia continues to decrease with time, it will lead to a significant polarization of effects on both farm gate and market prices, with substantial increases in prices anticipated.

CONCLUSION

The methodology presented in this study provides an opportunity for agriculturalists, spatial analysts and policy makers to analyse the effect of climate change on crop productivity to inform development of adaptive strategies and policy to minimise the negative impacts of climate change on teff production in Ethiopia. Moreover, it provides opportunities for further potential research to finetune the model and communicate model predictions better. However, it would be difficult to predict the magnitude of change in production due to the fact that the reduction in teff yield is a complex pattern of climate variables, CO_2 effects, and agricultural management systems.

All these contribute to aggregations of national crop production.

ACKNOWLEDGEMENT

We thank the International Development Research Centre for funding this work. Two anonymous reviewers provided suggestions that greatly improved this manuscript. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 859 - 874 ISSN 1021-9730/2014 $4.00

EFFECTIVENESS OF TECHNOLOGICAL OPTIONS FOR MINIMISING PRODUCTION RISKS UNDER VARIABLE CLIMATIC CONDITIONS IN EASTERN UGANDA

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ABSTRACT

This study employed the Just and Pope stochastic production frontier to assess the effectiveness of farmer-preferred technologies in reducing production risk related to climate variability in Eastern Uganda. Data for this study were obtained from 315 households, 9 focus group discussions and 23 key informants drawn from Mbale, Pallisa and Sironko districts. Results show that farmers employed a number of technologies/practices strategically in response to seasonal variations in climatic conditions. Most of the technologies showed significant positive impacts on mean yield, but had different risk-reducing effects on yield. Changing sowing dates and crop varieties, soil bunds, compost manure, cover crops, crop rotation and intercropping showed significant ($P<0.05$) risk-reducing effects on yield. However, their effects varied across agro-ecological zone, except soil bunds and compost manure whose use consistently exhibited both yield-increasing and risk-reducing effects across all the agro-ecologies. Farmer perceptions of technology effectiveness, to some extent, agreed with econometric evidence from this study. Study results have two implications: firstly, the need to develop and disseminate location specific adaptation technologies to reduce production risks, instead of blanket recommendations of similar adaptation measures across locations; and secondly, the need to focus not only on the technical aspects of technologies, but also the social dimensions such as perceptions of smallholder farmers of technology effectiveness, if adoption and retention of adaptation technologies is to be enhanced. Development and research organisations promoting adaptation options should involve farmers in technology evaluation so as to recommend the most feasible options given farmers' situations and local perceptions.

Key Words: Adaptation, climate variability, Just and Pope Framework

RÉSUMÉ

Cette étude a utilisé la méthode « frontière de production stochastique » de Just et Pope pour évaluer l'efficacité des technologies préférées par les agriculteurs pour réduire les risques de diminution de la production agricole liés à la variabilité climatique à l'Est de l'Ouganda. Les données de cette étude étaient obtenues à partir de 315 ménages, 9 groupes de discussion focalisés et 23 informateurs clés sélectionnés dans les districts de Mbale, Pallisa et Sironko. Les résultats ont montré que les fermiers utilisent stratégiquement un bon nombre de technologies en réponse aux variations climatiques saisonnières. Laplupart de ces technologies ont montré des impacts positifs significatifs sur les rendements moyens, mais présentaient des différences au niveau de leur effets sur les risques de diminution des rendements. Le changement des dates de semis et des variétés des cultures, du billonnage, de l'utilisation du compost, descultures de couverture, de la rotation et des cultures intercalaires ont manifesté des effets significatifs ($P<0.05$) sur le risque de diminution des rendements. Par ailleurs, leurs effets variaient en fonction des zones agro-écologiques, sauf pour le billonnage, et le compost dont l'utilisation a induit une augmentation des rendements et une réduction de risques à travers toutes les zones agro-écologiques. Les perceptions des agriculteurs sur l'efficacité de ces technologies sont en accord avec l'évidence économétrique de cette étude. Les résultats de cette recherche ont deux implications : premièrement, le besoin de développer et diffuser les

technologies spécifiquement adaptés aux conditions locales pour réduire les risques au lieu de formuler des recommandations générales pour diverses localités, et deuxièmement, le besoin de se focaliser non seulement sur les aspects techniques des technologies, mais aussi sur les les dimensions sociales telles que les perceptions des petits exploitants sur l'efficacité des technologies, si on veut s'assurer d'une adoption durable des technologies d'adaptation par les expoloitants. Les organisations de recherche et de développement engagés dans la promotion des options d'adaptation devraient dès lors impliquer les fermiers dans l'évaluation des technologies afin de recommander les options les plus appropriées compte tenu de la situatiion réelle des agriculteurs et de leurs perceptions au niveau local.

Mots Clés: Adaptation, variabilité climatique, structure de Just et Pope

INTRODUCTION

Among the many risks agricultural stakeholders face especially in Sub-Saharan Africa (SSA), production or yield risk is the most important (Chuku and Okoye, 2009). Rainfall variability influenced by large scale inter-seasonal and inter-annual variability resulting in frequent extreme weather events, is among the major risk factors affecting agricultural production and food security in SSA (Haile, 2005; Christensen *et al*., 2007; Easterling *et al*., 2007). This variability in rainfall has also been directly linked to decline in economic activity in most SSA countries, as measured by Gross Domestic Product (GDP) (Brown *et al*., 2011).

Managing risks paused by climate variability is important in agriculture not only for the direct impact it has on production, but also for the tendency of most farmers to be risk-averse (Cabrera *et al*., 2009). An increasing body of observations has emphasized the importance of managing production risks to optimise crop/ varietal choice, especially in marginal areas (Di Falco *et al*., 2006; Kurukulasuriya and Mendelsohn, 2006), and farm income (Jones *et al*., 2000; Kumar *et al*., 2004). Kassie *et al*. (2009) and Kato *et al*. (2009) demonstrated the importance of organic farming and, soil and water conservation techniques, as adaptation strategies to climate variability in specific farming systems. Other technologies that have been promoted include, new crop varieties, agronomic management adjustments, reforestation of fragile landscapes, response agriculture, down-scaled forecasting, and investment in low level irrigation infrastructure in watersheds (Goddard *et al*., 2001; Iglesias, 2005; Nzuma *et al*., 2010). In Eastern Uganda, some of these and other crop and land management practices have been observed at farm level (Kansiime, 2012).

As the role of technology continues to become more ingrained in strategic thinking of agricultural adaptation to climate variability and change (Smithers and Blay-Palmer, 2001), there is a need for systematic, location specific assessment of the technologies to improve adoption through unravelling their effectiveness, constraints, opportunities and synergies under variable climatic conditions. This will lead to better understanding of their effects on risks in agricultural production and facilitate decisions on which technologies to promote and where in particular.

Some assessments have been done linking technology adoption to production risks. For example, Kurukulasuriya and Mendelsohn (2006), Kassie *et al*. (2008), Kassie *et al*. (2009), and Sileshi *et al*. (2010) indicated positive relationships between technology adoption and production risk reduction. However, the performance of technologies was only judged based on mean yields, except Kato *et al*. (2009) who considered technology effects on both the mean and variance of crop production. Inference based on the means alone can be misleading if the variance around the mean, and hence the probability distribution of the risk is not known.

Other studies have used agricultural simulation models to capture these complex interactions. A range of methods for linking crop simulation models to seasonal climate forecast models have been advanced in Africa, Australia and USA (Hansen and Indeje 2004; Hansen *et al*., 2006; Cabrera *et al*., 2009). Multiple regression models have also been developed to represent process-based yield responses to these environmental and management variables (Di

Falco *et al*., 2006; Pender and Gebremedhin, 2006; Iglesias and Quiroga, 2007; Cabas *et al*., 2010; Sileshi *et al*., 2010), and could be used to estimate the risk associated with climate variability.

A major challenge facing these evaluations is the inclusion of both biophysical and socioeconomic aspects in the methodology (Iglesias and Quiroga, 2007). The present study used an integrated approach to assess the effectiveness of various farmer-preferred technologies in reducing production risks associated with climate variability across three agro-ecologies in Eastern Uganda. Specifically, this study addressed three open questions: (i) How do various farmer-preferred adaptation technologies affect mean and variance (as an index of risk) of crop yield in Eastern Uganda given actual and perceived variability in rainfall? (ii) How do the effects of these technologies on crop yield vary across agro-ecological zones in eastern Uganda? (iii) What is the perception of farmers regarding technology effectiveness in reducing production risks, and how do these perceptions compare with statistical evidence?

MATERIALS AND METHODS

Research design. The research used a cross sectional survey design and qualitative research approaches, including description of historical weather variability events. This allowed establishment of facts about actual and perceived climate variability, which were used as inputs in explaining factors underlying farmers' practices under variable climatic conditions based on descriptive research data.

Study area and sampling procedure. The study was conducted in Eastern Uganda, covering three distinct agro-ecological zones (AEZs) namely; the Lake Victoria Crescent, South East Lake Kyoga and Mount Elgon (Wortmann and Eledu, 1999). From each of the agro-ecological zones, one district was selected from which respondents were drawn. Sampled districts included, Mbale, Pallisa and Sironko; representing L. Victoria Crescent, SE L. Kyoga and Mt. Elgon agro-ecologies, respectively.

A sample size of 315 households, was obtained using probability proportional to size method. In addition, nine focus group discussions (FGDs) involving 104 community members, and 23 key informant interviews (KIIs) were conducted.

Further, observational rainfall data for the 40-year period; extending from 1971 to 2010 were obtained from the Uganda Meteorological Department, Ministry of Lands and Environment. Data were obtained for three meteorological stations, namely Tororo, Soroti and Sipi, representing the three sample districts of Mbale, Pallisa and Sironko, respectively. Each of the AEZs had one weather station, and data from these were used to generalise for the sample districts and the AEZs. Table 1 shows the study agro-ecological zones, their biophysical characteristics sampled districts and sample size.

Model specification. This study employed the Just and Pope stochastic production frontier framework (Just and Pope, 1979). Just and Pope Framework focuses on production risks measured by the variance of output, allowing yield enhancing inputs to have either a negative or a positive effect on the variance of yield by relating the variance of output to explanatory variables in a multiplicative heteroskedastic regression model (Kato *et al*., 2009). The study specified a single equation joint production function, which summarises the relationship among aggregate outputs and aggregate inputs in order to circumvent the problem of estimating production functions in the absence of activity-specific input data. Single equation approach has been used in several previous studies (Smale *et al*., 1998; Koundouri *et al*., 2006; Kato *et al*., 2009; Barnwal and Kotani, 2010). The stochastic production function is represented as:

$$Y = f(X, \beta) + \mu = f(X, \beta) + h(X, \alpha)^{0.5} + \varepsilon$$

Where:

Y = the yield, X = a vector of explanatory variables, f(.) denotes the deterministic component, the mean function of yield and relates X to average yield with β representing the set of estimated coefficients, μ = the heteroskedastic disturbance term with a zero mean, h(.) = the stochastic component i.e. variance function of

TABLE 1. Characteristics of the areas selected for the study

AEZ (weather station[a])	Biophysical characeristics	Sampled district (sub counties)	Respondents
Lake Victoria Crescent (Tororo)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 1503 mm; main crops include banana, Arabica coffee, maize, beans, sweet potato and rice; mean altitude is 1174 m.a.s.l., Petric Plinthosols (Acric) soils, and population density of 166.3 km^2	Mbale (Bungokho, Mutoto and Bumbobi)	105 household surveys, 35 participants in FGDs and 7 KIIs
South East Lake Kyoga (Soroti)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 1368 mm; main crops include cotton, finger millet, sorghum, groundnuts, sweet potato, cassava, beans and maize; mean altitude is 1075 m.a.s.l.; Gleysols soils; population density of 252 km^2; livestock rearing, especially indigenous cattle important	Pallisa (Olok, Apopong and Pallisa Rural)	105 household surveys, 36 participants in FGDs and 8 KIIs
Mount Elgon (Sipi)	Bimodal high rainfall, 1971-2010 mean annual rainfall is 2058 mm; main crops include; banana, Arabica coffee, maize, beans, rice, potato, sweet potato and vegetables; mean altitude of 1299 – 1524 m.a.s.l.; Vertisols soils and population density of 770 km^2	Sironko (Bumasifa, Buhugu, and Bumalimba)	105 household surveys, 33 participants in FGDs and 8 KIIs

[a] Observational rainfall data were obtained from these weather stations to generalise for the study districts. In each of the AEZs, only one weather station existed, indicated in parenthesis in the Table after AEZ. Source: Adapted and modified from Wortmann and Eledu (1999), Komutunga and Musitwa (2001) and Kansiime *et al*. (2013)

yield and relates X to the standard deviation of yield with α representing the corresponding set of estimated coefficients, and ε = a random error term with a mean of zero and variance of σ^2.

Thus this specification shows mean yield and yield variance as two separate components being explained by change in input variables, i.e. rainfall and other derived variables (Just and Pope, 1979; Chen *et al*., 2004).

The stochastic production function given above can be estimated using maximum likelihood estimation (MLE) or a three-step estimation procedure involving feasible generalised least squares (FGLS) under heteroskedastic disturbances (Cabas *et al*., 2010). Though most empirical studies have used the FGLS approach, MLE is considered more efficient and unbiased than FLGS estimation in the case of small samples (Saha *et al*., 1994).

Given the large sample in this study, the three stage estimation procedure as described in Judge *et al*. (1988) was used for analysis. In the first stage, Y was regressed on f(X, β) using Ordinary Least Squares (OLS); in the second step, least square residuals were calculated as $\hat{\mu} = y - f(X, \beta)$, where $\hat{\mu}$ is a consistent estimate of μ, a heteroskedastic disturbance term with zero mean. In the third step, squared residuals were used as the dependent variable for the variance function estimation h(X, α) using OLS, where h(.) is assumed to be in exponential form. The focus was on the coefficients for the variance function, where a positive coefficient implies risk-increasing effects, and a negative coefficient implies a risk-decreasing effect of the input on yield. Technologies that showed risk-reducing effects were, therefore, considered effective in reducing risks associated with climate variability.

The Semi-logarithmic functional form specification was used in the model and this helped to improve normality of the dependent variable and residuals, thus reducing problems of nonlinearity, heteroskedasticity and sensitivity to outliers (Kato *et al*., 2009). The data were tested for multicollinearity using the variance inflation factors (VIF) and also by pair-wise correlations. Multicollinearity was not a serious problem; the VIFs were less than 3.0 and the pair-wise correlations were less than 0.5, indicating that the standard errors were not being affected by collinearity problems.

Data and empirical specifications of model variables. Data for this study were made available as part of a larger study investigating determinants of crop and land management practices, and effects on production risks under variable climatic conditions in Eastern Uganda. The study was conducted during August - September 2011. Data were obtained on both the dependent and independent variables (Table 2). The dependent variable for the model Y was expressed as value of crop production per hectare (van de Steeg *et al*., 2010).

Value of production per hectare was preferred because some plots were intercrops, making estimation of single crop-production functions difficult. This approach has been used in many previous plot-level-based microeconometric studies in sub-Saharan Africa (Jansen *et al*., 2006; Pender and Gebremedhin, 2007; Nkonya *et al*., 2008; Kato *et al*., 2009). In estimating value of crop production at plot level, average market prices were used based on historical and current data from cross sectional survey and other qualitative research methods.

The model explanatory variables included farmer-preferred adaptation technologies. Rainfall variables were included in the model to capture effects of rainfall variability on the mean and variance of crop production. These included the rainfall satisfaction index of the preceding main agricultural season (August–November 2010), and the mean and standard deviation of monthly precipitation for the August-November growing season over a 40-year period, similar to the approach used by Cabas *et al*. (2010). The analysis also controlled for other variables that were hypothesized to be correlated with the observed plot-level crop outputs such as sex, age and education of household head, household size, use of chemical fertilisers, land size, and local agro-ecology.

RESULTS

Descriptive results. An inventory of farmer preferred management practices was made based

TABLE 2. Summary of variables used in the empirical model

Variable	Description	Mean	SD
Dependent variable			
Crop production (expressed as VOP)	Value of crop production measured as output x price (UGX '000' per hectare)[a]	894	719
Explanatory variables			
Technology adoption	Set of technological options employed by farmers to reduce climate-induced production risk. Dummy = 1 if farmer reported utilisation of given technology	0.71	0.46
Rainfall index	Rainfall satisfaction index constructed from a set of questions relating to rainfall adequacy during the season of August – November 2010 [b]	0.19	0.11
Mean rainfall	Mean monthly rainfall (mm) for the second season (September – November) over a 40 year period [b]	655.75	277.82
SD rainfall	Standard deviation of monthly rainfall for the second season (September – November) over a 40 year period [b]	193.84	95.90
Age	Age of the household head in years	44.93	14.89
Education	Level of education of the household head measured on a scale where 1 = none, 2 = Primary, 3 = Secondary, 4 = Tertiary	2.14	1.13
Household size	Household size measured by number of members in who contribute to farming operations	7.05	3.75
Gender	Gender of household head (1 = Male, 0 = Female)	0.84	0.36
Farm size	Total farm size measured in acres	1.33	1.22
Inorganic fertiliser	Use of chemical fertiliser	0.27	0.45
Local agro-ecology	Local agro-ecology represented by the study districts. District dummy 1 = 1 if Mbale, 0 otherwise; District dummy 2 = 1 if Sironko, 0 otherwise		

* Conversion rate used is 1USD = UGX 2470 (The New Vision, June 11, 2012, Vol. 27 No.116). [b] Kansiime *et al*. (2013)

on responses obtained from the survey. For each of the technologies or management practices on farm, adoption was dichotomised, where a value of one was given if a farmer reported to use a particular technology, and zero otherwise. Farmers employed a number of crop and land management practices on their farm, either singly or in combination (Table 3). It should be noted that there were multiple responses on farmers using more than one management practice.

A majority of farmers changed sowing dates to coincide with onset of rain or planted as and when it rained. Another important crop management practice was intercropping, practiced by 72% of the respondents. Other crop management practices included changing crop varieties, changing crop density and crop rotation. Farmers changed crop varieties to include early maturing ones particularly maize, beans and ground nuts. In Sironko, farmers introduced non - traditional crops such as paddy rice and coco yam to cope with increased incidence of soil water logging, while in Pallisa, farmers were moving back to local varieties of finger millet and sorghum, which they perceived to be more hardy and tolerant to dry spells as compared to improved varieties.

A majority of farmers reported to have increased crop density, particularly in Pallisa. Increasing crop density was linked to continuous planting, mixed cropping and re-planting or gap filling, which were commonly practiced and aimed at increasing chances of getting harvest even under climatic stresses. There were also cases of farmers increasing the number of seeds per planting hole, which they claimed increased chances of seed survival when soil temperatures increased immediately after planting, as narrated by Akol Pricilla (68 years), one of the participants in a focus group discussion conducted during this study in Komolo village, Pallisa district:

"When we plant more seeds in each planting hole, chances of seed survival are increased. The seeds that are in the middle, not in direct contact with soil retain the moisture, while the ones in contact with the soil are burnt away when it gets very hot. Therefore, we still have some seeds germinating even when there has been a dry spell immediately after planting. If we are lucky and the rain is normal, then we may remove the extra plants."

Cover crops, compost manure and crop rotation were the most common land management practices employed by farmers in the sampled

TABLE 3. Proportion of respondents using various adaptation technologies by district

Production technologies	% of respondents using technology			Pearson χ^2 (2)	P- value
	Mbale	Pallisa	Sironko		
Crop management					
Changed sowing date	63	100	74	45.251	0.000
Changed crop density	35	75	34	50.194	0.000
Changed crop varieties	39	27	30	3.808	0.149
Crop rotation	6	94	29	176.472	0.000
Intercropping	55	82	83	27.082	0.000
Land management					
Soil bunds	48	48	19	24.283	0.000
Mulching	13	50	30	34.123	0.000
Grass strips	15	43	36	19.786	0.000
Compost manure	36	55	50	8.379	0.015
Cover crops	11	76	58	95.382	0.000
Inorganic fertiliser	7	8	67	126.816	0.000

villages in that order. Other land management practices included, soil bunds, terraces, mulching, grass strips and inorganic fertiliser. The observed differences in adoption of production technologies per district were significant ($P< 0.05$) in the three sample districts. The strongest differences were observed for crop rotation, inorganic fertiliser and cover crops (ChiSq > 95, $P = 0.000$).

The study also included response variables measuring the reasons for farmers' change in farming practices in response to climate variability. In particular, the study primarily examined whether farmers made on-farm changes due to other reasons, and not only changes that were specifically in response to weather and climate patterns. The data reflect only reported changes, and not whether a change was adaptive, a concept implying that a change confers some benefit to the farmer that made that change.

Farmers' reasons for using various production technologies ranged from weather, to land and cost related issues (Table 4). Overall, climate related reasons (rainfall pattern, increase yield, reduce risk, reduce erosion and reduce flooding/water logging) were the commonly mentioned across the study districts. Limited land was a big factor in Mbale and Sironko rating 19 and 11%, respectively.

Effects of farmer-preferred adaptation technologies on the mean and variance of crop yield. Econometric results of the Just and Pope Production function are presented in Table 5 for the mean and variance functions of crop production in general. Changed crop varieties, soil bunds, and inorganic fertilizer showed positive and significant impacts on the mean of crop output. Soil bunds showed the largest production elasticity among the technologies. Technology effects on yield variability also differed with changing sowing dates and crop varieties, soil bunds, compost manure, cover crops, crop rotation and intercropping all showing significant negative coefficients on yield variability. On the other hand, changing crop density and mulching had significant positive coefficients, implying that they are risk-increasing.

Examination of effects of other non-technological variables on the mean and variance of crop production indicated that rainfall subjective index and rainfall standard deviation significantly and positively affected the mean yield, and negatively affected yield variability. Household and socio-economic characteristics such as age of household head, education level, household size, gender of household head and farm size did not show any significant impacts

TABLE 4. Farmers' reasons for adopting various production technologies

Change drivers	Percent of respondents			
	Mbale	Pallisa	Sironko	Average
No change [a]	60	0	25	28
Change	40	100	75	72
Reasons for change [b]				
Poor rainfall pattern	43	33	27	33
To increase crop yield	29	17	18	20
Limited land	19	2	11	8
To spread risk	2	30	6	17
Reduce soil erosion	2	5	24	11
Reduce flooding/water logging	0	8	14	8
Limited labour	5	2	0	2
Low cost	0	3	0	1

[a] No change is the total number of farmers who reported making no crop or land management related change; [b] Reasons for change are proportionately computed from only those who indicated to have changed their farming practices, irrespective of the technology they employed

TABLE 5. Effects of technologies on mean and variance of crop yield

Variables	Log VOP for mean		Log VOP for variance	
	Coef.	Std. Err.	Coef.	Std. Err.
Technologies				
Changed sowing date	0.110	0.246	-0.481*	0.753
Changed crop density	-0.093	0.128	0.340*	0.582
Changed crop varieties	0.456**	0.207	-0.951**	0.633
Soil bunds	0.971***	0.197	-2.865***	0.607
Mulching	-0.149	0.232	0.765*	0.704
Grass strips	-0.222	0.224	0.107	0.690
Compost manure	0.217	0.192	-0.824*	0.591
Cover crops	0.257	0.242	-1.444*	0.744
Crop rotation	0.209	0.301	-0.573*	0.921
Intercropping	0.259	0.211	-0.462*	0.642
Rainfall variables				
Rainfall index	0.507**	0.584	-1.252	1.797
Mean rainfall	-0.516	0.003	0.000*	0.009
SD rainfall	2.412*	1.518	-0.008*	0.017
Household characteristics				
Age	-0.002	0.006	0.004	0.019
Education	-0.121	0.091	0.581	0.353
Household size	0.009	0.091	0.006	0.079
Gender	0.099	0.294	-0.398	0.885
Land variables				
Farm size	0.071	0.101	-0.296*	0.308
Inorganic fertiliser	0.164*	0.152	-0.697*	0.808
Local agro-ecology (cf. Pallisa)				
Mbale	-2.561*	0.401	0.234	1.205
Sironko	3.713**	1.620	-0.856	4.871
Intercept	4.573	1.826	6.833*	5.490
R^2	0.250		0.211	
Adjusted R^2	0.189		0.151	
F	4.14		3.491	
Pr > F	0.000		< 0.0001	

VOP = value of crop production; Coef = Coefficient; Std Err = Standard Error; Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

on mean yield. Only farm size showed significant risk-reducing effects on crop variability.

The effect of agro-ecology on mean and variance of yield was such that location in Mbale decreased the mean yield by about 25%, while location in Sironko increased the mean yield by 37% as compared to Pallisa. Yield variability followed the opposite trend, with location in Mbale having positive effects and location in Sironko negative effects in comparison with Pallisa. That means that location in Mbale and Sironko were more and less risk–reducing, respectively, compared to location in Pallisa.

Yield effects and risk of farmer-preferred technologies by district. Results by district

TABLE 6. Effects of technologies on mean and variance of crop yield by district

Variables	Mbale Log VOP		Pallisa Log VOP		Sironko Log VOP	
	Mean	Variance	Mean	Variance	Mean	Variance
Technologies						
Changed sowing date	0.305	-0.554	-1.671	3.866	-0.261*	0.534
Changed crop density	-0.037	-0.845	-0.125	1.339	-0.429***	0.732**
Changed crop varieties	0.995**	-0.192	-0.126	0.833	0.328*	-0.264
Soil bunds	1.508***	-4.812***	0.337*	-0.619*	0.395**	-0.191*
Mulching	-0.377	1.404	0.035	0.341	0.019	0.038
Grass strips	-0.424	2.556	-0.106	0.320	-0.400**	0.348
Compost manure	0.146	-0.697	0.817**	-3.225**	0.267*	-0.321
Cover crops	0.681	-0.407	0.695*	-1.243	0.111	-0.557
Crop rotation	0.539	-2.144	0.759	0.204	0.043	0.072
Intercropping	0.432	-1.068	-0.463	0.377	0.571***	-1.300***
Rainfall variables						
Rainfall index	1.260	0.623	1.731	-5.786	0.417	-0.693
Mean rainfall	0.343	-2.574	-0.022	0.147	-0.001	0.003
SD rainfall	-0.002	-0.020	0.004	-0.016	-0.825	1.568
Household variables						
Age	-0.010	0.019	0.005	-0.006	0.004	-0.011
Education	-0.713**	0.495	-0.059	0.203	-0.014	0.168
Household size	-0.018	0.059	0.009	-0.034	-0.045*	0.131**
Gender	0.619	-2.678	-1.323	-1.343	-0.097	-0.309
Land variables						
Farm size	0.101	0.325	0.108	-0.531*	0.010	0.046
Inorganic fertiliser	0.736	-1.508	-0.475	0.535	0.531***	-0.614*
Intercept	-174.428	1351.872	15.113	-74.123	276.29	-515.2
Observations	104		102		104	
R^2	0.290	0.272	0.272	0.280	0.414	0.244
Adjusted R^2	0.119	0.097	0.092	0.102	0.273	0.061
F value	1.698	1.552	1.510	1.571	2.936	1.337
Pr > F	0.050	0.086	0.101	0.081	0.000	0.180

VOP = value of production; Statistical significant at the 0.01 (***), 0.05 (**), 0.1 (*) level of probability

(Table 6) showed varying effects of the various technologies by district. In Mbale, changed crop varieties and soil bunds showed significant positive effects on the mean of crop yield. In Pallisa, the technologies that showed positive impact on mean yield were, soil bunds, compost manure, and cover crops; while in Sironko, crop varieties, soil bunds, compost manure, intercropping and inorganic fertiliser use showed significant positive impacts on yield. Of the yield-enhancing technologies, only soil bunds showed significant risk-reducing effects on crop yield across all the districts.

Inorganic fertiliser use also had significant risk-reducing effect on crop yield in Sironko. Rainfall variables showed positive effects on yield across the locations, though not significant. Mean seasonal rainfall showed negative effects on the variability of yield in Mbale, while in Pallisa and Sironko, it showed positive impacts. This implies that mean rainfall generally increased risk in Pallisa and Sironko areas. Standard deviation

of rainfall generally increased risks in Sironko as opposed to Mbale and Pallisa.

Effectiveness scale of farmer-preferred technologies. Using the subjective effectiveness scale, farmers rated the various production technologies they employed according to their judgement of their effectiveness in reducing risk of crop failure associated with rainfall variability. Subjective effectiveness analysis was done per technology and by district. In Mbale, compost manure was rated as the most effective by the users. At least 73% rated it as either effective or very effective. Other technologies rated as effective in Mbale included, altering sowing date, changing crop density, changing crop varieties, mulching and cover crops. However, intercropping, crop rotation, grass strips and soil bunds were rated as either not effective or farmers were not certain about their effectiveness in reducing production risks.

In Pallisa, farmers rated changing crop varieties (82%), changing sowing date (74%), compost manure (68%) and mulching (64%) as either effective or very effective in reducing production risks. Changing crop density on the other hand, though practiced by a majority of farmers in Pallisa compared to Mbale and Sironko, about 62% of farmers in Pallisa rated it either as ineffective or they could not establish its effectiveness in reducing production risks. Other practices considered to be less effective in Pallisa were, mulching, grass strips, cover crops, and intercropping. In Sironko, most of the management practices were rated as effective or very effective by over 65% of the respondents (on average). Management practices considered least effective were, changing sowing date and changing crop density.

There was also a high proportion of farmers that were not able to assess the effectiveness of the management practices they employed on their farms for reducing production risks, especially in Mbale and Pallisa. A majority of farmers in Mbale using crop rotation, grass strips and soil bunds were not sure of their effectiveness in reducing production risks. It is no wonder that these management practices were employed by a very small proportion of farmers. On the contrary, in Pallisa, the management practices where farmers were not sure of their effectiveness were practiced by a majority of farmers. For example, intercropping, crop rotation, cover crops and grass strips.

Overall, across the study districts, changing crop varieties, compost manure use and changing sowing date were rated the most effective by 80, 72 and 62% of respondents (Table7). Changing crop density was generally rated less effective. A Kruskal-Wallis test was conducted to evaluate

TABLE 7. Subjective effectiveness scale of farmer-preferred technologies

Production technology	Sample space [a]	Effectiveness scales (subjective) (%) [b]					Kruskal-Wallis $\chi^2(2)$	Probability
		Not effective	Somehow effective	Not sure	Effective	Very effective		
Changed sowing date	244	19	-	18	13	49	42.300	0.0001
Changed crop density	148	37	3	17	20	24	24.364	0.0001
Changed crop varieties	100	3	3	14	17	63	2.665	0.2639
Soil bunds	119	2	1	46	27	24	9.638	0.0081
Mulching	95	2	-	52	7	39	5.624	0.0601
Grass strips	97	1	1	57	9	32	7.750	0.0208
Compost manure	145	4	1	23	19	53	21.706	0.0001
Cover crops	149	2	3	55	10	30	24.790	0.0001
Crop rotation	132	2	-	60	11	27	5.195	0.0744
Intercropping	227	1	3	42	22	32	51.455	0.0001

[a] Sample space is total response across the study districts; [b] Percentage is computed from only those respondents who indicated to have used the particular technology, not from the total respondents

differences among the three study districts on their rating of technology effectiveness (Table 7). The test results were significant for all technologies, except for changed crop varieties, mulching and crop rotation.

DISCUSSION

Farmers employed a number of technologies/ practices strategically in response to seasonal variations in climatic conditions (Table 3). Most of the technologies showed significant, positive impacts on yields (Table 5), but they had different risk-reducing effects on yield. The different effects on yield variability could be attributed to technology characteristics and their intention in farming systems. Changing crop varieties ensured that farming households introduced crops that were best suited to the current climatic and other biophysical conditions peculiar to the site. In most cases, farmers introduced new crop varieties, however, this strategy was limited by resources for purchasing improved seed, hence the few farmers using it. It was mainly used in Mbale and Sironko, with better access to markets and less constraining pedoclimatic conditions than Pallisa. In a similar way, Kurukulasuriya and Mendelsohn (2006) demonstrated that crop selection is an important adaptation strategy to climate variability.

Innovations in soil and water conservation such as soil bunds, compost manure and cover crops address the risk of soil moisture deficits associated with shifting precipitation patterns besides controlling soil degradation, which would otherwise render the crops prone to unfavourable climatic conditions. Soil bunds were effective in increasing yields and reducing risk in all agro-ecologies because they minimised runoff, thus increasing infiltration of water into the soil. In this way, the soil bunds facilitated recharge of soil water storage capacity for the benefit of the crops against drought stress, apart from controlling soil degradation through erosion. This is in line with the observation that soil bunds were particularly effective in Mbale, which had rugged terrain prone to soil erosion.

Compost manure was particularly effective in Pallisa (Table 6). This is because the area receives less rainfall yet it has light-textured soils with poor soil moisture storage capacity and low cation exchange capacity for holding nutrients against leaching loss. Application of manure may have improved the available soil water storage capacity through increase in soil organic matter, which may have also contributed towards increased basic cation nutrient retention against leaching loss due to increase in cation exchange capacity of the soil. Empirical evidences from other studies also confirmed effectiveness of manure in reducing production risks in low rainfall zones (Wahba and Darwish, 2008; Kassie *et al*., 2009; Kato *et al*., 2009).

Cover crops can also achieve the same effects (Table 6) since their biomass ultimately ends up contributing to soil organic matter, hence their yield-increasing and yield stability effects in Pallisa. The effects of crop rotation and intercropping are mainly on the ability of these innovations to break the pest cycle, ensure crop diversification and thus reduce the risk of crop failure. For example, Di Falco *et al*. (2006) reported that variety richness increases farm productivity, and reduces yield variability. Dixon *et al*. (2001) showed that mixed cropping systems reduce crop losses due to pests and diseases and make more efficient use of farm labour.

Changed sowing dates had risk-reducing effects, though it did not show significant effects on mean yield. Changed sowing dates ensures more effective use of precipitation available during the season such that yields are optimised. This is in agreement with Chiotti *et al*. (1997), de Loë *et al*. (1999) and Smit and Skinner (2002) who reported that changing the timing of farm operations had the potential to maximise farm productivity during the growing seasons and to avoid heat stresses and moisture deficits during times of increased climate perturbations. The observed risk-increasing effects of changing crop density, particularly in Sironko are attributed to the fact that increasing crop density increased crop competition and subsequently reduced productivity.

The observed variability of technology effects by agro-ecological zone is attributed to the different biophysical characteristics and farming systems in these areas that define the farming potential (Table 1). Sironko is generally high rainfall zone, with higher variability both of

annual and seasonal rainfall (Kansiime *et al*., 2013) compared to Pallisa and Mbale, thus the possibility that location in Sironko would increase crop production risks. Gebremedhin *et al*. (1999), Bekele (2005), Kassie *et al*. (2008) and Kato *et al*. (2009) indicated significant variations in the effect of technologies in low and high rainfall zones. The effect of farmers' perception of rainfall on yield variability could be due to the fact that farmers' perception determines the timing of operations as well as the type of crops to grow. It is anticipated that if farmers' perception of rainfall adequacy is correct, adjustment in their farming operations should give risk-reducing effects on the variance of crop yield. Similarly, farmers' perceptions of technology effectiveness have a strong bearing on the decisions of what adaptations to employ.

The subjective assessment of technology effectiveness by farmers indicated that changed crop varieties, compost manure use and changed sowing dates were considered effective practices across the three study districts. This is in agreement with results obtained on effect of these production technologies on variance of yield (Table 7). The difference in rating technology effectiveness by districts is related to the differences in biophysical characteristics. For example in Sironko, land management practices were ranked most important. The high rainfall amounts and steep slopes make it vulnerable to water logging, erosion and mud slides. As such, land management practices such as soil bunds, mulching and cover crops are more relevant to farmers there. Pallisa, on the other hand, is generally flat with lower rainfall amounts. Thus, interventions in crop management were more appreciated by farmers and, thus ranked more effective than land management practices.

Study results have two implications: first, the need to develop and disseminate location specific adaptation technologies to reduce production risks, instead of blanket recommendations of similar adaptation measures across locations. For instance, in high-rainfall, highland areas (e.g. Sironko and parts of Mbale), placing appropriate land management measures such as soil bunds, mulching and cover crops, could help minimise runoff, increase infiltration and reduce soil degradation. In low lying and low-rainfall areas (e.g. Pallisa), interventions such as soil bunds and compost manure may be appropriate in conserving the little rains received, and improving fertility, respectively. Second, the need to focus not only on the technical aspects of technologies, but also the social dimensions such as perceptions of smallholder farmers of technology effectiveness, if adoption and retention of adaptation technologies by farmers is to be enhanced.

RECOMMENDATION

Development and research organisations promoting adaptation options should involve farmers in technology evaluation so as to recommend the most feasible options given farmers' situations and local perceptions.

ACKNOWLEDGEMENT

This paper is part of the PhD research work for the corresponding author. The study was partially funded by The Climate Food and Farming Network (CLIFF) of the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS). The authors thank the Uganda Meteorological Department for providing the rainfall data for this study. Farmers and key informants in Mbale, Pallisa and Sironko are also acknowledged. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 875 - 881 ISSN 1021-9730/2014 $4.00

PERFORMANCE OF ARTEMIA SHELL-FREE EMBRYOS, *Moina micrura* AND PHYTOPLANKTON ON LARVAE OF REARED AFRICAN CATFISH

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ABSTRACT

Starter feeds are important in the growth of African catfish *Clarias gariepinus* (Burchell) larvae. A study was conducted to investigate the performance of Artemia shell-free embryos, *Moina micrura* (Kurz) and phytoplankton as starter feed for larvae rearing of *C. gariepinus*. The experiment lasted 15 days in a set of nine tanks of 900-litre capacity. The study was divided into two phases of 5 and 10 days. During the end of the 15 days, the larvae fed on *M. micrura* had a growth rate of 32.95±12.62 % day^{-1}, survival of 76.51±7.33% and Specific Growth Rate (SGR) of 0.17±0.00. The larvae fed on Artemia exhibited a growth rate, survival and SGR of 85.5±74.4% day^{-1}, 97.71±0.00 % and 0.28±0.18, respectively. The larvae fed on phytoplankton exhibited a growth rate, survival and SGR of 36.1± 44.58% day^{-1}, 45.73±24.14% and 0.12±0.11, respectively. The difference in performance between the feeds was mainly due to differences in their nutrient composition and levels. This study recommends the use of Artemia embryos as the best starter feed for the rearing of *C. gariepinus* larvae followed by the *M. micrura*.

Key Words: *Clarias gariepinus,* growth rate, specific growth rate, survival

RÉSUMÉ

Les aliments d'entrée sont importants pour la croissance des larves du poisson-chat Africain *Clarias gariepinus* (Burchell). Une étude était menée à la station de recherche de l'Institut de Recherche sur la Pêche (TAFIRI) de Mwanza en Tanzanie pour évaluer la performance des embryons dénudés d'Artémia, *Moina micrura* (Kurz) et les phytoplanctons comme aliments d'entrée pour la croissance des larves de *C. gariepinus*. L'expérience a durée 15 jours dans un ensemble de neuf réservoirs d'une capacité de 900 litres. L'étude était subdivisée en deux phases de 5 et 10 jours. Vers la fin de ces 15 jours, les larves nourris de *M. micrura* avaient un taux de croissance de 32.95±12.62 % par jour, 76.51±7.33% de survie et un taux de croissance spécifique (SGR) de 0.17±0.00. Les larves nourries sur base d'Artémia ont montré un taux de croissance ; un taux de survie et une SGR de 85.5±74.4% par jour, 97.71±0.00 % et 0.28±0.18, respectivement. Les larves nourries de phytoplanctons ont manifesté un taux de croissance, une survie et un SGR of 36.1± 44.58% par jour, 45.73±24.14% et 0.12±0.11, respectivement. La différence en termes de performance entre les aliments utilisés était principalement dûe aux différences dans leur composition en matière nutritives et concentration minérales. Cette étude recommande l'utilisation d'embryons d'artémia comme meilleur aliment d'entrée pour la croissance des larves de *C. gariepinus*, suivie de *M. micrura*.

Mots Clés: *Clariasgariepinus,* taux de croissance, taux spécifique de croissance, survie

INTRODUCTION

Aquaculture has been practiced since 1940s in East Africa, but the industry remains relatively undeveloped largely due to dependence on aquatic products from capture fisheries. Currently, due to decline in most of the capture fisheries and increased demand for protein of aquatic products, the need for an alternative source, particularly from aquaculture is growing. One of the major obstacles towards development and the ultimate takeoff of the aquaculture industry is lack of technologies and availability of affordable and quality fish seed and feed (FAO, 2006; Mwanja *et al.,* 2006). The need for quality fish seed for aquaculture production and availability has proved a challenge due to the associated larval complications during their ontogenetic stages (Luizi *et al*., 1999).

Since most larvae of marine and some fresh water species such as *Clarias gariepinus*, (Burchell 1822) do not have a functional digestive system at the start of exogenous feeding (Govonni *et al.,* 1986; Luizi *et al.,* 1999), feeding them with food containing simple compounds such as brine shrimps (Artemia), rotifers (i.e., *Brachionus plicatilis* (Müller 1786), cladocerans (i.e., Daphnids, *Moina micrura* (Kurz 1874)) and phytoplankton have been employed with successful outcomes (Govonni *et al.,* 1986; Lubzen *et al*., 2001; Hamre, 2006; Olurin *et al.,* 2012). Normally, most live feeds used perform differently in different larval types (Lubzen *et al*., 2001; Hamre, 2006; Olurin *et al.,* 2012). Therefore, it is important that any live feed type is tested first for its performance before it is assigned for a particular species.

Although *Artemia nauplii* and decapsulated cysts have for long been used successfully in first feeding of most fish larvae (Luizi *et al.,* 1999; Yilmaz *et al*., 2006; Olurin *et al.,* 2012), their increasing cost is a constraint to most of the poor subsistence farmers, especially in sub-Saharan Africa. In this regard, efforts towards the search for alternative feed sources have been ongoing. Although copepods are much more nutritious than rotifers and cladocerans in larval culture, the preference is more for rotifers and cladocerans mainly because of their relative easiness of mass culture (Luizi *et al.,* 1999; Evjemo *et al.,* 2003; Mckinnon *et al.,* 2003). In addition, the cladoceran zooplankton of the genus Moina have for long been used as a starter food for the larvae of most fish like *Chanos chanos* and *Clarias macrocepaphalus* (Yilmaz *et al.,* 2006).

This study aimed at exploring the performance of Artemia shell-free embryos, *M. micrura* and phytoplankton as feed for larvae of African catfish (*C. gariepinus*). It was hypothesized in this study that *C. gariepinus* larvae fed on Artemia shell-free embryos will attain higher growth performance than those fed on *M. micrura* and phytoplankton.

MATERIALS AND METHODS

The experiment was carried out at the Tanzania Fisheries Research Institute (TAFIRI) located at Mwanza, Tanzania from 10 March 2013 to 25 March 2013. Three African catfish females and four males were subjected to artificial propagation (Olumuji and Mustapha, 2012) to lead to larvae for the study. During the implementation of this study, it was difficult to get enough sperms from individual males to fertilise the eggs, which necessitated the use of more males than females. Five days old post-hatch larvae (already exhausted their egg yolk and ready for exogenous feeding) were used to test the performance of Artemia shell-free embryos, *M. micrura*, and phytoplankton feeds.

Initially, the larvae were randomly picked and distributed equally into nine experimental tanks (white plastics of 900 litre capacity). Each of the nine tanks contained 800 larvae. Before the start of the experiments, 20 larvae were randomly collected from each of the tanks, and their individual weights and total lengths measured using a 110 g capacity and 0.0001g sensitivity balance (MODEL ADVENTURE PRO AV114C, USA) and a 30-cm ruler, respectively. The tanks (each feed treatment replicated thrice) were maintained on flow-through-system using water directly pumped from Lake Victoria, then filtered, aerated, and allowed to flow under gravity. The larvae in the experimental tanks were fed to satiation three times a day, at 09.00, 13.00 and 16.00 hr. Concurrently with feeding, water quality parameters (pH, dissolved oxygen, and temperature) were monitored three times a day.

Temperature and pH were measured using a portable pH-Temperature meter (HI 991300 pH/EC/TDS/Temperature meter, USA), while dissolved oxygen (DO) was measured using a portable Oxygen meter (HI 9143 Microprocessor Oxygen meter HANNA instruments, USA).

The feeds performance experiment lasted 15 days and was divided into two phases. The first phase, which lasted five days involved feeding the larvae in their respective replicate tanks with Artemia, *M. micrura*, and phytoplankton per se. The second phase (the weaning phase) lasted 10 days and involved supplementing the larvae with a formulated diet (Ugachick: 35% crude protein, 7% lipid, 6.5% crude fibre, 7% ash and 11% moisture), an acclimatisation process towards feeding them with formulated feeds. Ugachick supplementary feed was obtained from Ugachick Poultry Breeders Ltd, based in Uganda. At the end of each phase, the larvae in the nine tanks were randomly sampled to obtain 30 larvae, which were weighed using a 110 g capacity and 0.0001g sensitivity balance, MODEL ADVENTURE PRO AV114C. The total lengths of the larvae were also measured to the nearest 0.1 millimetre using a 30-cm ruler. The faeces and uneaten feed at the bottom of each tank, including the dead larvae were syphoned out daily at 08.00 hr, using a 1 cm thick and 5 m long plastic pipe. The dead larvae were counted for calculation of percentage survival, while the live larvae were separated from the impurities and returned to the tanks.

Growth performance indices. Growth parameters were determined using both length and weight following the formulas provided in Olurin *at al*. (2012):

$$GR = 100 \times (W_f - W_i)/(T \times L_i) \quad \text{(i)}$$

$$GR = 100 \times (L_f - L_i)/(T \times L_i) \quad \text{(ii)}$$

$$SGR = (\ln W_f - \ln W_i)/(T_2 - T_1) \quad \text{(iii)}$$

$$SGR\ (mm/day) = (\ln L_f - \ln L_i)/(T_2 - T_1) \quad \text{(iv)}$$

$$SR\ (\%) = 100 \times N_s/N_{-i} \quad \text{(v)}$$

Where:

GR = growth rate,
SGR = specific growth rate,
SR = survival rate,
W_f = final weight (mg),
W_i = initial weight (mg),
L_f = final length (mm),
L_i = initial lenght (mm), and
T = time in days

T_1 and T_2 represent initial and final time (days); Ns and Ni represent number of survivors and initial number of fish, respectively.

The condition factor of *C. gariepinus* larvae was calculated according to Madu *et al.* (2003):

$$CF = 100 \times W/L^3 \quad \text{(vi)}$$

Where: w = weight of fish in mg, L = length of fish in mm.

Feed preparation and application. The *M. micrura* cultured in the six black plastic tanks (900-litre capacity) were filtered and concentrated using a 60 µm zooplankton net to make a solution with a density of >2000 individuals in a litre of water, prior to being fed to *C. gariepinus* larvae. Nine litres of the Moina solution were prepared for feeding *C. gariepinus* larvae in the Moina treatment tanks in each feeding day. The *C. gariepinus* larvae in each tank were supplied with 1 litre of the solution three times a day at 09.00, 13.00 and 16.00 hr making a total of three litres per day per each tank.

The phytoplankton used as feed in this study was obtained from three 900 litre-capacity black plastic tanks, which were initially applied with 250 g of urea and lake water (containing phytoplankton) and then left for two months for algae to develop. The algae in the tanks peaked and collapsed from time to time before it changed to some naked eye visible particles. Water in the tanks was first homogenised using a 5 cm thick and 1 m long stick and then filtered for debris and some water insects that otherwise would scare or predate on the larvae. Twenty litres of phytoplankton were then added to the three tanks to test its performance as feed for *C. gariepinus* larvae. The feeding protocol (specified time interval) followed above was also adopted here.

The Artemia shell-free embryos (INVE Aquaculture, INVE (Thailand) LTD. www.ive.com) were imported from Durante Fish Company in Nigeria, at an average price of US$ 45 per tin of 500 g. A tin of 500 g was enough to rear an average of thirty thousand African catfish larvae in 2 weeks. During each feeding interval, Artemia were weighed and then fed to larvae by smearing on the surface of the water in the tanks.

Samples of the dried *M. micrura,* phytoplankton and Artemia shell-free embryos were proximate analysed for crude protein, lipid, crude fibre, and ash contents.

Statistical analysis. A One-way Analysis of Variance (ANOVA) was used to test for significant differences in growth performance, water quality parameters among the treatments, and in nutrient composition among different experimental diets. Post hoc analysis was done using Tukey HSD test (Zar, 1999). The analyses were done using SPSS version 17 (SPSS Inc, USA). The p-value was set at < 0.05.

RESULTS

During the 1st phase of the experiment, there were no significant differences (P>0.05) in growth of the three different tested feeds (Table 1). However, *C. gariepinus* larvae fed with Artemia shell-free embryos had the highest growth rate, while the larvae fed with phytoplankton tended to have the poorest respective parameters. During this phase, pH values ranged from 7.36 ± 0.34 to 7.85 ± 0.014, while DO and temperature ranged from 4.17 to 5.86 mg O_2 L^{-1} and 27.30 to 28.50 °C, respectively. There was no significant difference between the measured water quality parameters (P>0.05).

During the 2nd phase (weaning) of the experiment, there were significant differences in growth performances of the African catfish larvae (P = 0.007, Table 2), with larvae fed on phytoplankton performing best (Table 2). The catfish larvae fed with phytoplankton had the highest growth rate (67.62% day^{-1}) and SGR (0.2), however, with lowest survival percentage (28.66%). During this phase pH values indicated a range of 6.66 ± 0.12 to 6.89 ± 0.04, while DO and temperature ranged from 3.84 ± 0.08 to 4.89 ± 0.01 mg O_2 L^{-1} and 23.15 ± 0.07 to 25.90 ± 0.14 °C, respectively. There was no significant difference between the measured water quality parameters.

On average, Artemia-shell free embryos performed the best, *Moina micrura* the second and phytoplankton the last (Table 3). There was significance in differences of all the growth parameters, except for conditional factor (P= 0.005).

Artemia had the highest crude protein content (41.89%), followed by *M. micrura* (38.25%) and phytoplankton (14.36%) (Table 4, P<0.01).

DISCUSSION

Artemia shell-free embryos performed best in the larvae rearing of *C. gariepinus*, which can be attributed to the fact that this feed had the best nutrient composition (i.e. highest protein and lowest ash content) compared with *M. micrura*

TABLE 1. Growth rate, SGRs, and percentage survival of the *Clarias gariepinus* larvae fed with Artemia shell-free embryos, live *Moina micrura,* and phytoplankton during the 1st phase (the first five days) in a feeds experiment in Tanzania

Parameter	Artemia	*Moina micrura*	Phytoplankton
Initial average weight (mg)	3.28±0.01	3.28±0.01	3.28±0.01
Final average weight (mg)	25.93±5.02	7.22±1.17	4.03±0.57
Initial average length (mm)	7.00±0.00	7.00±0.00	7.00±0.00
Final average length (mm)	14.2±0.78	11.20±0.84	9.57±0.79
Growth rate (% day^{-1})	138.11	24.02	4.57
SGR	0.41	0.16	0.04
Percentage survival	97.70	81.70	62.8
Condition factor (CF)	0.906	0.514	0.459

TABLE 2. Performance of *Clarias gariepinus* larvae fed with Artemia shell-free embryos, live *Moina micrura,* and phytoplankton during the 2nd phase (the last 10 days or the weaning phase) in a feeds experiment in Tanzania

Parameter	Artemia	*Moina micrura*	Phytoplankton
Initial weight (mg)	25.93±5.02	7.22±1.17	4.03±0.57
Final weight (mg)	111.23±41.10	37.46±8.13	31.28±10.78
Initial length (mm)	14.2±0.78	11.20±0.84	8.23±0.76
Final length (mm)	20.60±1.58	13.60±2.27	13.20±2.28
Growth rate (%/day) (nsd)	32.89	41.88	67.62
SGR(sd)	0.15	0.17	0.2
Survival (%) (sd)	97.71	71.32	28.66
Condition factor (CF) (sd)	1.27	1.49	1.36

nsd = not significant difference, sd = significant difference

TABLE 3. Average growth rate, specific growth rate, and survival percentages of *Clarias gariepinus* larvae fed with Artemia shell-free embryos, live *Moina micrura,* and phytoplankton

	Artemia	*Moina micrura*	Phytoplankton
Initial average weight(mg)	3.28±0.01	3.28±0.01	3.28±0.01
Final average weight(mg)	111.23±41.10	37.46±8.13	31.28±10.78
Initial average length (mm)	7.00±0.00	7.00±0.00	7.00±0.00
Final average length (mm)	20.60±1.58	13.60±2.27	13.20±2.28
Growth rate (%/day) (sd)	85.5±74.4	32.95±12.62	36.1± 44.58
SGR(sd)	0.28±0.18	0.17±0.00	0.12±0.11
Survival (%)(sd)	97.71±0.00	76.51±7.33	45.73±24.14
Condition factor (CF) (nsd)	1.10±0.26	1.00±0.69	0.90±0.64

nsd = not significant difference, sd = significant difference

TABLE 4. Proximate analysis of feeds used in a study of catfish in Tanzania

Feed	Crude protein (%)	Lipids (%)	Crude fibre (%)	Dry matter (%)	Ash (%)
Artemia	41.89	1.55	3.35	89.26	10.89
M. micrura	38.25	6.61	9.51	94.33	44.41
Phytoplankton	14.36	3.74	13.62	87.32	24.14

and phytoplankton. The Artemia shell-free embryos had, as well, some special advantages over other live feeds used. For example, the product was clean and easily administered to fish in specified amounts without requiring further processing; and could safely be stored for longer time periods. The only major constrain with the feed was that it was not available in the East African markets, thus the need for importation. The finding that Artemia was superior in our study corroborates with that of Olurin and Oluwo (2010) and Olurin *et al*. (2012) who compared the performance of decapsulated Artemia, copepods, and a commercial diet. Their work attributed the best performance of Artemia to the fact that it had balanced nutrient composition compared to other feeds. Generally, Artemia has been appreciated worldwide as a good starter feed for

the larvae of most fresh water and marine fish (Harzevilli *et al.,* 2004; Olurin and Oluwo, 2010; Olurin *et al.,* 2012).

The *M. micrura* feed ranked second after Artemia shell-free embryos. This finding corresponds with the documented nutrient composition of the feeds, which was best for Artemia and *M. micrura* the second. The possibility that *M. micrura* was a bit less palatable compared to Artemia cannot be ignored as *C. gariepinus* larvae when feeding depend heavily on chemosenses rather than visual or mechanical senses (Mukai and Seng Lim, 2011). The possibility that the larvae had small mouths to ingest some big sized *M. micrura* is not a possibility. Yilmaz *et al*. (2006) indicated that African catfish larvae normally have mouths big enough to ingest some big sized zooplankton, such as copepods and cladocerans. Fish larvae of one week old of common carp failed to ingest the *M. micrura,* but ingested higher number of rotifers (Yilmaz *et al*., 2006). The suitability of zooplankton of the genus *Moina* as a good starter feed for fish larvae was also recommended by Hashim and Ali (1990) and Adeyemo *et al*. (1994).

M. micrura contained 38.25% crude protein, 6.61% crude lipid, 9.51% crude fibre and 44.41 % ash (Table 4). Our finding differ from those of Hashim and Ali (1990) that *M. micrura* contained 60.72% crude protein, 18.12% crude lipid, 9.95% carbohydrate, 11.21% ash, 7.81 dry matter and 93.46% moisture. This suggests that the nutrient composition of the cultured *M. micrura* normally vary depending on geographical locations.

The phytoplankton exhibited the poorest growth and survival which can be attributed to the fact that this feed had poorest protein and highest ash content. The fact that phytoplankton does not make a good feed to the larvae of *C. gariepinus* was also observed by Yilmaz *et al*. (2006). Thus, when using phytoplankton as a feed it is important to consider other supplement feeds such as rotifers and *M. micrura.* The lowest survival rate observed in this study could be attributed mainly to cannibalism due to large differences in size, suggesting that the weak and small sized larvae were selectively eliminated by the strong ones (Olurin and Oluwo, 2010; Marimuthu, 2011; Olurin *et al.,* 2012).

ACKNOWLEDGMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 883 - 896 ISSN 1021-9730/2014 $4.00

ENHANCING PRODUCTION THROUGH OPTIMISATION OF DPPH AND RADICAL SCAVENGING ACTIVITY OF GRAPE SEED EXTRACTS

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ABSTRACT

Polyphenols are important for their pharmacological activity and positive contribution to cellular processes within the body. They have the capacity to protect against oxidation of High Density Lipids (HDL) and, thus help the body to retain HDL, while removing the problematic Low Density Lipids (LDL). Polyphenols also possess anti-ulcer, anti-carcinogenic and anti-mutagenic activities. The objective of this study was to evaluate the effect of temperature and grain size of grape seed on the efficiency of extraction of polyphenols from grape seed, using the compressed hot water and solvent extraction techniques. Polyphenols were extracted from milled (<0.5 mm) and whole grape seed, using compressed hot water (high temperature and high pressure) and solvents (Acetone, Methanol and Ethanol). The total polyphenol content and DPPH radical scavenging activity of the extracts were determined using spectrometer and the active compounds identified using HPLC. Total polyphenol content increased with extraction temperature, but decreased at 200 °C. The difference in polyphenol extracts from the milled and whole seed decreased with increase in temperature, but was more evident at 135 °C. The 2 hour extracts showed relatively higher values than those for 1 hour, with the lowest difference occurring at 165 °C and the highest at 180 °C. Solvent extracts from whole seeds were very low compared with the milled seeds, with acetone showing the highest value of 105 mg g^{-1} dry matter for polyphenol content and 110 mg g^{-1} of dry matter for DPPH radical scavenging activity. Methanol had the lowest value (78 mg g^{-1} dry matter) for polyphenol extracts and 80 mg g^{-1} for the DPPH radical scavenging activity. The main extract compounds were gallic acid, catechin and epicatechin.

Key Words: High density lipids, polyphenol, radical scavenging

RÉSUMÉ

Les polyphénols sont importants eu égard à leur activité pharmacologique et leur contribution positive aux processus cellulaires dans le corps. Ils sont doués d'une capacité protective contre l'oxydation des Lipides à Densité Elevée (HDL) et, ainsi aident le corps à maintenir le HDL, tout en éliminant les problématiques Lipides à Basse Densité. Les polyphénols possèdent aussi des activités anti-ulcères, anticarcinogènes et antimutagènes. L'objectif de cette étude était d'évaluer les effets de la température et taille des grains de raisin sur l'efficacité de l'extraction des polyphénols des grains de raisin, utilisant une eau chaude compressée et des techniques d'extraction au solvant. Les polyphenols étaient extraits des grains entiers de raisin et des grains moulus (<0.5 mm) à l'aide d'une eau chaude compressée (température élevée et haute pression) et des solvants (Acétone, Méthanol et Ethanol). La concentration totale des polyphénols et l'activité d'absoption du radical DPPH des extraits étaient déterminés à l'aide du spectrophotomètre et les composés actifs identifiés par HPLC. La concentration totale des polyphénols a augmenté avec la température d'extraction, mais a diminué à 200 °C. La différence dans les extraits de polyphénol des grains moulus et entiers a diminué avec l'augmentation de la temperature, mais était plus

évidente à 135 °C. Les extraits de deux heures ont montré des valeurs relativement plus élevées que ceux d'une heure, avec les différences les plus faibles apparaissant à 165 °C et les plus élevées à 180 °C. Les extraits de graines entières aux solvants étaient de faible quantité en comparaison avec ceux des grains moulus, les valeurs les plus élevées étant de 105 mg g^{-1} de matière sèche de polyphénol et 110 mg g^{-1} de matière sèche d'absorption du radical DPPH obtenues en utilisant l'acétone comme solvant. Les extraits obtenus au méthanol comme solvant étaient encore en plus faible quantité avec 78 mg g^{-1} de la matière sèche pour les extraits du polyphénol et 80 mg g^{-1} pour l'activité d'absorption du DPPH. Les principaux composés de ces extraits étaient des acides galliques, des catéchines et des epicatéchines.

Mots Clés: Lipides à densité élevée, polyphénol, radical de fouille

INTRODUCTION

Plant polyphenols are the most important group of natural antioxidants because of their diversity and extensive distribution. They possess the ability to scavenge both active oxygen species and electrophiles. Recent investigations have shown that many phenolic compounds, including flavonoids, tannins and phenolic acids, exhibit strong antioxidant properties. In some fruits, polyphenols with antioxidant properties such as flavonoids, procyanidins and anthocyanins, have been identified by High Performance Liquid Chromatography (HPLC), Nuclear Magnetic Resonance (NMR) or Mass Spectrometer (MS) methods (Sun *et al.,* 2007).

Several methods have been used to approximate the antioxidant efficiency of natural extracts, and one such common method is the diphenylpicrylhydrazyl (DPPH) radical scavenging activity method. Some of the areas of application of antioxidants that are of great concern to human beings include aging and age-related diseases. Attention has, therefore, been focused on plant resources that contain physiologically active phenolic compounds that show chelation and antioxidative effects of the radicals responsible for the aging process (Barclay, 2008).

Antioxidant compounds are chemical substances that donate an electron to the free radical and convert it to a harmless molecule. They are able to intercept free radicals and protect cells from the oxidative damage that cause aging and age related diseases. They also prevent injury to blood vessel membranes, help to optimise blood flow to the heart and brain, provide defence against cancer-causing DNA damage, and help to lower the risk of cardiovascular disease and dementia including Alzheimer's disease (Duthie, 1999; Barclay, 2008).

There is increasing consciousness among consumers about the role of food in the management of lifestyle diseases, and more people are now adopting natural and healthy body care practices. Thus, more healthy products are being developed and recognised as useful commercial products. One of the well known sources of such healthy products is the grape seed. Effective and efficient extraction of polyphenols from grape seeds has, however, remained one of the biggest challenges. Use of water as a solvent has been recommended by many researchers (Murga *et al.*, 2002; García-Marino, 2006; Nawaz *et al.*, 2006; Yilmaz and Toledo, 2006) since it has been found to be safe and efficient. This method is classified as a hydrothermal reaction (reaction with hot water at high pressure). During hydrothermal reaction, the rise in temperature decreases permittivity of the water resulting in change of the ionic compounds. It is, therefore, a simple process through which extractions can be done at about 180 °C. Such high temperature of extraction falls in the super-criticality and sub-critical regions (Amano, 2006). Although much work has been done on the properties of grape seed extracts, optimisation of effects of temperature and grain size of grape seed on the efficiency of extraction of polyphenols from grape seed using the compressed hot water and solvent extraction techniques has not been done.

The objective of this study was to evaluate the effect of temperature and grain size of grape seed on the efficiency of extraction of polyphenols from grape seed using the compressed hot water and solvent extraction techniques.

MATERIALS AND METHODS

Seed preparation. The test material used was grape (*Vitis vinifera*) seed (cv. Campbell Early) from a wine factory in Iwate Prefecture, Japan. The grape seed was washed sufficiently in a laboratory with tap water, allowing it to attain 20% moisture content. The seeds were then dried in a constant temperature oven (SANYO, MUV-212) to 13% moisture content and stored under refrigeration at 4 °C.

Variation of grain size was attained through pulverisation using a rice mill (National, MK-51M, Japan). Pulverisation was done intermittently using a rice mill at 10 seconds interval to minimise heat generation. The seeds were milled using a rice mill and sieved using a 0.5 mm screen sieve to obtain samples of <0.5mm. Before extraction, about 5 g of the seed and milled sample were weighed and used to determine the moisture content using the oven method at 105 °C for 24 hours. The final dry weight of the sample was obtained at equilibrium and used in the computation of the wet and dry basis moisture content.

Sample extraction

Hydrothermal extraction. Three samples were extracted each at 80, 105, 120, 135, 150, 165, 180 and 200 °C. A sample of 0.4 g was taken and put in a batch type titanium autoclave container of 80 ml capacity (40 mm diameter, 125 mm length and 4 mm thickness) (Figs. 1 and 2). A volume of 40 ml of distilled water was then added before tightly closing the container and putting it in a hot air oven for 1 and 2 hours for each sample.

After extraction, the titanium autoclave container was removed from the oven and cooled suddenly with cold tap water. Samples from the container were filtered using a 0.2 µm micro-filter (ADVANTEC, DISMIC-25cs) as described by Xu *et al.* (2003), Buciæ-Kojiæ *et al.* (2007) and Wiboonsirikul *et al.* (2008). The filtered sample (Fig. 3) was then subdivided into 1.5 ml tubes and frozen in liquid nitrogen before being stored in a freezer. The frozen sample was only removed and thawed at room temperature for analysis.

Organic solvent extraction. Solvent extraction was carried out using 50% proportion of acetone, methanol and ethanol solutions separately at 25 °C. A total of 0.4 g of whole seed and milled samples (<0.5 mm) were put in a conical flasks

Figure 2. Titanium extractor.

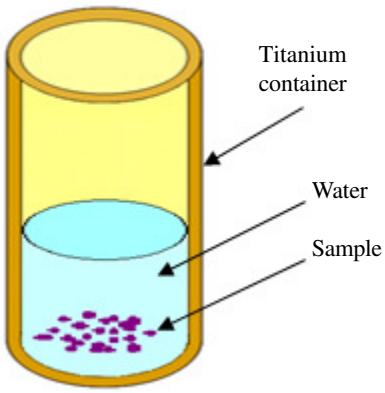

Figure 1. Sketch of Titanium extractor.

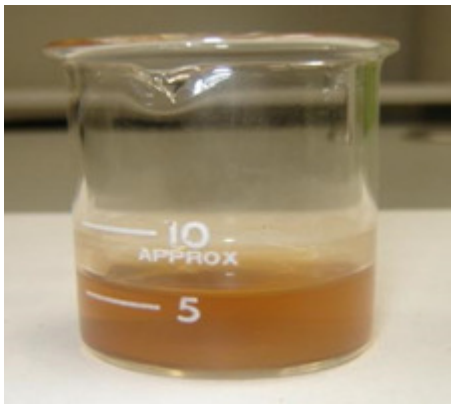

Figure 3. Grape seed extract at 200 °C (2 hrs).

and 40 ml of the solvent added. The mixtures were covered with aluminium foil and allowed to settle, without shaking, for 2 hours. The extract was then filtered using a 0.2 µm micro-filter (ADVANTEC, DISMIC-25cs). The filtrate was directly used for analysis.

Sample analysis

Polyphenol content. Total polyphenol content was determined using the Folin-Ciocalteu method, outlined by the Journal of the Japanese Society for Food Science and Technology (2006). The samples from the fridge were warmed to melt and diluted five times for those extracted between (80-165 °C); and ten times for those extracted between 180-200 °C, using distilled water as per equipment specification. A volume of 0.1 ml of the diluted sample was added to 1.6 ml of distilled water before adding 0.1 ml of Folin-Ciocalteu liquid and 0.2 ml of 20% $NaCO_3$. The mixture was homogenised using an electric stirrer and allowed to react under darkness for 30 minutes. The absorbance of the mixture was measured at 760 nm, three times using a UV/VIS spectrometer (JASSO, V-530). The spectrometer absorbance was calibrated using gallic acid solution of 10 mM L^{-1} obtained by dissolving 170.1 mg of gallic acid in 100 ml of distilled water. The solution was diluted to give 5, 2, 1 and 0.5 mM L^{-1} solutions, which were used in place of the sample. The spectrometer reading of the diluted solutions was plotted against their concentrations to derive the calibration curve to standardise the sample spectral readings. The total phenol content was, therefore, calculated as the weight of gallic acid equivalent per dry matter content of the sample. The test was repeated twice for the temperature range of 150-180 °C, in order to improve accuracy of results.

DPPH Radical scavenging activity. The DPPH radical scavenging activity was determined according to the methods by Ye *et al.* (2009) and Leong and Shui (2002), with minimal modification. DPPH (1-1Diphenyl-2Picrylhydrazyl) solution was prepared by dissolving 8 mg of DPPH in ethanol and then diluting it with distilled water to make 50 ml of DPPH solution. A total of 0.2 ml of water was mixed with 1.8 ml of DPPH solution and its absorbance measured immediately using the spectrometer set at 517 nm to give the reading C_0. A similar sample was kept in a dark cabin at 25 °C for 30 minutes and its absorbance then measured to give the reading C_{30}. A measure of 0.2 ml of the diluted sample was added to 1.8 ml of DPPH solution and 1.8 ml of distilled water. The samples were shaken and kept at 25 °C in a dark cabin for 30 minutes. The absorbance of the samples was then measured by the spectrometry to give the readings C_D for DPPH mixture and C_W for water mixture. The DPPH radical scavenging activity of the sample (SA) was computed as:

$$SA = \frac{\{C_0 - (C_D - C_W)\} \times 100}{C_{30}} \quad \text{..... (1)}$$

Calibration of the spectrometer was done using Trolox (97%) solution of 1 mM L^{-1} obtained by dissolving 25 mg of the organic compound in 100 ml of water. The solution was diluted into four different portions of 0.5, 0.4, 0.2 and 0.1 mM L^{-1}. The four portions were then used in place of the sample during the spectrometer analysis. A calibration curve of SA value for Trolox against Trolox concentration was plotted and its gradient used to approximate the actual SA value of the sample reported as mg of Trolox equivalent per g of dry matter.

HPLC analysis. The High Performance Liquid Chromatography analysis was carried out using the LC-20A type (Shimazu-Japan) analyser using 23% Methanol and 77% phosphoric acid mixture as column fluid flowing at 1.0 ml min^{-1}. The test column temperature, pump pressure and wavelength were set at 40 °C, 6.0 MP and 280 nm, respectively. The samples were diluted 5, 10 or 20 times based on their concentration. Measurement was done by injecting 20 µl of the diluted sample into the analyser resulting in the print out of the sample chromatogram. The calibration of the analyser was done using gallic acid, catechin, epicatechin, epigallocatechin and epigallocatechin gallate. Using the sample chromatogram area and that of the calibration compound with the same retention time, the compounds in the sample were identified and quantified in mg 100 ml^{-1}. The tests were repeated twice and the average computed. Statistical

analysis was done using the Tukey method, at five percent confidence level ($P < 0.05$).

RESULTS AND DISCUSSION

Compressed hot water extraction

Polyphenol content. The polyphenol content in the extracted samples generally increased with increase in temperature, with the fine milled sample showing the highest value (Fig. 4). The extractable value for seeds more than doubled between 80 °C (hot water extraction) and the 120 °C (compressed hot water extraction) with a similar trend occurring between 120 and 135 °C. The extractable values for milled seeds increased gradually with temperature, increasing sharply at 180 °C and then decreasing at 200 °C. The decrease could be attributed to denaturing of polyphenols due to high temperatures. There was a significant difference in the extractable values from whole and milled seeds between 80 and 120 °C and at 180 °C (Fig. 4). However, between 135 and 165 °C and at 200 °C, no significant difference ($P>0.05$) was observed, indicating that whole seed would be suitable for polyphenol extraction.

Extraction time between one and two hours, showed no significant variation in the extractable values except at 180 °C (Fig. 5). This implies that extraction time could significantly be reduced with minimal effect on the efficiency of polyphenol extraction.

DPPH radical scavenging activity. The DPPH radical scavenging activity of grape seed generally increased with temperature and reduction in grain size, with a sharp increase for seed between 80 and 105 °C and between 120 and 135 °C. The extractable values for milled seed, however, increased gradually over the whole temperature range, showing a decrease at 200 °C (Fig. 6). The extractable values after one hour of treatment were generally lower than those after two hours. The difference between the two, however, decreased with increase in temperature (Fig. 7).

There was a strong linear correlation between polyphenol content of whole seed and the DPPH radical scavenging activity ($r^2 = 0.974$, Fig. 8). The relationship showed that the DPPH radical scavenging activity of the seed extract was higher than the polyphenol content by about 20%, irrespective of temperature and form of seed used to extract the compounds. The relationship for milled seed was, however, exponential, with a correlation coefficient of $r^2 = 0.953$ (Fig. 9). In this case, the DPPH radical scavenging activity was still high.

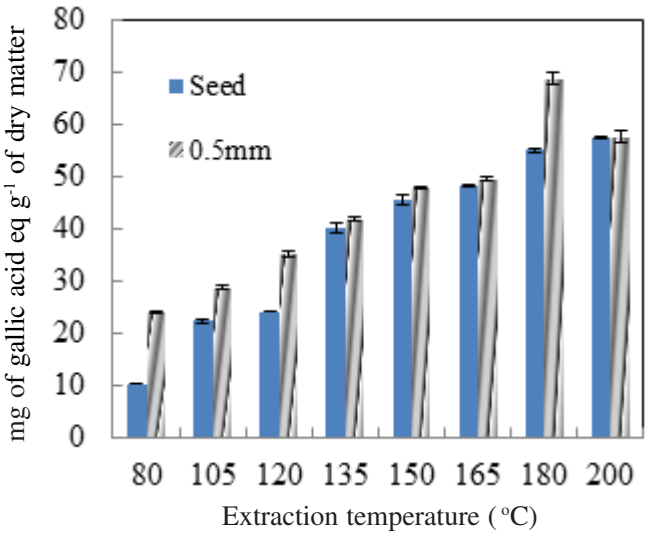

Figure 4. Effect of temperature and seed size on polyphenol content of whole and milled grape seed.

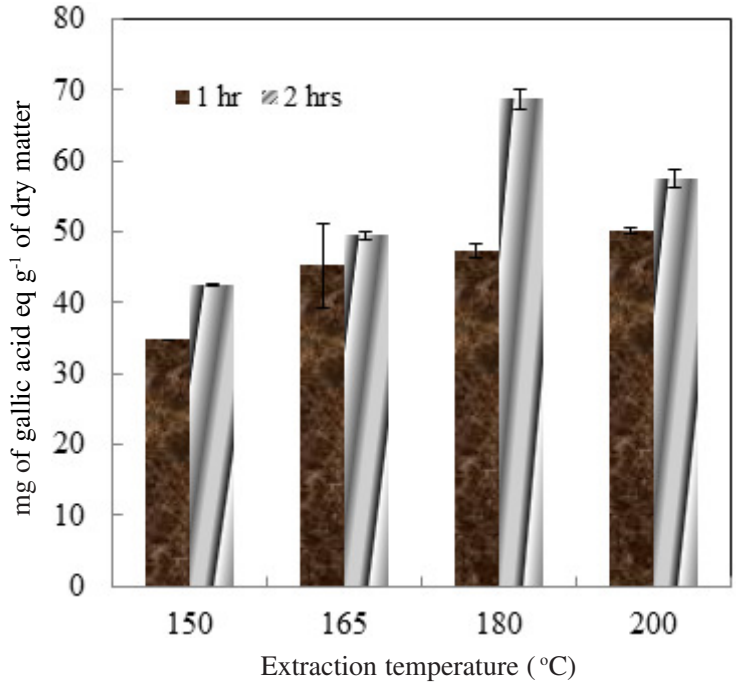

Figure 5. Effect of time and temperature on polyphenol content of milled grape seed.

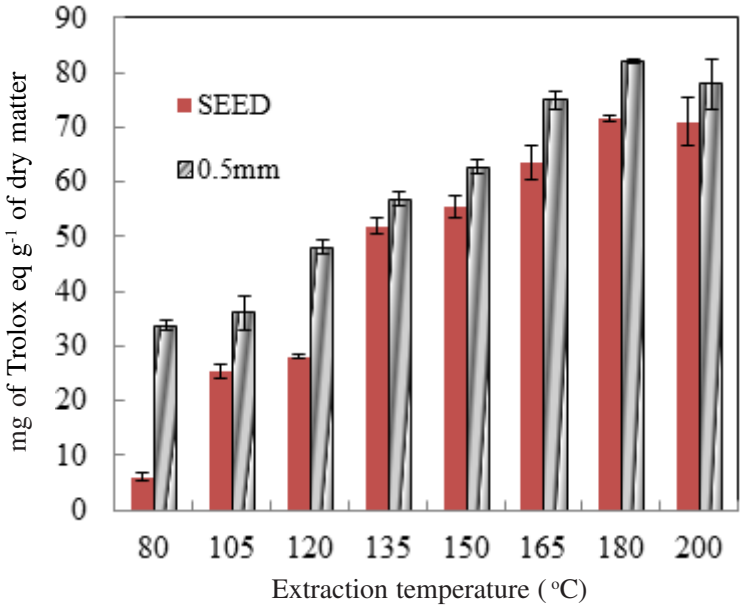

Figure 6. Effect of temperature in DPPH radical scavenging activity of whole and milled grape seed.

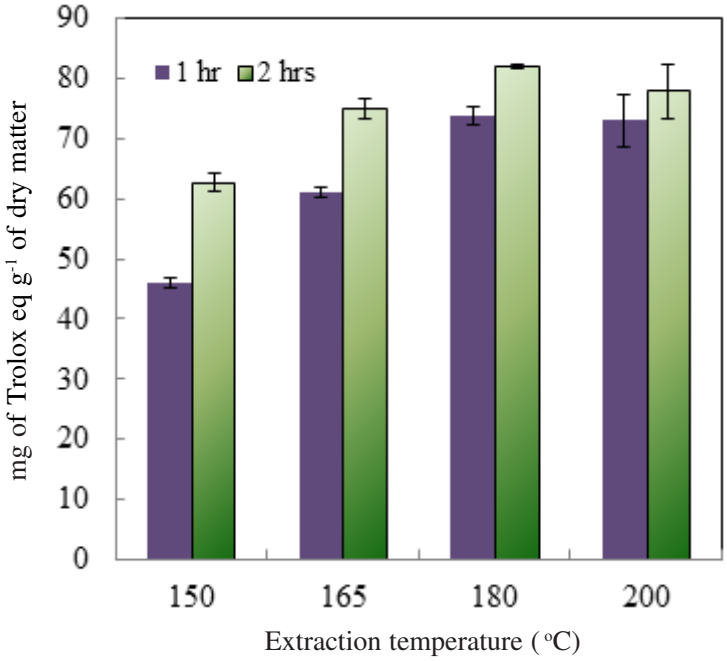

Figure 7. Effect of time and temperature on milled grape seed (<0.5 mm).

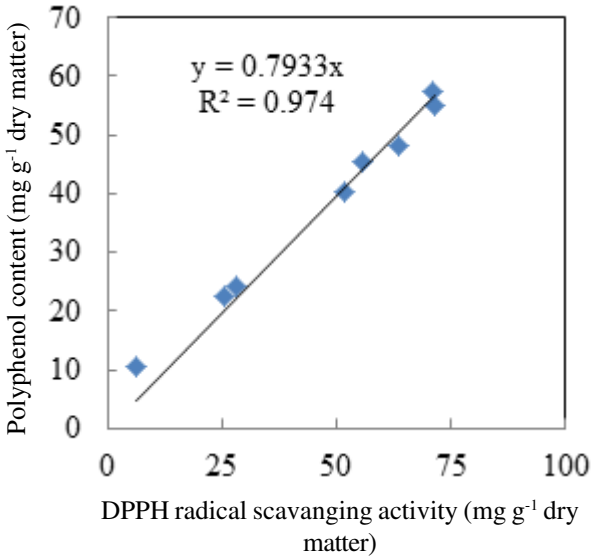

Figure 8. Correlation of polyphenol and DPPH for whole grape seed.

HPLC analysis. Based on HPLC analysis, four types of organic compounds were identified in the compressed hot water extracts at all temperatures (Fig. 10). The identified compounds were mainly Gallic acid (GA), Catechin (CT), Epicatechin (ECT), Epigallocatechin (EGCT) and Epigallocatechin gallate (EGCTG). There were, however, many other compounds which were not identified.

The content of organic compounds increased slightly with increase in temperature, with an extract content of less than 10 mg/100 g^{-1} of dry

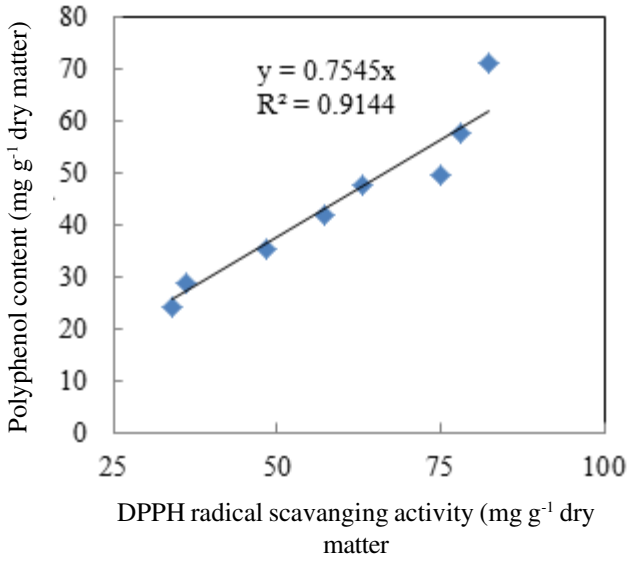

Figure 9. Correlation of polyphenol and DPPH for milled grape seed.

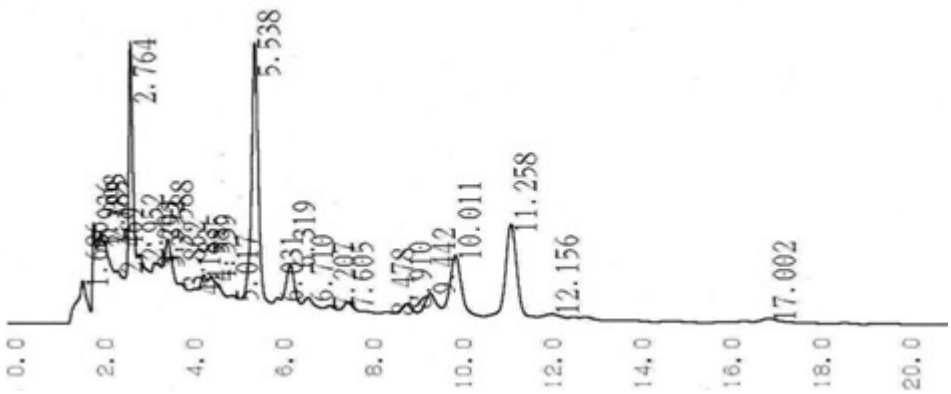

Figure 10. HPLC Chromatograph of milled grape seed extracts at 120 °C.

matter for both whole and milled grape seeds. The trend was, however, different for the catechin which increased significantly above 150 °C and sharply at 200 °C to 113 mg 100 g^{-1} of dry matter (Figs. 11 and 12, respectively). This trend agreed with that shown for tea extracts (Xu, 2003), which is indicative of lack of epimerisation of catechin at high temperatures. The whole seed extracts had generally low contents, particularly at temperatures below 165 °C, contrasting with the data for the milled seeds extracts. The trend, however, changed at higher temperatures, which shows increased ease of release of organic compounds from the seeds. This finding suggests that whole seeds could effectively be used for organic compounds extraction at high temperatures without milling, thus saving the milling time energy and cost.

Organic solvent extraction

Polyphenol content. Polyphenol content for solvent extracts is shown in Figure 13. Acetone showed the highest extractable polyphenol content for milled grape seeds (79.3 mg g^{-1}); whereas ethanol had the lowest value (36.3 mg g^{-1}). The acetone extract compared very well with that of compressed hot water at 180 °C, which

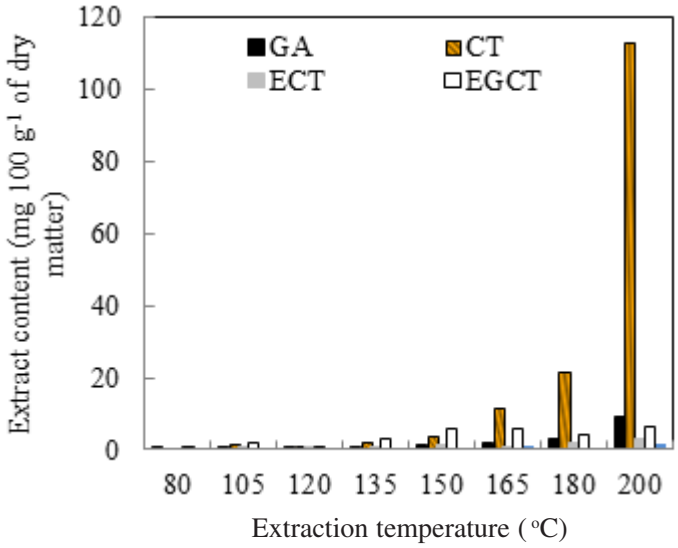

Figure 11. Organic compounds in whole grape seed extract (GA = Gallic acid, CT = Catechin, ECT = Epicatechin, EGCT = Epigallocatechin).

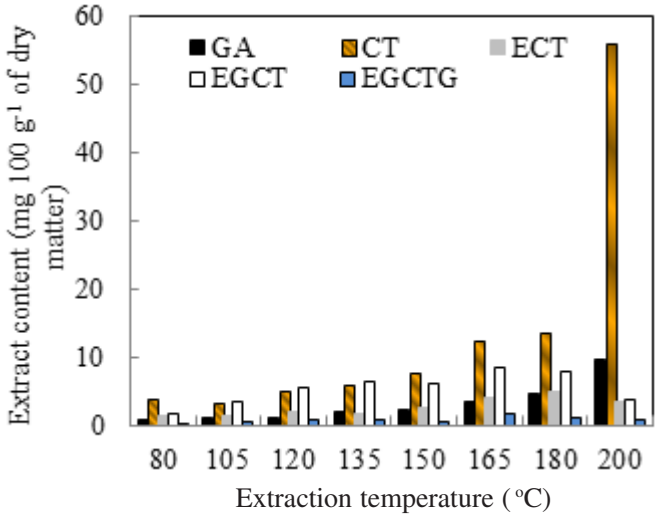

Figure 12. Organic compounds in milled grape seed extract (GA = Gallic acid, CT = Catechin, ECT = Epicatechin, EGCT = Epigallocatechin).

stood at 74.0 mg g^{-1}. The whole seed solvent extracts, however, showed very low polyphenol yields, (<12 mg g^{-1}) compared with 55 mg g^{-1} for compressed hot water. Thus, the solvent can only effectively be used on milled grape seeds.

DPPH radical scavenging activity. The DPPH radical scavenging activity of the solvent extracts, for whole and milled seeds showed a similar trend as that of the polyphenol content (Fig. 14). Milled seed acetone extract had the highest value (104.4 mg g^{-1}), whereas ethanol had the lowest (60.6 mg g^{-1}. The acetone extract compared very well with that of compressed hot water at 180 °C, which yielded 82.3 mg g^{-1}. However, the solvent extracts from whole seeds yielded very low values of less than 7 mg g^{-1} compared with compressed water yield of 71.4 mg g^{-1}. This showed that the

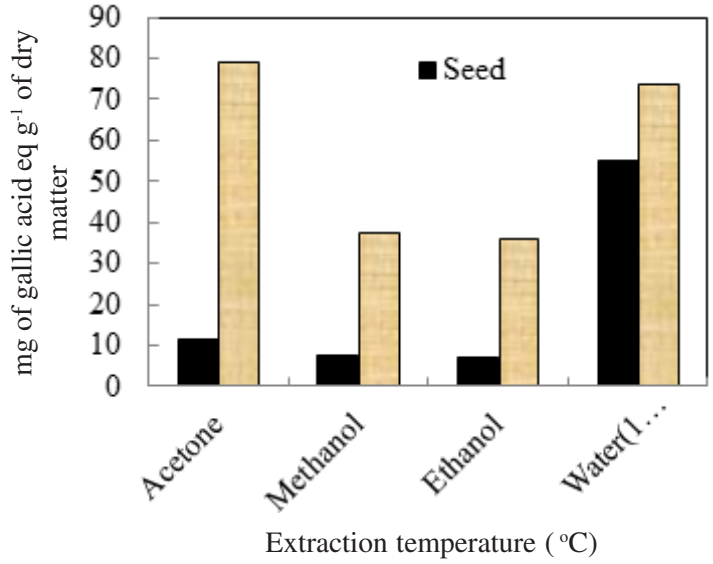

Figure 13. Polyphenol content of solvent extracts of whole and milled seeds.

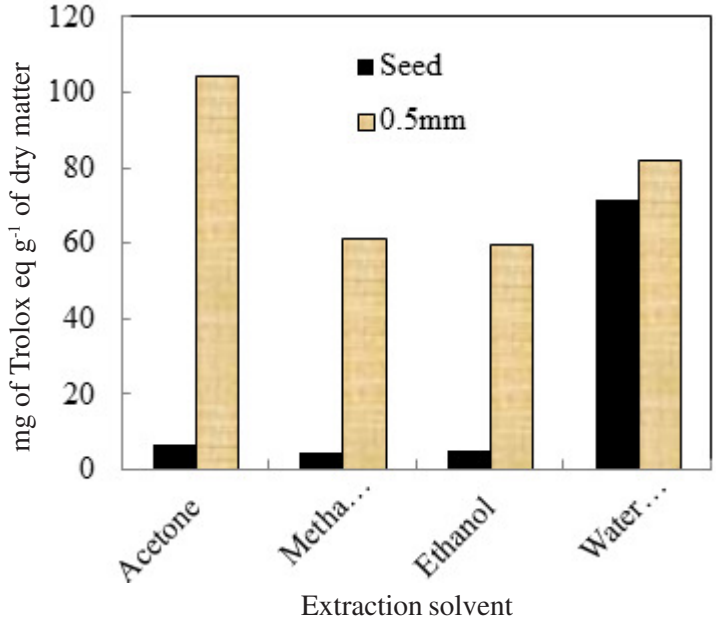

Figure 14. DPPH Radical scavenging activity for solvent extracts of whole and milled seeds.

solvents were unsuitable for polyphenol extract from whole grape seeds.

There was a strong correlation ($r^2 = 1$) between the polyphenol content and DPPH radical scavenging activity of the solvent extracts for milled seeds compared to the whole seed (r^2 = 0.8790, Figs. 15 and 16). In both cases, however, the DPPH radical scavenging activity was generally higher than the polyphenol content in the milled seed extracts, showing the highest difference of over 20 mg g^{-1} of dry matter. This correlation was the first of its kind, showing that an empirical relation can be developed between the tested parameters. It also clearly indicated

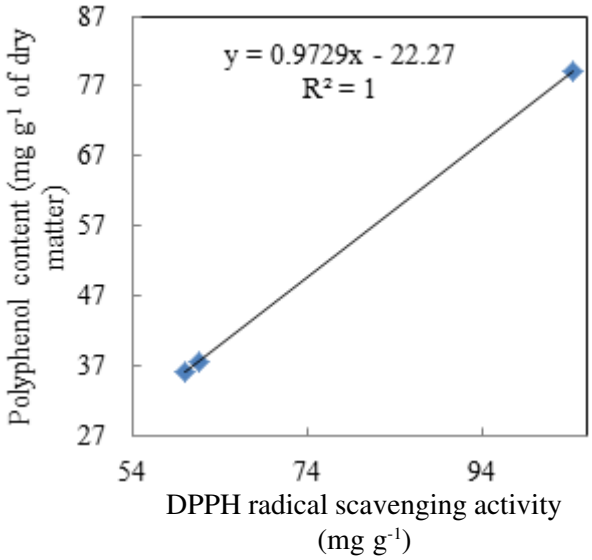

Figure 15. Polyphenol and DPPH comparison for solvent extracts of milled grape seeds.

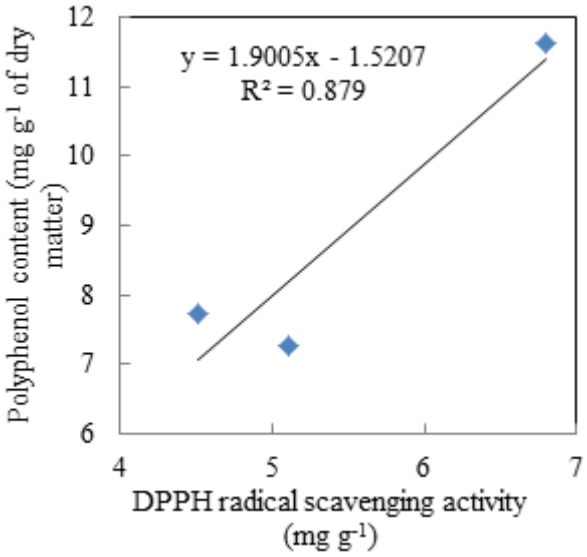

Figure 16. Polyphenol and DPPH comparison for solvent extracts of whole grape seeds.

the effect of the grain size when carrying out extraction of specific compounds from the seeds thus establishing the base for effective and efficient compounds extraction.

HPLC analysis. HPLC analysis chromatogram for whole grape seed acetone extracts is shown in Figure 17. The main peak was located at 2.712 minutes for gallic acid; whereas the other compounds were significantly low. Based on the calibration chromatograms, the other minor organic compounds in the solvent extracts were catechin, epicatechin, epigallocatechin and epigallocatechin gallate.

Gallic seemed to be the only main compound extracted from the seeds (S) by acetone (Fig. 18). The acetone extract from seeds had over 129 mg 100 g^{-1} of dry matter compared to the next highest

Figure 17. HPLC Chromatogram for grape seed acetone extract.

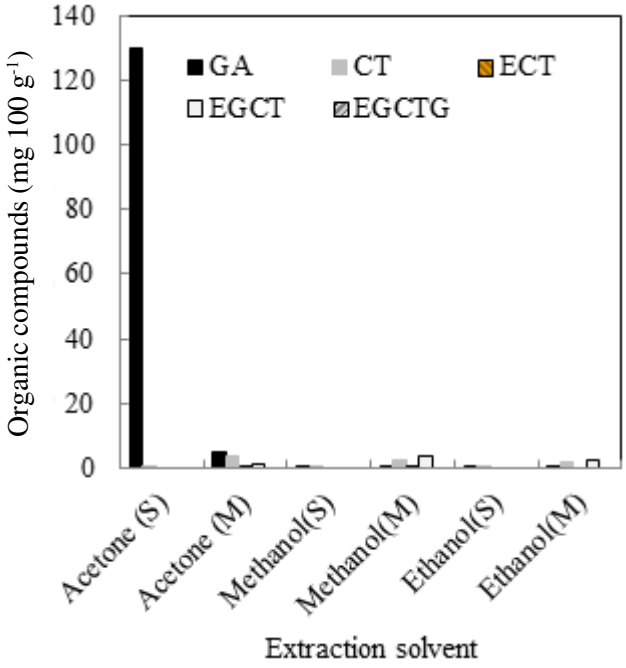

Figure 18. Identified organic compounds in grape seed solvent extracts (GA = Gallic acid, CT = Catechin, ECT = Epicatechin, EGCT = Epigallocatechin).

extract of catechin (4 mg 100 g^{-1} dry matter) by acetone from milled grape seeds (M). It is not clear why acetone extract from milled grape seed showed low gallic acid concentration; but this may be attributed to the epimerisation of catechin during milling. Thus, based on the solvent extraction, acetone was an effective solvent for gallic acid extraction from grape seed without milling. Such similar results for grape seed have not been documented before.

CONCLUSION

The results confirm the presence of anti- oxidising compounds in grape seed, with compressed hot water extraction effectively being used for organic compounds extraction. Higher temperatures above 135 °C for two hours are effective for whole grape seed, thus reducing the need for milling. Reduction in extraction time and temperature above 200 °C; however, shows

decrease in extraction efficiency. Temperature and time are major factors contributing to the compressed hot water extracts content. The main organic compounds identified are catechin, epicatechin, epigallocatechin and gallic acid in decreasing order. Epigallocatechin gallate only occurs in trace levels. Although compressed hot water extraction is the common method for polyphenol extraction, acetone shows very high effectiveness in the extraction of gallic acid from whole seeds. There is, however, need for further research to perfect the extraction of polyphenols from grape seed. This will include evaluation of high temperature effects above 200 °C and effectiveness of other commonly used solvents. A model can then be developed to simulate the extraction process and the extraction condition optimised for economic operation.

ACKNOWLEDGEMENT

The authors thank the Japanese Student Service Organisation (JASSO) for the award of research fellowship and Jomo Kenyatta University of Agriculture and Technology in Kenya for granting sabbatical leave to the lead author that enabled him to undertake this research. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 897 - 904 ISSN 1021-9730/2014 $4.00

SOME FACTORS INFLUENCING THE FREE FLUORIDE CONTENT IN BLACK TEA INFUSIONS

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ABSTRACT

Fluoride is an essential micro-nutrient owing to its role in the prevention of dental caries. Chronic exposure to high levels of the ion (F^-) results in both dental and skeletal fluorosis. A study was carried out to determine free fluoride content in tea (*Camellia sinensis*) infusions of different grades of black Cut, Tear and Curl (CTC) tea. Tea infusions, 1% w/v of 112 teas of different grades and origins, were prepared using boiling distilled water and their free fluoride contents quantified using a Fluoride Ion Selective Electrode (FISE) method. The free fluoride content of the teas was 0.37±0.04 µg F^- ml^{-1}. Infusions of tea grades BP1 and BMF gave the highest (0.40±0.22 µg F^- ml^{-1}) and lowest (0.32±0.10 µg F^- ml^{-1}) free fluoride contents, respectively. There being no national and international Maxima Residue Limit (MRL) for fluoride in tea, all the teas analysed may be regarded to be safe for consumption with regard to their free fluoride contents based on the 1.5 µg F^- ml^{-1}, World Health Organisation's (WHO) guideline for fluoride in drinking water. Further, the effects of tea grades and area of production, on the fluoride content in tea infusions were significant ($P<0.05$), hence the need to enact safety guidelines and monitor continuously the fluoride levels for all types of tea products to prevent excessive intake.

Key Words: Agronomic practices, *Camellia sinensis,* regional variations, tea grades

RÉSUMÉ

Le Fluor est un micro-élément essentiel lorsque consommé en dessous de certains seuils eu égard à son rôle dans la prévention des caries dentaires. Par ailleurs, lorsqu'utilisé en excès, les ions (F^{-}) entrainent une fluorose des dents et du squelette . Une étude était menée pour déterminer la concentration en fluor libre des infusions de thé (*Camellia sinensis*) de différentes classes de the noir de la catégorie CTC. Les infusions de thé, 1% p/v de 112 thés de différentes classes et origines étaient préparées en utilisant une eau bouillante distillée et leurs concentrations en fluor libre quantifiées par la méthode dite de Fluoride Ion Selective Electrode (FISE). La concentration en fluor libre dans les thés était de 0.37±0.04 µg F^-ml^{-1}. Les classes de thé BP1 et BMF ont présenté respectivement des concentrations les plus élevées de (0.40±0.22 µg F^-ml^{-1}) et moins elevées de (0.32±0.10 µg F^-ml^{-1}) du fluor libre. Etant donné que sur le plan national et international il n'ya pas de Limite Maximale de Résidus (MRL) pour le fluor dans le thé, tous les échantillons des thés analysés pourraient être considérés comme appropriés à la consommation eu égard à leur concentrations en fluor libre sur base de 1.5 µg F^-ml^{-1} tel que recommandé par l'Organisation Mondiale de la Santé (OMS) pour l'eau potable. En plus, les effets des classes du thé et les régions productrices sur la concentration du fluor dans les infusions de thé étaient significatives ($P<0.05$), d'où la nécéssité de mettre sur pied des mesures de protection et faire le suivi régulier des niveaux du fluor pour tous les types de produits de thé afin d'éviter une consommation excessive du fluor.

Mots Clés: Pratiques agronomiques, *Camellia sinensis*, variations régionales, classes de thé

INTRODUCTION

A moderate amount of fluoride has been confirmed to be effective for reducing dental caries in humans (Levi *et al.,* 1983; Pehrsson *et al.,* 2011). The ion (F^-) interacts with hydroxyapatite, replacing the hydroxyl ions (OH) to form fluoroapatite, a more crystalline phase that is more resistant to erosion by plaque acid and demonstrates a lower surface energy which makes plaque adhesion more difficult. However, excessive intake of fluoride results in both dental and skeletal fluorosis (Cao *et al.,* 1995; WHO, 2002). Jin *et al.* (2000) attributed the endemic fluorosis in Tibet, to heavy consumption of foodstuffs prepared with brick tea.

Appreciable amounts of fluoride are found in plants with the actual concentrations being dependent on the species, part and age of the plant (Leone *et al.,* 1956). The mechanism of uptake of fluoride from acidic (pH < 5.5) soils by the tea plant is well understood (Wong *et al.,* 2003). The mobility of the fluoride ion in the soil is influenced by a number of factors, including the quantity of the minerals present, soil pH and adsorption of positively charged complexes (Fung *et al.,* 1999). Under acidic conditions, aluminium-fluoride-halide complexes present in the soil decompose into aluminium and fluoride ions, enhancing their availability to tea plants. The free fluoride ion is then absorbed by tea roots and transported to and stored in the plant's leaves (Ruan and Wong, 2001). The fluoride level in tea leaves has been shown to increase with the maturation of the leaves (Lu *et al.,* 2004; Yi and Cao, 2008), observations that have resulted in the tea plant being referred to as a fluoride accumulator (Pehrsson *et al.,* 2011).

Tea is consumed by over two thirds of the world's population, owing to its medicinal, refreshing and mild stimulating effects (Karak and Bhagat, 2010). However, chronic consumption of large volumes of tea has been reported to result in skeletal fluorosis (Shu *et al.,* 2003; Izuora *et al.,* 2011; Kakumanu, and Rao, 2013); hence, the need for a safe threshold for fluoride exposure.

Kenyan teas are grown in different regions that differ in soil and other environmental characteristics (Moseti, 2013). Major growing areas in the country include the Aberdare highlands, Mt. Kenya region, Nyambene hills, Nandi Hills, highlands around Kericho, Mt. Elgon region and Kisii highlands (TRFK, 2002). Kenya's tea industry is characterised by two sub-sectors; the large-scale sub-sector (estate plantations) with production units larger than 20 ha; and the small-scale farmers with smaller production units averaging 0.25 ha per farmer (TBK, 2007). Tea plantations of the large-scale sub-sector are managed by well trained personnel; whereas the farmers in the small-scale sub-sector rely on agricultural extension officers for advice (Ogola and Kibiku, 2004). However, the extension officers available to the small-scale tea farmers are not adequate to serve them effectively, hence, low adoption of technologies for optimum yields from their tea farms.

Kenya predominantly produces black CTC tea, about 95% of which is sold in the export market in bulk; accounting for over 20% of the global market (International Tea Committee, 2009). This type of tea has the advantage of quicker brewing and makes mores cups per kg (KTDA, 2011). The nature and quality of a given tea product is mainly dependent on the chemical composition of the fresh tea leaves and the reactions they undergo during the manufacture process. Significant differences in the free fluoride content in infusions of Kenyan black tea due to variations in soil characteristics in the different areas of production, agronomic practices in the small and large-scale sub-sectors, as well as the grain sizes of the grades of black CTC tea, have been reported (Moseti *et al.,* 2013). The objective of this study was to establish the free fluoride content in infusions prepared from black CTC tea sourced from different areas. Data obtained could be an important source of information with regard to quality and standards, nutrition and contamination.

MATERIALS AND METHODS

Collection of tea samples. A simple random sampling technique was used to select 29 tea factories from the small (14) and large-scale (15) tea sub-sectors in Kenya where tea samples were collected in 2011 and 2012. From each factory, black CTC tea samples of the three primary grades (BP1, PF1 and PD) were collected in triplicates.

Further, 25 tea samples of different grades (BP1, PF1, PD, D1, D2, FNGs and BMF) were sourced in triplicates from Kisigo, Kibwele, Lugoda, Mufundi, Njombe and Kibena tea factories managed by Unilever Tea Tanzania Limited. In total, 33 BP1, 35 PF1, 35 PD, 6 D1, 1 D2, 1 FNGs and 1 BMF black CTC teas were collected. They were oven-dried (Memmert, 854 Schwabach, Germany) to a constant weight at 103 ºC and stored in desiccators before analysis.

Preparation of tea infusions. Tea infusions were prepared using a tea to water ratio of 1% w/v as described by Moseti *et al*. (2013); where 1.0 g of oven-dried tea was added into 100 ml of boiling distilled water and agitated for 10 minutes on a mechanical speed variable reciprocal shaker (100 oscillations per min; Gallenkamp Flask Shaker, England). The mixture was filtered through a Whatmman No. 1 filter paper (Fung *et al.,* 1999) and the filtrate allowed to cool to room temperature. For analytical method validation purposes, two control samples, A and B, were spiked with known analyte concentrations for recovery studies whereas sample blanks were prepared as described by Moseti *et al*. (2013).

Analytical procedure and determinations. Analysis of the tea infusions for free fluoride extracted from the teas was carried out potentiometrically. The instrumentation consisted of a flow plus fluoride ion selective electrode (EDT, directION 3221, UK) and an ion analyser (EDT, directION, DR359TX, UK). Working solutions in the order of 0.1, 1.0, 10.0 and 100.0 µg F^- ml^{-1} were prepared by serially diluting a commercial fluoride stock solution (1000 µg F^- ml^{-1}; EDT, directION 2133, UK). Equal volumes (25 ml) of a Total Ionic Strength Adjustment Buffer (TISAB, pH 5.30-5.35) prepared as described by Shyu *et al.* (2009) and each of the working and blank solutions, control samples and tea infusions were thoroughly mixed using a magnetic stirrer (Digisystem Laboratory Instruments Inc., Model MS-90, Taiwan) for one minute.

Readings of the above mixtures were taken at room temperature. A standard calibration curve was obtained by plotting the machine response (mV) against the logarithm of the concentrations of the working solutions. A potential change of -59.4 mV per decade of fluoride concentration was recorded with a correlation coefficient (r) of 0.9992; a value in good agreement with the theoretical Nerstian slope (Giljanovic *et al*., 2012). The limits of detection and quantitation were estimated to be 0.02 and 0.07 µg F^-ml^{-1}, respectively. Further, the current method demonstrated good accuracy (96.7 and 102.0%) and precision (0.67 and 2.59) as is evident in the percent recoveries and standard deviations of the triplicate analyses of the control samples A and B, respectively.

Statistical analysis of data. Statistical comparisons of the various groups of data were carried out by ANOVA, using GraphPad Prism Version 5.0 statistical analysis package, for Windows at $P<0.05$. The Least Significant Difference (LSD) test was used in mean separation where statistically significant differences were recorded.

RESULTS AND DISCUSSION

Free fluoride content of Kenyan black tea infusions. The mean free fluoride content in the 87 tea infusions of Kenyan black CTC tea from the 29 tea growing catchments was 0.39 µg F^- ml^{-1}. Figure 1 presents the mean free fluoride contents of the triplicate determinations. A critical examination reveals that the amount of fluoride released into infusions during the tea making process varies with; (i) the origin of the tea product, in this case the factory; and (ii) the grade of the tea product. Indeed, the differences in the mean free fluoride content in tea infusions from one factory to another as well as from one grade to another were statistically significant ($P<0.05$), consequently resulting in significant interaction effects.

It is evident from this study that tea, if consumed regularly can be an important dietary source of fluoride. Taking into consideration that tea is not the only dietary source of fluoride, continuous monitoring of fluoride levels and enactment of safety guidelines should be done for all types of tea products to prevent excessive intake of fluoride. The current data is comparable with recent findings by Shyu and Chen (2013) in

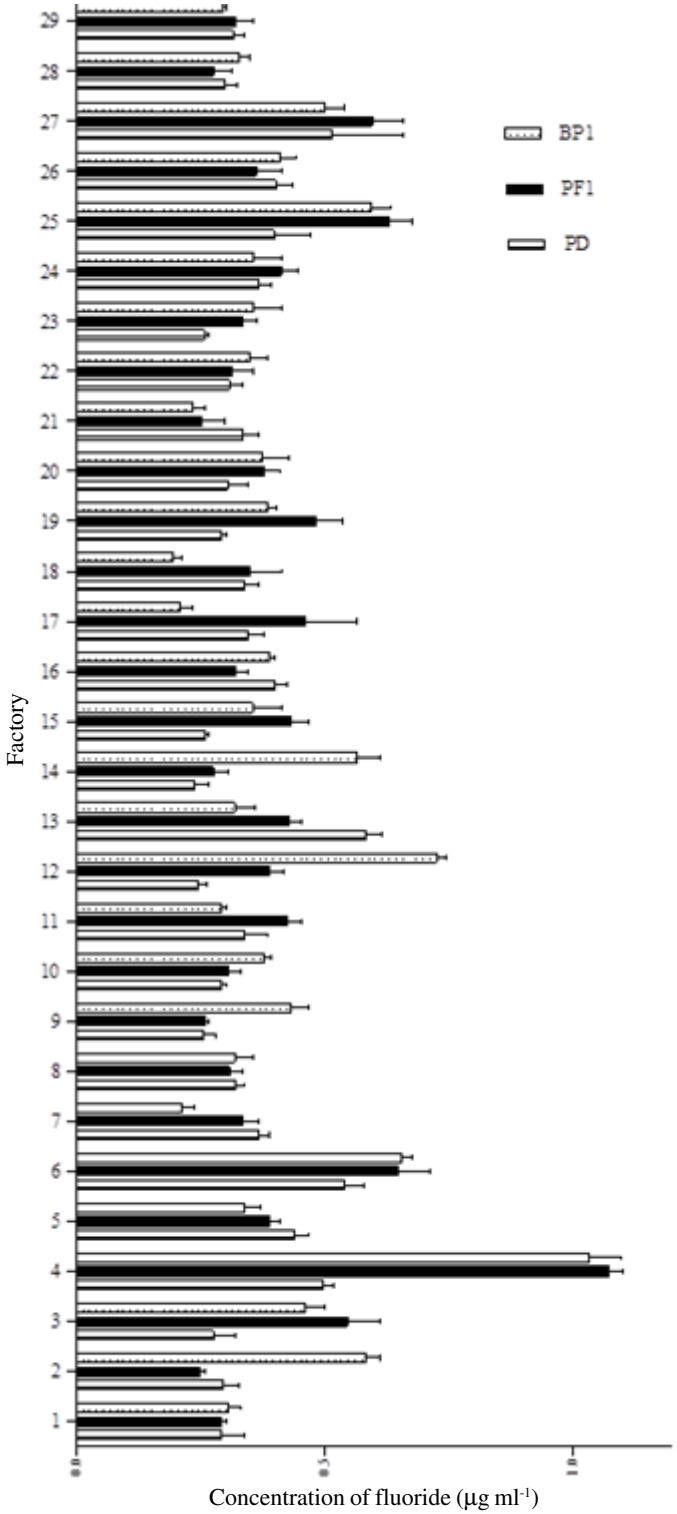

Figure 1. Mean free fluoride contents in tea infusions prepared from black tea sourced from 29 tea growing catchments in Kenya.

Taiwan and Moseti *et al*. (2013) in Kenya, who reported fluoride in tea infusions to range between 0.23 and 3.60 µg F^- ml^{-1} and 0.11 and 1.35 µg F^- ml^{-1}, respectively. The implication of this is that, tea contains fluoride a portion of which is water soluble and is released into tea infusions during the tea making process.

Agronomic practices. Mean fluoride contents extracted from the different grades of tea from the two sub-sectors are given in Figure 2. The differences were significant ($P<0.05$); the mean free fluoride content in infusions prepared from teas from the large-scale tea sub-sector being lower than those from the small-scale sub-sector. These findings suggest that the amount of water soluble fluoride is not only affected by the region of production of the teas but also by the agronomic practices in place.

However, this is not in agreement with our early findings, where the differences in the mean fluoride content in tea infusions prepared from teas form the two sub-sectors were not significant ($P>0.05$) (Moseti *et al.,* 2013). The implication of this is that there are other factors, such as seasonal variations possibly playing a role in the amount of fluoride accumulated in tea leaves, hence, the proportions released into tea infusions during the tea making process. Thus, there is need for extensive studies on this subject to determine the dynamics of the fluoride ion along the food chain and the associated health implications.

The Kenyan tea industry is characterised by two sub-sectors (Large and Small scale), whose agronomic practices differ due to low adoption of recommended technologies for maximisation of tea yields, such as planting of elite tea varieties with high yield and quality potentials, correct plant spacing and fertiliser application frequency and rates (Kagira *et al.,* 2012). This has mainly been attributed to poverty and poor access to information, as a result of poor extension services, by the small-scale farmers among other factors. A total of 15 of the 29 Kenyan factories considered in this study belonged to the large-scale farmers, and the rest were managed by the small-scale farmers.

Grading and fluoride levels in tea infusions. The mean free fluoride content in tea infusions of the seven grades of tea considered in the current study are given in Table 1. Different tea grades gave different levels of fluoride in their infusions; grade BP1 and BMF giving the highest and lowest levels, respectively. During grading, tea granules resulting from the Cut, Tear and Curl operations during the manufacture of black CTC tea are separated into various "groups" based on size. This gives primary (BP1, PF1, PD and D1) and secondary grades (BMF, Fannings and D2) with

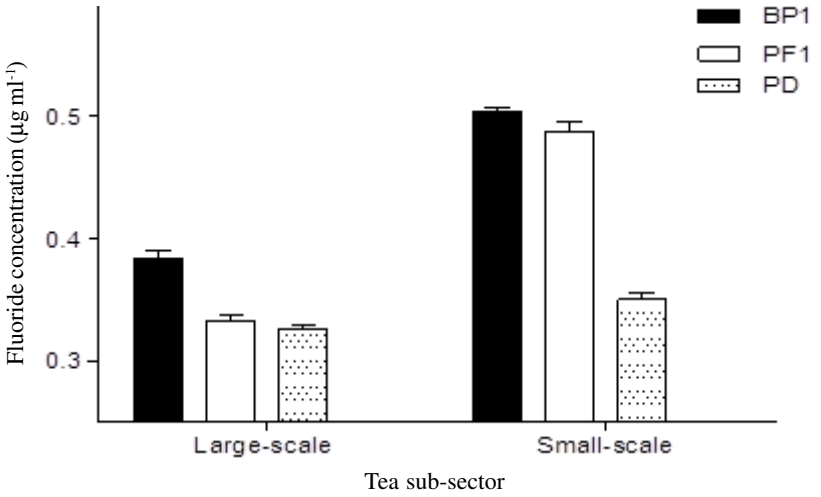

Figure 2. A comparison of the mean free fluoride contents in tea infusions of black teas from the small and large-scale tea sub-sectors.

TABLE 1. Mean fluoride concentration in tea infusions of different grades of tea

Tea grade	Sample size	Fluoride concentration (μg F^- ml^{-1})		
		Minimum	Maximum	Mean±SD
BP1	33	0.11	0.98	**a0.40±0.22
PF1	35	0.26	0.40	b0.40±0.04
PD	35	0.20	0.95	ab0.39±0.20
D1	6	0.25	0.36	ab0.33±0.05
D2	1	0.37	0.47	ab0.43±0.05
Fannings	1	0.27	0.49	ab0.37±0.11
BMF	1	0.37	0.44	c0.32±0.10
Grand mean		0.26	0.58	0.37±0.04
Coefficient of variation (%)				11
LSD (P=0.05)				0.09

Means preceded with a similar letter are not significantly different (P>0.05)

whole, large tea leaves gaining a higher grading (KTDA, 2011). These help in facilitating the tea trade and is the central component in assessing the monetary value of various types of tea. These results suggest that the fluoride content in infusions of different grades of tea depends on the size of the tea granules; with BP1 the highest grade giving the highest content. However, sample size, especially of the secondary grades of tea, is a major limiting factor and as such, this trend might be misleading. Therefore, extensive studies with better sample sizes are necessary to confirm these findings.

The water extractable fluoride content depend on a number of factors including the infusion duration, temperature of infusion and the type of tea (Giljanovic *et al.*, 2012). Since the infusion method used for all the groups of tea samples in this study was the same, then the data obtained demonstrate that tea from different regions, in these case factories, contain different concentrations of fluoride. These differences can be attributed to the geological, soil chemical and physical characteristics of the area of production (Hudaykuliyev *et al*., 2005). Soils are clearly the main source of fluoride and other trace elements for the tea plant. However, in order to boost tea yields, most tea growers use nitrogenous fertilisers, which may further increase the fluoride content in tea by (a) contributing additional fluoride, and (b) making the soils acidic by producing hydrogen ions (H^+) *via* nitrification ($NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$) induced by bacteria present in the soil (Ishibashi *et al.,* 2004). This in turn increases the mobility and consequently the bioavailability of fluoride for uptake by the plants (Fung and Wong, 2002). Other factors that may influence the fluoride content in tea infusions include leaf age (Shu *et al.,* 2003) as well as genetics factors.

The World Health Organisation (WHO), in light of the associated health effects of fluoride has set the guideline for fluoride in drinking water at 1.5 μg F^- ml^{-1} (WHO, 2011). However, the upper limit for fluoride uptake from tea is not included in the current Kenyan black tea quality standard (KS 65: 2009). Based on the guideline for drinking water, black CTC tea may be regarded as safe for consumption with respect to fluoride content.

CONCLUSION

Tea contains fluoride, part of which is released into tea infusions during the tea making process. However, in Kenya, tea grades and tea sub-sectors have significant effects on the fluoride content in tea infusions. Thus, regular tea consumption is a potential additional source of dietary fluoride and in light of these findings, inclusion of an upper limit for fluoride exposure from tea by the relevant national regulatory bodies in the Kenyan black tea quality standard is recommended. Further, the effect of leaf age and clonal variations on fluoride content in tea leaves

is an aspect that should be considered in future investigations.

ACKNOWLEDGMENT

The authors thank the management of the Tea Research Foundation of Kenya (TRFK) for funding this study. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 905 - 915 ISSN 1021-9730/2014 $4.00

TRANSFORMING AGRICULTURE THROUGH CONTRACTED EXTENSION SERVICE DELIVERY SYSTEMS: THE CASE OF KENYA'S AGRICULTURAL PRODUCTIVITY AND AGRIBUSINESS PROJECT

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ABSTRACT

Transformation of small holder agriculture from subsistence farming to agribusiness focused systems, is paramount towards attainment of Kenya's vision 2030 and the Millennium Development Goals. This requires extension service delivery systems that focus on addressing challenges within agricultural product value chains (APVC) continuum. The existing extension systems have not contributed much towards this transformation due to their limited capacities, including inadequate expertise and diversity. The Kenya Agricultural Productivity and Agribusiness Project (KAPAP) is implementing an innovative service delivery model, whose approaches include a Community Driven Development (CDD), demand driven and public private partnerships through contracted Service Providers (SPs). The aim of the model is to contribute towards increasing smallholder farmers' productivity and incomes. The implementation of the model brings together sector players as implementing agents; while the SPs consortia were competitively selected. The services delivered to farmers' common interest groups (CIGs) include high level value chain interventions such as organising farmers for marketing, and linking them to markets and other service providers. Payment for services is done using farmer grants and is pegged onto achievement of set income indicator benchmarks negotiated and agreed upon between farmers and their SPs. The implementation of the model is guided by operational procedures, designed to ensure that a harmonised process is followed within the targeted counties. A total of 109 SPs consortia were contracted in January 2012 to offer services to 118,865 farmers (Males = 57%; Females = 43%) organised into 4,355 Common Interest Working Groups (CWGs). The achievements made by end of 15 months show an increase in production for the 36 target enterprises and farmer incomes. The farmers earned a total of US$ 44,118 million at a service delivery of US$ 1,124,706, giving an econometric return to investment of 39.4. The achievements of this model qualifies it for inclusion among other feasible extension approaches or "islands of success" that have the potential to transform the agricultural sector in Kenya and in other developing nations with minimal modifications.

Key Words: Community driven development, innovative extension delivery

RÉSUMÉ

La transformation de l'agriculture des petits exploitants de la subsistance en agriculture de marché est primordiale pour atteindre les objectifs de la vision 2013 au Kenya et les Objectifs Millénaires de Développement (MDGs). Ceci nécessite des systèmes de vulgarisation visant à adresser les contraintes tout au long des chaines de valeurs. Les systèmes de vulgarisation existants n'ont pas contribué grand-chose à la transformation de l'agriculture de subsistence en une agriculture de marché à cause de leur capacité limitée y compris l'absence d'une expertise adéquate et diversifiée. Le projet « Productivité Agricole et Agribusiness » au Kenya (KAPAP) est entrain d'exécuter un modèle innovateur de prestation de services suivant une approache incluant un développement piloté par les communautés, répondant directement à la demande et basée sur un partenariat public-privé à travers des contrats avec les prestataires des services et fournisseurs des intrants. L'objectif de ce modèle est de contribuer à accroître la productivité agricole et augmenter les revenus des petits exploitants. L'exécution de ce modèle regroupe les différents acteurs dans le secteur comme agents d'exécution tandis que tous les prestataires des services et fournisseurs d'intrants sone séléctionnés sur des base compétitifs. les services fournis aux

associations des producteurs sont entre autres des interventions dans la partie supérieure au long des chaines de valeur tel l'organisation des producteurs pour la commercialization de leurs produits ; leur connection avec les marchés et fournisseurs de services et d'intrants. Le paiement des services est généralement à travres des subventions aux producteurs basées sur un contrat de performance économique à évaluer sur base d'indicateurs précis préalablement négociés et approuvés en même temps par les producteurs et les fourniteurs de services et d'intrants. L'exécution du modèle est guidée par des procédés opérationnels conçus pour assurer qu'un processus harmonisé est bien suivi dans l'ensemble des zones du projet. Un total de 109 groupement de fournisseurs de services et d'intrants était contracté en Janvier 2012 pour offrir des services à 118,865 producteurs (Hommes=57% ; Femmes= 43%) organisés en groupes partageant les mêmes intérêts. Les résultats obtenus après 15 mois d'exécution du projet indiquent une augmentation de la production pour les 36 entereprises visées et une augmentation du revenu des exploitants. Les producteurs ong gagné un total de 44,118 million de dollars US contre un coût des services ou intrants fournis de 1.124.706 dollar US, indiquant un retour économétrique à l'investissement de 39,4. Les succès de ce modèle le qualifie pour son inclusion parmi les approaches efficaces de vulgarisation « ilots de succès » ayant le potential de transformer avec des modifications minimales le secteur agricole au Kenya et dans d'autres pays en voie de développement.

Mots Clés: Développement communautaire, vulgarisation innovatrice

INTRODUCTION

Inadequate extension service provision is a major barrier to East Africa's agricultural sector realisation of its full potential. Ram Basavaprabhu and Manveer (2009) reported that despite the progress in quality and quantity of research in Kenya that has resulted in good technologies, the information and communication support to farmers remains conventional and inadequate. A World bank evaluation report (Pre'cis, 1999) noted that the Kenyan extension systems lack focus on farmer empowerment and were based on traditional top-down and supply driven approaches that give little or no voice to the farmer. The situation remains unchanged even today; that is, the agricultural extension systems lack appropriate strategies for capacitating their target farmers to demand for services. Equally important, is the fact that they are often not sensitive to the needs of women and youth farmers who make up one-third and 81% of the farming communities respectively. These largely public-based systems are also constrained by a declining human and financial capital, lack of private sector input, poor coordination among various players and lack of accountability.

The extension messages communicated, mostly focus on agronomic practices rather than the complexities along the value chain which include value addition, processing and marketing of produce and products. Lack of marketing strategies is not only a disincentive towards increased production, but continues to affect the sustainable economic growth of the agricultural sector. The purpose of this paper is to share emerging lessons from the implementation of the KAPAP model with stakeholders and the broader global readership. The objectives of KAPAP were to (i) empower farmer organisations and other stakeholder to influence planning, design, funding, implementation, monitoring and evaluation of extension services; and (ii) contribute to the development of agribusiness along commodity value chains through value addition and marketing.

METHODOLOGY

The KAPAP Model. The KAPAP model was designed from the strong desire to reform the public extension services and to address the challenges faced by the various approaches to extension services, used in Kenya over the past two decades (Anderson and Feder, 2003; Kibett *et al.,* 2005). The lessons learnt from such models and in particular the national Agriculture and Livestock Extension Programme (NALEP) and KAPP 1, were taken into account in the new design.

The key principles of the KAPAP model are participation, demand driven, pluralism, transparency and accountability in resource management, and cost-effectiveness with inbuilt mechanisms to ensure sustainability (KAPAP, 2013). The model is innovative in that as reported

by Connolly (2004) from his review of twelve case studies, there are no external prescriptions that are applicable to all countries. As such, the KAPAP model has been designed in an innovative way to meet the demands of small holder farmers in Kenya and the conditions set by the World Bank that the service interventions be undertaken through contracting in the context of community driven development (World bank, 2009). This, coupled with the need to address the attainment of the set performance indicators for the project provided the building blocks of the model. The key assumption was that the farmers would adhere to the set guidelines in the management of the grants and would be willing to invest in their priority value chains.

Area of implementation. The implementation of KAPAP's Extension Service Delivery model (KESDM) was done in twenty out of the 47 counties including; West Pokot, Trans-Nzoia, Busia, Kakamega, Butere Mumias, Siaya, Homa Bay, Kisii, Nakuru, Nyandarua, Nyeri, Embu, Meru, Makueni, Taita Taveta, Kwale, Kilifi,Tana River, Garissa and Wajir. The implementation that started in 2011 is expected to end in 2014. Only 2 divisions and 2 locations in each division were targeted in the first phase of the project, with projections of out-scalling to cover the whole county in the follow up phases. The implementation of the model brought together representatives from all sector players (sector Ministries, KARI, KENFAP) who form technical teams; namely, the County Technical Team (CTT) and Divisional Technical Team (DTT). These teams had at least 6 members each. The coordination in counties was done by a County Service Units (CSU) team of three officers (Coordinator, M&E officer and accountant) at the grassroots, and KAPAP secretariat (KS) of 13 member personnel at the national level. County Agricultural Steering Committee (CASC) composed of the heads of departments within the implementing agencies oversee the implementation processes.

The target farmers were enlisted into Value Chain (VC) specific Common interest Working Groups (CWGs) at the location level. Prioritisation of the target VCs was done using participatory approaches where the participation of men, women and youth farmers was ensured. The common interest was the increased productivity and incomes as indicated by the service providers in the opportunity flagging poster that were to be accrued when a farmer invested in a particular VC. The membership to the CWGs was left open throughout the implementation period in order to attract as many interested farmers as possible. All the CWGs aggregated at the location level to form Common Interest Groups (CIG).

The CIGs received extension services from Service Providers (SPs) consortia that were competitively selected by the County Agricultural Sector Steering Committee (CASSC) through use of an expression of interest approach and evaluation of proposals developed by the successful SPs. A set of criteria was used to ensure that the selected SPs possess the right qualifications in terms of professionalism, diversity of expertise, capacities to address the farmers needs along the value chain continuum, as well as adequate grass root partners that reached out to all the targeted location with trainings and demonstrations

Value chain specific farmer management structures were established at various levels (CIG officials, location, division and county value chain official) to empower beneficiary communities to take charge of implementation of the Value Chain based Development Plans (VCDP), collect data, keep records and track the progress towards achievement of the set benchmarks. The County value chain officials managed the farmer grants that were availed by the project to the farmers to meet the SPs contract fees.

The implementation process of KAPAP was guided by operational procedures that were designed to ensure a harmonised process within the target counties. The development of the procedures took into account the key attributes of the extension model, agribusiness, beneficiary empowerment and participation, social and environmental concerns; and adoption of good practices that avoided perpetuation of dependency syndrome among beneficiaries.

The steps followed in the implementation process are described below:

(a) mobilisation of the implementing agencies by the CSU office to constitute implementing teams at the county and divisional levels (CTT and DTT);
(b) mobilisation of communities by the CSU team, CTT and DTT through farmer meetings or *barazas* to create awareness on the Project and to sensitise communities to participate in the project activities;
(c) carrying out a Community Resource Assessment (CRA) by the DTT to establish the baseline status, identify priority enterprises, challenges, and farmers' needs towards increased productivity and incomes. Both secondary and primary data sources were used and participatory approaches and tools were used during primary data collection to ensure farmer involvement. The data collected were synthesized into problem statements that were used as the launch pads for competitive and accountable service delivery system;
(d) identification of the appropriate service provider *consortia* was done using the normal government procurement procedure that includeds; advertisement through an "Expression of Interest (EOI)" that highlights the issues to be addressed in each value chain and the requirements for the service provision. The EOI responses were vetted and the selected SP firms developed and sent detailed technical and financial proposals to the CSU office in the County they intended to offer services. Vetting of EOI and proposals was done by County Agricultural Sector Steering Committee (CASSC) and CTT;
(e) flagging of opportunities by each selected *consortia* involved development of investment opportunity posters for each target value chain by the SP and mounting the posters in appropriate places within the county accessed by the farmers. A community *baraza* was held at least two weeks after placement of the posters to enable farmers express interest and enlist into Common Interest Groups (CIGs). Gender/social concerns were taken into account during these activities by ensuring that men, women and youth farmers participated and their voices were taken into account. A number of follow up meetings were held to accomplish start up activities that included; negotiations on service delivery road map, putting in place the necessary CIG management structures, developing the group constitution and CIG registration with the department of social services; and
(f) holding a participatory planning workshop (PPW) at the County level to plan the implementation of the service delivery process that was attended by CSU office, the DTT/CTT, SPs and CIGs representatives. The activities undertaken during this workshop included:

  (i) negotiations on service delivery road map which involved identification of the value chain challenges and opportunities;
  (ii) development of Value Chain based enterprise Development Plan (VCDP) and their time-bound implementation schedules. This involved drawing a work plan on the trainings and demonstrations to be undertaken;
  (iii) development of the specific enterprise development budgets negotiating on the cost of services and setting of the payment benchmarks;
  (iv) setting up the farmer grant management structures that involved the farmers' representatives electing their County value chain officials. The 30% gender rule as stipulated in the Kenya constitution was adopted during these elections as well as all CWG/CIG elections to ensure the vulnerable groups get elected; and
  (v) signing of contracts between the SP consortia and County value chain officials. This involved development of a contract document that summarises the agreements made during the negotiations in the set format by the CSU office that is signed by the SP and VC officials and witnessed by the CSU coordinator.

Implementation process. The implementation started with the transfer of farmer grant funds from KS to value chain specific bank accounts, opened and managed by the County value chain

officials. These funds were used for payment of services offered to the CIGs by their service providers. Payment was done in installments of 10, 20, 30 and 40% that were pegged on achievement of predetermined outcome indicator benchmarks (productivity and incomes realised by a CIG), as agreed during the PPW. Payment of the first installment was done immediately after signing the contract to enable SPs meet their operational costs in order to start the implementation. The rest of the payments were based on actual outcomes achieved by the beneficiaries as a result of SPs' interventions. As such, the SP had to concentrate on high value interventions that earned higher and quicker returns to the farmers in order to receive his/her payment.

Monitoring and evaluation. The monitoring and evaluation (M&E) exercise involved the beneficiaries as the owners and managers of the grant. Each farmer kept records on his/her productivity and sales, and was expected to avail these data to the CIG secretary for onward transfer to the CSU M&E officer through the laid down farmers' structures. The same data were used by the County value chain officials and the SPs, assisted by the CSU to monitor the achievement of the set benchmarks. A project Management Information System (MIS) was designed at the start of the project to capture and document gender disaggregated data in regard to beneficiaries' details (farmer's names and contacts, baseline status), and their progressive achievements on production and incomes. The data collected from the farmers was entered into the MIS system at the CSU office and exported to KS. The other M&E structures included inbuilt tools within the implementation processes, regular monitoring exercises by KS and CSU, as well as quarterly and annual reports by the CSU and SPs.

Major achievements. A total of 109 SP *consortia* were contracted in January 2012 to offer services to the farmer beneficiaries in the 20 target Counties along the value chains of 36 priority agricultural enterprises (Table 1). The total contract fee (farmer grants) for the first 12 months contract period was U$1,826,176. However, by the time of this study, majority of the SPs had not achieved all their set benchmarks and were still offering services to their farmers. The following section outlines the achievements made within 15 months implementation period.

Number of participating farmers. A total 4,355 common interest working groups were formed with an initial membership of 63,839 (males = 58.2%, females = 41.8%) that gradually increased to 118,865 (males = 57%, females = 43%) (Table 1). Trans-Nzoia county had the largest membership of 14,124 members (males = 63%, females = 37%) and Homa Bay the least with 1,817 (males = 57%, females = 43%). Local Poultry had the highest membership of 22,537 (males = 45%, females = 55%); followed by dairy cattle with 20,338 members (males = 61%, females = 39%).

Grants payments to the SPs. The total payment to the 109 service providers by the end of the 12 months contract period, as per the set benchmarks, was U$ 880,744 representing 48% of the total cost. However, the payment rate improved to 62% (U$ 1,125,352) at the end of 15 months period (Table 2). Only 24 SPs *consortia* had received all their payments, with the best performing County being West Pokot

Earnings made by the beneficiaries. The total earnings achieved by beneficiaries by the end of 15 months period was U$44,118 million out of the expected U$ 93,259 as agreed upon in the contracts. The SPs interventions were (i) organising farmers for collective marketing leading to more bargaining power and better prices; (ii) linking farmers to better markets or buyers; (iii) introducing new marketing approaches such as sale of bananas by weight rather than bunches; and (iv) value addition on produce. Table 3 shows the annual baseline and the total earnings of 14 enterprises during the contract period.

Volume of produce sold. The increase in earnings, alongside capacity building towards the end of 15 months period, increased quantity and quality of produce and linking farmers to input suppliers (seed and feeds), veterinary services and credit facilities which triggered an increase in production

TABLE 1. Beneficiary membership across CSU, value chains/enterprises for the implementation of the KAPAP in Kenya

Beneficiaries across counties by gender					Beneficiaries across value chains by gender				
CSU	No. CWGs	No. of farmers	M%	F %	Value chain	No. CWGs	No. of farmers	M%	F %
Busia	306	6,582	53	47	Green grams	57	1,556	41	59
Butere-Mum.	187	5,581	51	49	Groundnuts	135	3,145	45	55
Embu	274	5,171	61	39	Soya beans	41	973	47	53
Garissa	55	1,648	49	51	Cassava	76	1,856	46	54
Gucha	359	8,456	63	37	Peas	69	2,266	59	46
Homa Bay	137	1,817	58	42	Sorghum	89	2,245	54	46
Kakamega	204	3,928	54	46	Maize	69	5,503	64	36
Kilifi	207	3,865	45	55	Cassava	76	307	38	62
Kwale	204	6,098	60	40	Peas	69	94	33	67
Makueni	191	6,564	42	58	Sorghum	89	5,609	72	28
Meru Central	194	5,432	50	50	Maize	69	8,385	56	44
Nakuru	120	2,785	58	42	Black beans	16	712	62	38
Nyandarua	319	10,218	63	37	Grain Amaranth	8	697	67	33
Nyeri	340	10,107	51	49	Mango	222	1,631	73	27
Siaya	417	7,962	57	43	Banana	384	6,940	51	49
Taita Taveta	1 74	6,622	60	40	Passion fruit	36	202	46	54
Tana River	138	2,115	85	15	Pawpaw	29	797	46	54
Trans Nzoia	300	14,124	63	37	Citrus	41	3,320	71	29
West Pokot	184	6,102	83	17	Potatoes	194	1,172	95	52
Wajir	129	3,688	32	68	Sweet potatoes	8	2,537	45	55
118,865	4,439	118,865	57	43	Afr Be Chilli	68	1,923	49	51
					Tomatoes	128	5,002	63	37
					Bulb onions	16	20,338	62	38
					Local poultry	781	2,426	39	61
					Rabbit meat	76	5,178	75	25
					Shoats meat	127	7,021	78	22
					Dairy cow	568	829	41	59
					Dairy goat	136	990	20	80
					Fish	318	715	37	63
					Apiculture	387	417	71	29
					Aloe (20)	20	1,556	48	52
					Dairy camel	36	3,145	76	24
					Camel meat	26	973	63	37
					Gums & resins	15	1,856	67	33
					L. Vegetables	137	2,949	48	52
					Farm forestry	14	109	76	24
					Rice	8	141	63	37
					Beef	11	475	159	67
					Beans	4	175	79	55
					Sunflower	316	141	58	42
					Avocado	96	89	48	52
					Total		118,865	57	43

CSU = County Service Units, CWGs = Common interest Working Groups, M = Male, F = Female

TABLE 2. Grants payments to the extension service providers and beneficiary earnings at the end of 12 months during implementation of the KAPAP in Kenya

Installments (%)	No. of consortia paid	Amount paid (US$)	Total earnings at each payment (US$)
10	109	176,475	Paid on signing the contract
20	84	294,121	11,827,443
30	58	247,062	14,617,729
40	24	141,186	9,018,724
Total	-	858,844	35,463,896

TABLE 3. Earnings made by the beneficiaries for selected enterprises during implementation of the KAPAP in Kenya

Enterprise	CIG membership	Baseline annual earnings (thousand US$)	Total Earnings achieved in 15 months (thousand US$)
Apiculture	7,021	306	790.240
Bananas	8,385	1,850	4,091
Bulb onions	1,172	1,273	1,942
Dairy cow	20,338	7,568	6,372
Fish	5,178	192	544
Groundnuts	3,145	180	459
Local poultry	22,535	567	1,935
Mangoes	5,609	610	887
Rabbit meat	1,923	87.9	51.5
Aloe vera sap	829	3.36	28.3
Soya beans	973	15.4	110.3
Sorghum	2,245	162	70.4
Local vegetables	2,949	10,069,833	111,751,930.6
Maize	5,503	187,857,080	474,680,346

CIG = Common Interest Groups

TABLE 4. Baseline data and production levels for selected agricultural enterprises. Achieved in 15 Months during implementation of the KAPAP in Kenya

Enterprise	Unit measure	CIG membership	Annual baseline production	Produce sold in 15 months
Apiculture	Liters of honey	7,021	320,632	304,054
Bananas	Bunches	8,385	1,224,330	2,441,697
Bulb onions	kg	1,172	2,784,876	2,861,948
Dairy cow	Liters	20,338	24,026,454	17,908,696
Fish	kg	5,178	310,853	714,811
Groundnuts	kgs	3,145	297,548	330,356
Local poultry	Numbers	22,535	258,697	901,273
Mangoes	Numbers	5,609	20,740,344	15,955,400
Rabbit meat	kg	1,923	2,165	6,332
Aloe vera sap	kg	829	342	2,392
Soya beans	kg	973	55,245	156,731
Sorghum	kg	2,245	86,274	310,899
Local vegetables	kg	2,949	677,656	2,827,313
Maize	90 kg bags	5,503	309,858	1,894,067

CIG = Common Interest Groups

TABLE 5. Return to investments for selected enterprises during the implementation of KAPAP project in Kenya

Enterprise	CSU	RI
Grains	Trans-Nzoia	261
Bulb onion	W. Pokot	200
Fruits/l.veges	Siaya	175
Dairy cow	Nyandarua	145
Snow peas	Nyandarua	127
Dairy cow	Gucha	113
Banana	Embu	103
Fruits/veges	Nyandarua	95
Fruits/veges	Gucha	80
Fruits/veges	Nyeri	45
Dairy cow	Nyeri	40
Apiculture	Busia	0.69
Apiculture	Homa Bay	1.01
Soya bean	Butere	1.49

CSU =County Service Units, RI = Return to Investment

TABLE 6. Return to investments and ranking for the target counties during the implementation of KAPAP project in Kenya

CSU	RI	Rank
Trans-Nzoia	187.18	1
Nyandarua	146.55	2
Siaya	98.78	3
Nakuru	52.46	4
Gucha	46.88	5
W.Pokot	35.17	6
Meru Central	28.41	7
Nyeri	23.83	8
Kwale	22.31	9
Tana River	21.02	10
Embu	17.93	11
Kilifi	17.19	12
Taita-Taveta	16.17	13
Makueni	14.74	14
Butere Mumias	11.90	15
Busia	11.57	16
Kakamega	7.10	17
Homa Bay	5.04	18
Wajir	1.19	19
Garissa	0	20

CSU = County Service Units, RI = Return to Investment

for the various enterprises (Table 4). Sorghum production increased by 72%, maize by 83.6 % and local poultry by 71.6%.

Returns to investments. An assessment of the overall cost effectiveness of the KAPAP model, using ratio of cumulative earnings of U$ 44,118 million and the total cost of service delivery of U$ 1,124,706, shows a Return to Investment (RI) of 39.4. Table 5 shows RIs across value chains and Counties, with maize in Trans-Nzoia reporting the highest RI (261); followed by bulb onions in West Pokot County (RI = 200). Apiculture in Busia County showed the lowest RIs (0.69). A ranking of the 20 project County units on the basis of their RIs shows Trans-Nzoia leading (RI = 187.18); followed by Nyandarua (RI = 146.55) (Table 6).

DISCUSSION

The findings from this study qualify the KAPAP service delivery model as a pragmatic model with attributes of pluralism, demand-driveness, innovativeness, accountability and cost effectiveness. The model also has potential to improve the welfare of smaller holder farmers, reduce rural poverty and increase food production, a characteristic now widely accepted for judging the effectiveness of a good extension service delivery system. The design of such a system must also include a combination of strategies towards better access to resources and markets (CTA, 2011). The design and achievements of KAPAP meet all the qualities and indicators of good practice as identified in a Tegemeo's study (Muyanga and Jayne, 2006), where market linkage that is a key focus in the KAPAP model had scored the lowest for the extension systems assessed during that study.

Judging on such qualities, the model and its achievements have contributed highly towards the development of Kenya's agricultural sector and improvement of small holder farmers' livelihoods.

The approach used in this model is pluralistic as it brings together all the agricultural sector

players as implementing agencies (Ministries, KARI and KENFAP) and draws its service providers from both the public and private sector in form of consortia. The approach is also innovative in that payment of services is pegged on outcome indicator benchmarks, and the management of farmer grants and data collection are done by the beneficiaries.

This innovation, not only enhances accountability by addressing the challenges of public based systems where their failures are attributed to lack of accountability to clientele (Jock and Gershon Feder, 2003); but also empowers farmers to take charge of assessing the quality and effectiveness of the service.

The processes used to identify priority value chains and beneficiaries (mobilisation, CRA, flagging and enlisting into CIGs) were participatory, enabling the model to avail to farmers a basket of options in regard to targeted enterprises, and in ensuring that the extension services were demand-driven and met the farmers' needs. This approach has enhanced the participation of farmers as shown by the growth in CIG membership from the initial 63, 839 (Males = 58.2%, Females = 41.8%) to the current 118,865 (Males = 57%, Females = 43%). This, together with gender mainstreaming efforts during prioritisation of value chains and use of a group approach, have resulted in improved participation of women in the project, unlike in past extension systems most of which lacked gender disaggregated data. This participation shows a gendered pattern reported earlier by NALEP (2009), that men prefer enterprises of strategic nature that result in high returns to investment. For the KAPAP model, bulb onions and tomatoes had the highest male membership (95% and 72%, respectively); while female membership was highest in subsistence level enterprises such as grain amaranth and black beans (67% and 62% respectively).

The model has also succeeded in addressing value chain continuum challenges by organising farmers to access inputs and markets as well as value addition and processing initiatives, particularly in dairy, honey and groundnuts. These achievements are attributed to the tapping of the elusive capabilities and talents from the private sector under the Public Private Partnership (PPP) arrangements to complement what exists in the public sector. The agribusiness focused interventions resulted in an increase in beneficiary incomes as reported for all the enterprises; the most notable being maize (baseline-US$ 2,210,083, achieved-US$ 5,368,077) and local poultry (baseline-US$ 566,717, achieved-US$ 1,193,428). The percent increase in these earnings, (i.e. 196% for maize and 111% for poultry) far surpasses the 5% target in the projects results framework (Project Appraisal Document, 2009). The overall impact of these earnings towards poverty reduction and improvement on beneficiaries' welfare cannot be over emphasized.

The increased incomes reported here contribute towards transforming smallholder agriculture from subsistence to agribusiness ventures by making the targeted enterprises economically viable. This transformation fits well in the current recognition that subsistence farming should be viewed as a temporary phenomenon that needs a transition through availing small holder farmers with high-quality agricultural advice (CTA, 2011). However, to ensure sustainability of these impacts, further interventions are needed to formalise the market linkages established through the SPs interventions, by signing of legal agreements such as tender documents between CIGs and the buyer or through contracted farming.

The KAPAP model's focus on markets has triggered increased production as envisioned in the design process, resulting in a drastic increase in production of traditionally subsistence enterprises such as peas in Nyandarua and sorghum in Meru central, whose production levels changed by 84.9 and 72%, respectively. The impact of this on the household and national level food and nutritional security cannot be underestimated. Lack of remunerative markets and marketing channels has been an impediment to farmers' efforts towards increased production.

The model is also cost effective as shown by its return to investment of 39.4. This is not a mean achievement for agricultural development in a developing country like Kenya that depends on donor funding for its development efforts. It is important to note that just as recommended by the Journal of Extension (undated, www.joe.org); most extension costs within the model were

incurred upfront and the cost-benefit multiple will continue to increase as the interventions are adopted in a sustainable manner. This cost effectiveness was also enhanced by the use of the CIG approach that enabled the project to reach a large number of farmers within the 15 months, compared to the past individual farmer based extension. The increase in benefits to members is expected to trigger an increase in the CIG membership.

The achievements of KAPAP's extension model, as discussed in this paper, qualify the model's inclusion among other feasible extension approaches or "islands of success" that with minimal modifications, have the potential to transform the agricultural sector in developing countries in Africa. However, just like in most other approaches reviewed in the World Bank Discussion Paper no 45, the KAPAP model is not a 'magic bullet'; as such requires appropriate strategies to ensure its sustainability beyond project period.

Exit plan for KAPAP extension service delivery model. In recognition that farmers in Kenya are accustomed to accessing agricultural extension services free of charge from the public extension systems, NGOs and private sector actors, the KAPAP project envisages sustainability challenges on its model beyond project funding. From this realisation, the project designed some safe exit strategies that include establishment of legal entities and empowerment of beneficiaries to adopt farming as business. With the assistance of their service providers, the beneficiaries have been facilitated to develop co-operative based and value chain specific business plans that focus on pursuing high level interventions. These include enhancing access to inputs and markets, as well as diversification of products through value addition and processing. The membership for such co-orparatives target both the CIGs and other new members to be recruited through out-scaling efforts within each County.

Cooperatives are legal business entities and the registration and buying of shares by the beneficiaries will foster ownership and contribute highly towards the sustainability of the service delivery system as well agricultural sector transformation. The beneficiaries and their leaders have also been empowered through capacity building and participation in farmer fora spearheaded by the Kenya Federation of Agricultural Producers (KENFAP) to enable them articulate their issues and take charge of their needs including extension service delivery.

The project set aside some funds to co-finance the implementation of these business plans, while the rest of the funding will be raised through share holding capital from members and other financial arrangements. It is also expected that the business plans will attract funding from the County government and other funding agents within their localities. Further exit plan strategies will be identified during the models evaluation exercise that will be implemented before the end of project.

ACKNOWLEDGMENT

The authors acknowledge the Common Interest Group (CIG) members and the implementing agencies (CASSC, CTT and DTT) for participation leading to successful implementation of the model. We are grateful for the financial support provided by the World Bank and the Kenya Government. The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 917 - 927 ISSN 1021-9730/2014 $4.00

EFFECT OF FARMER GROUP MEMBERSHIP ON AGRICULTURAL TECHNOLOGY ADOPTION AND CROP PRODUCTIVITY IN UGANDA

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ABSTRACT

The deteriorating agricultural performance over the past decade that coincided with the duration of targeting farmer groups as the sole public supported extension approach in Uganda, calls for intervention on agricultural information dissemination. Uganda Census of Agriculture database of 2008 - 2009 was used to evaluate the effect of farmer group membership on agricultural technology adoption and crop productivity. This particular study aimed at providing policy; answers to whether the use of farmer' groups approach in agricultural information dissemination is resulting in increased adoption of technologies and improved yields. Descriptive statistics and results of translog production function, and propensity score matching were used to provide insights into household major characteristics and to assess the impacts of group membership on adoption of technology and agricultural productivity. Membership to farmer groups in Uganda is low. Only 16 percent of household heads belonged to a group. Although membership to groups resulted in increased yields for banana and cassava, negative impacts were observed for sweet potatoes, beans and maize. Group members were less likely to adopt inorganic fertilisers ($P<0.01$) and improved seed ($P<0.05$) than non-groups members. Although not significant ($P<0.05$), group members' achievement of yields of 3 and 2 t ha^{-1}, respectively, for banana and cassava than non-group members is quite high and of interest for development agencies. On the other hand, non-group members' sweet potato yields were 1.0 tonne per hectare, higher than group's members although not significant ($P>0.05$).

Key Words: Farmer groups, extension, impacts, technologies, Uganda, yields

RÉSUMÉ

La détérioration du niveau de performance agricole au cours des dix dernières années coïncide avec la duréé de la stratégie de d'utilisation des associations de producteurs comme unique approche de vulgarisation appuyée par le gouvernement en Ouganda, ce qui nécessite des interventions en ce qui concerne la diffusion de l'information agricole. Les données d'une enquête nationale en 2008-2009 sur l'Agriculture en Ouganda ont été utilisées pour évaluer l'effet d'organiser les producteurs en associations sur l'adoption des technologies et la productivité agricole. L'objectif de cette étude était de d'éclairer les politiques agricoles sur la question de savoir si l'approche d'utiliser les associations des producteurs pour diffuser l'information agricole résulte en une amélioration du niveau d'adoption des technologies et d'une augmentation de la productivité agricole. Les statistiques descriptives et les résultats de la fonction translog de production et le score de tendance correspondant étaient utilisés pour fournir d'information sur les caractéristiques principales des ménages, et évaluer les impacts de l'appartenance aux associations sur l'adoption des technologies et la productivité agricole: Le niveau d'adhésion aux associations est faible en Ouganda avec seulement 16% des chefs des ménages appartenant à une association. Bien que l'adhésion aux associations a entrainé une augmentation des rendements pour les cultures de la banane et le manioc, des impacts négatifs étaient observés pour la patate douce, le haricot et la maïs. Les membres des associations étaient les moins enclins à adopter l'utilisation des engrais minéraux ($P<0.01$) et les semences améliorées($P<0.05$) par rapport au non adhérents. Bien que pas significatif ($P<0.05$), les différences de rendement de 3 et 2 t ha^{-1} respectivement pour le bananier et le manioc obtenus par les adhérents aux associations par rapport aux non adhérents est tout à fait élevée et d'intérêt pour les agences de développement. D'autre part, les non

adhérents ont des rendement de patate douce de 1.0 t ha^{-1} tout à fait plus élevé que celui obtenu par les adhérents aux associations bien que la différence n'était pas significative (P<0.05).

Mots Clés: Groupes des fermiers, vulgarisation, impacts, technologies, Ouganda, rendements

INTRODUCTION

In Uganda, farmer groups are targeted as an important means of increasing uptake of agricultural technologies to enhance agricultural productivity, commercialisation and linking farmers to markets (MAAIF, 2010a). Although the approach has attracted attention, little is known on how successful the approach is in addressing the country's agricultural transformation. Ugandan government considers transformation of agriculture as a major driver in changing the country from a peasant to a modern and prosperous economy (GoU, 2010). Despite the group approach being embraced in developing countries to addressing a plethora of rural development challenges (Loevinsohn, *et al*., 1994; Woomer *et al.,* 2004), queries still linger on how to enhance farmer groups' membership, cohesiveness, mandate, resources availability, integrity and members' managerial capacity (Mwaura *et al.*, 2012). Nevertheless, well conceptualised and supported groups like in the case of tea smallholders in Kenya have been observed to successfully drive a sub-sector where they collectively own factories, dictate on market prices and are able to employ experts and set agenda for research (Mwaura *et al*., 2010).

Although the National Agricultural Advisory Services (NAADS) programme and other development agencies have used farmer organisations as a major avenue for information dissemination intended to spur agricultural productivity since 2001, little is known about the strategy's impacts on technology adoptions and yields (Bahigwa *et al.*, 2005). Government commitment in agriculture has been through budgetary support to the sector, which accounted for about 5% of the 2010/2011 national allocation, with about 40% of the allocation directed to extension services through NAADS (MoFPED, 2010). More money has been allocated to agricultural research, training and rural infrastructural development in an effort to stimulate economic growth including agricultural transformation (GoU, 2010). Despite the efforts by government, wide yield gaps have been observed between research trials and farmers' fields for the major crops (MAAIF, 2010a). Research yields for maize, beans, banana, groundnuts, and coffee are above 800, 400, 100, 300 and 800 percent, respectively, more than farmers' average yields, indicating that more efforts are required to close yield gaps between research and farmers (MAAIF, 2010a).

Low agricultural productivity has had detrimental effects on economic welfare of rural populations (Ssewanyana and Okidi, 2007) and food security measured in terms of caloric intake (Ssewanyana and Kasirye, 2010). High prevalence and incidence of poverty have been observed in the country (UBOS and ILRI, 2007), with the main contributory factor being low agricultural productivity. Insufficiency in household food production has exposed farmers to severe food insecurity and high prices of food. In Uganda, only 12 percent of households are significant net sellers of food, with 66 percent being net food buyers and relying on market for more than 25% of the value of the food they consume (Benson *et al*., 2008). This implies that improved agricultural production remains an important intervention in addressing welfare and economic development in Uganda. The role of farmer group membership in achieving enhanced technology adoption and yield is yet to be evaluated.

Despite paucity of information on the impacts of farmer groups on agricultural production, their operations, organisation, capacity and sustainability, the new Agricultural Sector Development Strategy and Investment Plan (DSIP) 2010/11-2014/15) proposes to use the group approach for the more complex market oriented activities. The DISP targets farmer groups to improve produce marketing, increase access to financing, and produce value addition with an aim of initiating agricultural transformation (MAAIF, 2010a). It is important, therefore, to understand the role that farmer groups could play in facilitating the agricultural transformation.

Although decisions for targeting groups for extension have already been reached based on the "cooperative paradigm" and success of few groups (Bahigwa *et al.,* 2005; Adong *et al.,* 2013), especially the farmer field schools (FFS) that were highly supported by donors (Godtland *et al.,* 2004; Davis *et al.,* 2012), it is necessary to evaluate the approach's achievements considering the deteriorating agricultural performance (MAAIF, 2010a). This particular study aimed at providing policy answers to whether the use of farmer' groups approach in agricultural information dissemination is resulting to increased adoption of technologies and improved yields.

MATERIALS AND METHODS

A number of recent studies have addressed the evolution and shifting of paradigms on the best agricultural technology dissemination approach (Glendenning *et al*., 2010). Stoop (1988) addressed challenges associated with the "transfer-of technology" approach and the opportunities presented by "training-and-visit" system of agricultural information dissemination. The challenges associated with the "training-and-visit" systems of extension in developing countries, in light of adoption and implementation of liberalisation protocols (Pinstrup-Andersen and Pandya-Lorch, 1994) were highlighted. Pretty (1995), described the promotion impetus of participatory technology development approach which involves collaboration between researchers, extension and farmers in the analysis of agricultural problems and testing of alternative farming practices.

Akinnagbe and Ajayi (2010) highlighted the learning opportunity availed by participatory technology development and extension to researchers and extension agents through working closely with farmers. Effectiveness of the participatory approach has been associated with its ability to incorporate the socio-economic characteristics of the targeted clientele (Scoones and Thompson, 2009). Angstreich and Zinnah (2007) showed similarities between the participatory technologies development and extension approaches, and the farmers field schools (FFS). The potential and effectiveness of FFS approach as the appropriate mechanism for diffusing knowledge-intensive technologies, e.g. integrated pest management, has been described (Gotland *et al*., 2004). A synthesis of immediate and developmental impacts of FFS in various developing countries, in relation to intensive pest management technologies was published a decade ago by van den Berg (2004). Thiele *et al*. (2001) shared experience in implementation of FFS in the Andes and recommended groups quality and development of virtuous circle between participatory research and training.

Kenmore (2002) described the FFS concept as utilising participatory methods "to help farmers develop their analytical skills, critical thinking and creativity and also help them learn to make better decisions". Extension agents who are viewed as facilitators rather than instructors, conduct learning activities in the field on relevant agricultural practices. Through interactive learning and field experimentation, FFS programmes teach farmers how to experiment and solve agricultural problems independently. The cost effectiveness of FFS arising from the fact that farmers adopt the technologies to their own specific environmental and cultural needs even with limited extension budget (Vasquez-Caicedo *et al.,* 2000).

The concept of farmer groups in Uganda as the main component of technology dissemination borrows extensively from the FFS model. The Ugandan government has published guidelines on group formation among farmers and criteria for selection for technological and financial support (MAAIF, 2010b). As per the guidelines, all farmers above 18 years old are targeted to enroll in farmers groups through mobilisation by the local political leadership. By enrolling in groups, farmers were to be supported through provision of extension, technological inputs and other development capacities to achieve food security or transform to commercial farmers. The use of groups in extension is also viewed as more decentralised and demand driven, hence is expected to facilitate farmers to achieve higher agricultural yields. Considering that for farmers to access resources and gain capacity support from the National Agricultural Advisory Service (NAADS) they must be in groups. The main driver

of farmers participating in groups may not be entirely agricultural. Other development partners have adopted the group approach in targeting interventions, with beneficiaries being those enrolled in groups (Adong *et al.,* 2013).

Little literature is available on the operations of farmer groups in the country whether those supported by donors or self-support in terms of membership, group dynamisms, operations, financing, growth trajectories and conflicts management. Steven and Terblanche (2004) outline the experience of establishing and working with farmer groups as they progressed through the different stages of group development and social capital formation. Critical to success of group formation processes, is the skills of the group promoter and the adherence to certain basic group dynamic principles. Thorp *et al.* (2005) queried the real motivation of group formation, members' interest, organisation, operational and performance of groups in achieving desired changes in rural development. Thorp *et al.* (2005) associated other pecuniary benefits and personal interest to override the aim of group formation.

Low levels of membership, both at individual and household levels, with marked differences in regional participation in farmers groups was reported in Uganda (Adong *et al.,* 2013). Key drivers for membership to groups included household's head education attainment, distance to extension service and quality of road infrastructure. In Kenya, acceptance of produce marketing group by farmers was evaluated (Mwaura *et al.,* 2012); it was observed that only a small proportion of farmers who had attended recruitment meetings ended up enrolling as members.

Comparison of farmers under NAADs and those in non-NAADs sub-counties in Uganda has been undertaken (Benin *et al.,* 2011). Using national representative data collected by Uganda Bureau of Statistics, Okoboi *et al.* (2013) evaluated participation of vulnerable households headed by females, youths or people living with disabilities in NAAD's supported groups. The study also evaluated groups affiliated with NAADs programme on agricultural households' access to extension services, the use of improved technologies, crop yield and share of output sold, consumption expenditures and poverty level.

A number of studies have used various yardsticks to compare performance of farmers working in groups and non-group members. Friis-Hansen and Duveskog (2012) used welfare indicators (resources including land, livestock, clothing and housing ownership, non-agricultural income, work as casual labour, food security, quality of diet, health, children education, marital status, and age of household head), to compare FFS members and controls in Kenya, Uganda and Tanzania. All positive attributes were associated with FFS membership than control. The study also showed that FFS had positive attributes on empowerment aspects (various indicators for innovation uptake, access to services, engaging with markets and collective actions/social relations) than non-FFS members. Non-FFS showed some significant positive empowerment attributes in Tanzania such as vaccination of livestock than FFS. Farmers who joined FFS had positive welfare and empowerment attributes prior to membership since most of the factors, e.g. housing standard and age of household could not been affected by being in FFS.

FFS participation significantly enhances knowledge on pests, fungicides and resistant varieties among Peruvian potato farmers (Godtland *et al.,* 2004). The robustness of the positive results of FFS participation on knowledge was demonstrated by the fact that two separate approaches used for estimating the effect of FFS, yielded the same results, a 14 percentage-point increase in knowledge score for FFS participants. This result was observed, despite the low participation rate in FFS of about 5 percent of the targeted population of 900.

Variations were observed among East African countries in effectiveness of FFS to increase farmers' yields (Davis *et al.*, 2012). In Kenya, the value of crop productivity per hectare for farmers participating in FFSs increased by about 80%; however, no significant impact was observed in Uganda. Over the East African countries, the impact of FFS differed significantly across gender, land resource endowment and level of education. Per *capita* agricultural incomes for female-headed households increased by 187%;

while the equivalent income for male-headed did not change. Both, Godtland *et al.* (2004) and Davis *et al.* (2012) used the propensity matching score (PSM) methods of comparison.

METHODOLOGY

Data sources. Data used in this study were derived from the Uganda Census of Agriculture (UCA) of 2008/09, collected by Uganda Bureau of Statistics (UBoS), in collaboration with the Ministry of Agriculture, Animal Fisheries and Industries (MAAIF). Rainfall information was derived from the 2011 Statistical Abstract which reported amounts received for selected towns over the 2008/09 farming seasons. UCA covered 80 districts and through two stage sampling procedures. A total of 31,340 households were surveyed across the four geographical regions, namely Central, Northern, Western and Eastern. The census captured information on socio-economic characteristics, technology use, crop area, crop production, extension, information source, and credit source for the sampled households. The data were nationally representative, rich in agricultural information and covers information on farmers' enrolment in groups. Crops popularly grown by farmers across the country were used as a test for the yield response to farmer groups' enrolment (UBOS, 2010). These crops included maize, bean, banana, cassava and sweet potatoes.

Model specification. Two economic models were used in this study, each contributing to its strength in addressing the objective of the study.

Translog model. An unrestricted translog production function was adopted to estimate factors affecting productivity. The translog is used because it is general and flexible to allow analysis of interaction among variables. The model has been used widely on various studies relating outputs to inputs (Byiringiro and Reardon, 1996; Iraizoz *et al.,* 2003). The model has also been used to analyse technical efficiency of agricultural enterprises (Byiringiro and Readon, 1996; Amudavi *et al*., 2009)**.** The model is generally specified as:

$$InY = \beta + \sum \beta_i InX_i + \sum \beta_i InZ_i + \sum_i \sum_i \beta_i InX_i InX_i + \sum_i \sum_i \beta_i InX_i InZ_i + \beta_K D_K \quad \text{..... (1)}$$

Where:

βs = coefficients, Xs = inputs, Zs = conditioning factors and Ds = dummy variables

Y = productivity of various crops, where inputs (X) included: landholding, years of education, distance from local inputs market, age (years of farming experience), total rainfall and the household size. Dummies (D) used included sex, household reports of using organic and inorganic fertiliser, improved seeds, and access to credit. Other dummies were for region namely, Central, Eastern, Northern and Western.

Propensity score matching. Both acceptance to participate in farmer groups and adoption of any other agricultural technologies have similarity in that both follow Roger's innovation adoption curve (Lapple and van Rensburg, 2011). Economists establishing factors influencing group membership and technology adoption have used similar models mostly the logit or probit, closely related explanatory variables largely categorised as either length of exposure, technology/groups' characteristics, environmental factors or farmers' inherent characteristics (Adesina and Zinnah, 1995; Mwaura *et al.,* 2012; Adong *et al.,* 2013).

Participation in farmer groups could be considered as an adoption of technology with probabilities of adopting any other technology following the same trajectory (Mwaura *et al.,* 2012). To avoid selection and placement bias, propensity score matching (Heckman *et al.*, 1997) has been used to compare performance of groups and non-group members in terms of agricultural knowledge, adoption and productivity (Godtland *et al.*, 2004; Davis *et al.*, 2012).

To determine whether participation in farmer groups results into transformation of agriculture through higher productivity, propensity score matching (PSM) was used. PSM is a methodology

of impact evaluation that tries to match those treated (in this case those in farmer groups) to the untreated (that is those in non-farmer groups) based on observable characteristics. Otherwise, the estimate of a causal-effect obtained by comparing a treatment group with a non-experimental comparison group could be biased because of problems such as selection, placement or some systematic judgment by the researcher in selecting units to be assigned to the treatment (Dehejia and Wahba, 2002).

In this case, i is an index of enrolment to farmers group. Y_{it} is the value of the achieved crops' productivity when unit i represent a group member, and y_{i0} is the value of the same variable when the unit is non-group member. The treatment effect of the unit then becomes $P_i = Y_{i1} - Y_{i0}$.

In non experiments, the treatment effect is the expected treatment effect expressed as:

$$P|_{T=1} = E(P_i \mid T_i = 1) = E(Y_{i1} \mid T_i = 1) - E(Y_{i0} \mid T_i = 1) \quad \text{..... (2)}$$

Where:

$T_i = 1$ if the unit was assigned treatment and $T_i = 0$ is the unit that was assigned to the control.

We can observe $E(Y_{i1} \mid = T_i = 1)$ but not $E(Y_{i0} \mid = T_i = 1)$. In matching, we try to construct the control units based on observable characteristics and obtain $E(Y_{i0} \mid = T_i = 1)$, whereby it is possible to construct the treatment effect as noted above.

$$P|_{T=1} = 1/\|N\|\left(\sum_{j \in J_T} Y_i - 1/|J_i| \sum_{j \in J_T} Y_i\right) \text{N|}$$

(Heckman *et al*., 1997) ..... (3)

N is the treatment effect, $|N|$ is the number of units in the treatment groups, and is the set of comparison units matched to the treatment unit.

The nearest neighbour matching (Dehejia and Wahba, 2002) method was adopted. In this method, each unit/case in the control group (not group member) is matched to a treated case (group member) on the closest propensity score.

RESULTS AND DISCUSSIONS

Memberships to farmer's groups. Table 1 presents characteristics of farmers who are group members and non-members in terms of socio-economic factors and agricultural productivity. Only 16 percent of household heads were group members. Considering that farmer group approach was generally the adopted model for agricultural development by both government and other donors (Bahigwa *et al.,* 2005; Adong *et al*., 2013), it implies that most farmers are not accessing the desired agricultural information. Furthermore, the efforts by government and other development agents to target the same approach for produce marketing and value additions (MAAIF, 2010a) may fail to achieve the desired outcomes. Across regions, enrolment in groups was 20, 18, 17 and 13 percent in Northern, Western, Eastern and Central regions, respectively.

The high level of membership to farmer groups in the Northern region is partially attributed to the existence of targeted government programmes and many non-governmental organisations that have been involved in rehabilitation of the area in the post conflict period (Adong *et al*., 2013). Farmers in groups were observed to be significantly (P<0.01) younger than non-members; had more education than their counterparts; had relatively large landholdings; had bigger families; accessed extension and credit services; and reported higher yields of maize than farmers who were non-group members. On the other hand, non-group members had significantly (P< 0.01) adopted the use of inorganic fertiliser and achieved better yields of sweet potatoes.

Effect of group participation on agricultural productivity. Outputs of the translog production function estimation of factors influencing crop productivity is presented in Table 2. Various crops were influenced differently by explanatory variables used in this regression. Group members had significantly higher maize and banana yields (P<0.001) compared to non-group members. Non-group members, however, recorded significantly (P<0.001) higher yields of sweet potatoes

TABLE 1. Socio-economic characteristics and agricultural productivity among NAADS groups and non-groups members in Uganda

Variable	Member[1]	Non-members	Prob>F
Age of household head (yr)	32.2	33.2	0.000
Years of education for hh head (yr)	6.12	5.48	0.000
Total household landholding (ha)	1.45	1.13	0.000
Household size	7.71	6.43	0.000
Received extension visits a year	53.41	13.97	0.000
Maize yield (t ha^{-1})	6.75	5.56	0.000
Sweet potato yield (t ha^{-1})	6.72	8.24	0.000
Cassava yield (t ha^{-1})	9.73	10.03	0.604
Bean yield (t ha^{-1})	2.74	2.47	0.122
Banana yield (t ha^{-1})	15.42	14.98	0.329
Distance to feeder road (km)	5.08	4.95	0.022
Distance to gravel road (km)	9.82	9.88	0.574
Sex (percent female)	49.46	49.53	0.344
Inorganic fertiliser use (percent)	8.68	9.74	0.000
Organic fertiliser use (percent)	28.29	27.93	0.385
Improved seed use (percent)	33.68	34.30	0.162
Access to credit (percent)	12.83	10.81	0.000
Region			
Central (percent)	13	87	
Eastern (percent)	17	83	
Northern (percent)	20	80	
Western (percent)	18	82	
National	16	84	-

[1] Household with its head as a member of a NAADS group. Source: Author summary based on UCA 2008/9

compared to group members. Yields of beans and cassava were not significantly different between group and non-group members. These mixed observations were unexpected considering that groups are meant to empower farmers to achieve higher yields (Godtland *et al.,* 2004; van der Berg, 2004). The results imply that membership to groups has no advantages in all crop management technologies and, in fact their practices may lead to inefficiency in other crop enterprises.

A few studies points to this mixed results of crop yields and interventions through collective extension. It was reported that groups supported by NAADs promoted improved seed and high yielding enterprises, but failed on soil fertility enhancing technologies (Benin *et al.,* 2011). Although farmers in groups were observed to have adopted improved crop technologies more than the non-members in Kenya, Uganda and Tanzania, non-group members showed significantly higher levels of livestock vaccination (Friis-Hansen and Duveskog, 2012). Davis *et al.* (2012) showed that group members had no significantly higher crops yields than non-members in Uganda, while in both Kenya and Tanzania, group members had recorded significant higher yields and household incomes. Higher yields of maize and banana reported among group members are consistent with results of other studies, where group extension had been associated with superior yields (Godtland *et al.,* 2004). The lower yield of sweet potatoes reported by group members raises concern on the effectiveness of groups strategies. Initially, the group approach targeted complex technologies such as integrated pest management and were observed to lead to increased adoption of technologies and consequently higher yields (Godtland *et al.,* 2004). The low productivity could be associated with shifting of resources including capital, management and labour to other crop's enterprises (MAAIF, 2010a) that

TABLE 2. Translog production function estimation of factors influencing agricultural productivity for selected crops among farmers in 2008/9

Variable	Maize	Bean	Sweet potatoes	Cassava	Banana
Sex	0.002	-0.002	-0.029	-0.035	-0.015
Age	-0.000	-0.000	0.001	0.002**	-0.000
Edyrs	0.005**	0.002	0.011***	0.014***	0.006*
farmer group	0.107***	0.008	-0.091***	-0.029	0.166***
Hhsize	0.010***	0.004*	0.021***	0.010***	0.023***
inorganic f~t	-0.026	0.026	0.042	-0.070*	0.040
improved seed	-0.025	-0.064***	-0.008	-0.023	-0.031
organicfert	-0.046**	0.005	-0.052**	-0.076**	-0.038*
Credit	0.013	-0.030	-0.010	0.050	-0.087***
logtland2	-0.334***	-0.177***	-0.401***	-0.434***	-0.821***
Inputsqrt	-0.005	-0.001	-0.009*	-0.009	-0.025***
Lgraintot	0.746***	0.278***	1.314***	1.237***	-0.816***
p1 (Central)	0.000	0.142***	0.000	0.000	-0.108***
p2 (Eastern)	0.026	0.000	0.082**	0.073*	0.000
p3 (Northern)	-0.266***	0.194***	0.123***	0.178***	-0.157
p4 (Western)	0.210***	0.341***	0.292***	0.267***	0.404***
_cons	-4.171***	-1.418***	-7.948***	-7.279***	8.014***
N	22187	14973	16936	15158	19748
r2	0.083	0.060	0.061	0.051	0.171

NB: Significance levels, * P<0.05; ** P<0.01; *** P<0.001

are of higher commercial values and maintaining the crop as a secondary food and income enterprise.

The possibility that farmers in groups could have adopted sweet potatoes' inferior technologies cannot be ignored considering that weak linkages between farmer groups, research institutions and extension systems (World Bank, 2010) raise questions on the quality and consistence of information reaching the groups and first line extension agents.

Other factors that were observed to be significant in influencing efficiency in productivity of various crops include household size (hhsize); total landownership (logtland2); total annual rainfall received (lgraintot) and regional dummies.

Agricultural productivity levels. Table 3 shows propensity matching scores for farmers in groups and non-members. Matching farmers with similar characteristics, except membership to groups, showed that group members were unlikely to adopt the use of inorganic fertilisers and improved seeds. Membership to groups had an average treatment effect of 2.83 and 1.86 tonnes per hectare for banana and cassava, respectively. Results indicate that group members are likely to achieve higher yields of banana and cassava than non-members. A reduction of productivity was observed for sweet potatoes, maize and bean with membership to groups. An average treatment effect of negative one tonne per hectare for sweet potatoes was observed with group membership.

No treatment effects were significantly different between farmers in groups and those operating individually on crops' productivity achieved. Overall, group's membership was observed to have a mixed impact on agricultural crops productivity. While banana and cassava yields showed improvement (positive average treatment effect) with groups' membership, it may be difficult to conclude that they were very effective in improving agricultural productivity considering the negative impact for some crops including bean, maize and sweet potatoes. The observed mixed results using the PMS mirror those observed using the translog model.

TABLE 3. Propensity score results of technology adoption and productivity differences between NAADS groups and non-groups in Uganda

Technology/crop	Number of treated	Number of control[1]	Average treatment effect	Std. Err.	t-value
Inorganic fertiliser	2591	13127	-0.024**	0.009	-2.64
Organic fertiliser	2591	13169	0.014	0.013	1.06
Improved seed	2603	13238	-0.036*	0.014	-2.53
Extension visits	337	1855	0.52	0.32	1.63
Maize	947	4991	-0.10	0.45	0.21
Sweet potato	787	3972	-0.97	0.89	-1.09
Cassava	702	3396	1.86	1.75	1.07
Bean	757	3356	-0.067	0.27	-0.25
Bananas	938	4730	2.83	1.56	1.81

NB: Significant *P<0.05; ** P<0.01. [1]Do not belong to farmer groups

CONCLUSION

Membership to farmer groups in Uganda is barely 16%, which is considerably low. The study concludes that membership to farmer groups does not necessarily lead to adoption of high yielding technologies (e.g. use of inorganic fertiliser) and increased productivity. In fact, membership to groups has detrimental effects on adoption of inorganic fertiliser and improved seeds. Nevertheless, membership to farmer groups was observed to lead to achievement of higher yields for banana and cassava.

The low rate of participation in groups should also concern policy makers, especially considering that the country invests in agricultural extension through groups. Adoption of groups by farmers could be considered to be at an early stage with only innovators and early adopters joining. Development agencies need to undertake a detailed audit of farmer groups formation, leadership, organisation, operation, dynamics, facilitations and sources of technology disseminated. Promoters of farmer groups should direct efforts in ensuring the efficacy of the strategy in enhancing productivity thereby improving the welfare of farmers. Failure for such intervention would result to farmers developing negative perception on the group approach of agricultural information dissemination. Negative perception on the group strategy will not only discourage more farmers from joining but also lead to decreased membership.

ACKNOWLEDGEMENT

The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 929 - 939 ISSN 1021-9730/2014 $4.00

FOOD PRICE TREND ANALYSIS: LESSONS FOR STRENGTHENING FOOD SECURITY POLICY IN TANZANIA

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ABSTRACT

Increase in global prices for most key cereal crops has had an unprecented effect on local markets prices for maize (*Zea mays* L.) and rice (*Oryza sativa*), raising policy concerns especially in eastern and southern Africa. The objective of this study was to analyse maize and rice price transmission within Tanzania domestic markets. The study used monthly wholesale prices from nine local markets in Arusha, Dar es Salaam, Iringa, Lindi, Mwanza, Rukwa, Dodoma and Morogoro from January 2004 to August 2013. The Vector Error correction model was used. Markets were categorised into leading and follower markets. Results showed that 88 percent of maize prices in selected markets were stationary, while for rice it was 100 percent. Further analysis using Johansen test indicates 63 percent of selected maize market pairs and 75 percent for rice markets pairs were co-integrated. Leading markets were found to transmit relatively small percentages (20 percent) compared to more than 70 percent of prices transmitted by follower markets. It took relatively longer for smaller markets to transmit prices to their larger counterparts. This was also supported by granger causality analysis, where larger markets prices failed to be transmitted to small markets. Very few pairs of markets (5%) had bi-directional movement of prices, indicating limited flow or market rigidity in sharing price information. The speed of price adjustment was also very slow, especially when higher prices originate from smaller markets. This trend implies presence of many layers of markets and the prices were largely controlled by fewer traders rather than marketing forces or other actors like farmers who were down to the value chain. This kind of monopoly leads to price volatility and consumers are forced to pay more, hence, affecting affordability of majority net buyer consumers.

Key Words: Co-integration, Vector Error Correction Model

RÉSUMÉ

L'augmentation des prix de la plupart des céréales a eu un effet sans précédant sur les prix du maïs (*Zea mays)* et du riz (*Oryza sativa* L.) sur les marchés locaux, causant des soucis au niveau des politiques agricoles spécialement en Afrique de l'Est et du Sud. L'objectif de cette étude était d'analyser la transmission des prix de maïs et du riz sur les marchés domestiques en Tanzanie. L'étude a utilisé les prix mensuels des grossistes collectés sur neuf marchés locaux d'Arusha, Dar es Salaam, Iringa, Lindi, Mwanza, Rukwa, Dodoma et Morogoro, de Janvier 2003 à Août 2013. Le modèle de Correction d'Erreur Vectorielle était utilisé. Les marchés étaient catégorisés en marchés principaux et marchés secondaires. Les résultats ont montré que 88 et 100% respectivement des prix du maïs et du riz sur les marchés sélectionnés étaient stationnaires. Une autre analyse utilisant le test de Johansen indique que 63 % des pairs de marchés du maïs sélectionnés et 75% des pairs de marchés du riz étaient co-intégrés. L'étude a montré aussi que les marchés principaux transmettaient relativement un faible pourcentage (20%) comparés à plus de 70% des prix transmis par les petits marchés. La transmission des prix des marchés secondaires aux marchés principaux a relativement pris une longue période. Ceci était aussi confirmé par une analyse de causalité de Granger qui montra que la transmission des prix des marchés principaux aux petits marchés a échoué. Très peu de pairs de marchés (5%) avaient un mouvement bidirectionnel des prix, indiquant une certaine rigidité dans la transmission de l'information sur les prix. La vitesse dans l'ajustement des prix était aussi très lente, spécialement lorsque les prix les plus élevés provenaient des petits marchés. Cette

tendance implique la présence de plusieurs couches de marchés et les prix étaient largement contrôlés par peu de vendeurs plutôt que les forces régissant les marchés ou d'autres acteurs tels les producteurs qui sont dans la partie inférieure de de la chaine de valeur. Ce type de monopole conduit à une volatilité des prix et les consommateurs sont obligés de payer plus, affectant ainsi la capacité d'achat de la majorité des consommateurs.

Mots Clés: Co-intégration, Modèle de correction d'erreur vectorielle

INTRODUCTION

Global food prices, especially for key cereal crops, oilseeds, dairy products and meat increased at unprecedented rates in sub-Saharan Africa (SSA) since 2007/08, leading to the current food price crisis among millions of people. This has had adverse effects on many countries, with significant hunger, poverty and macro-economic disorders (Karugia *et al.*, 2009). When global prices rose sharply, prices in eastern and southern Africa increased at lower rates over the same period. Toward 2010 and 2011, prices within the sub-region continued to rise in tandem with world prices (Nzuma, 2013), thus becoming an issue of concern for the government of the sub-region including, Tanzania.

Studies have revealed different causes of the higher food prices, including low levels of world cereal stocks, crop failures in major exporting countries, population growth, urbanisation, rapidly growing demand for biofuels and rising oil prices (FAO, 2008; von Braun, 2008; Balter, 2013; Nzuma, 2013). As the price surge spread across countries, several other factors emerged to reinforce the crisis; most importantly, export ban by main exporting countries such as Tanzania, weakening of the United States dollar, increase in speculation and the global fuel and financial crisis. Tanzania's scenario was associated with adhoc measures such as the cereal export ban and market functionality factors.

Other studies have extensively reported on the causes of the higher prices in domestic markets (FAO, 2008; von Braun, 2008; Balter, 2013; Nzuma, 2013). This paper examines the trend and price transmission within markets for maize and rice in Tanzania during the 2004 to 2013 period.

METHODOLOGY

This study used the modified vector error-correction model (VECM) (Minot, 2010) to examine price transmission between domestic food market prices in Tanzania during the period of January, 2004 to August, 2013 in various markets (Arusha, Dar es Salaam, Iringa, Lindi, Mwanza, Rukwa, Dodoma and Morogoro). Data for maize and rice were obtained from Ministry of Industry and Trade (MIT). The Ministry collects daily spot prices in all larger markets around the country. Daily prices were cleaned, standardised and calculated into monthly average prices and entered into the model.

Structure and operationalisation of the VECM model. VECM model consists of a domestic price for one commodity in one market against prices of the same commodity in another market (Minot, 2010). For each pair of domestic markets, the analysis consists of three steps; (i) price variables tested individually to establish whether they were non-stationary. This was tested with the Augmented Dickey-Fuller test (ADF). (ii) The Johansen test was used to determine whether the two series were co-integrated, meaning that each variable was non-stationary. The analysis also tested for a long-run relationship between prices in different markets. (iii) If the Johansen test indicated presence of a long run relationship between the two variables, then the price transmission was estimated using VECM. The model takes the following general form:

$$\Delta Pt = \propto + \cap P_{t-1} + \sum_{k=1}^{q} rk\,\Delta P_{t-k} + \varepsilon_t \quad \text{..... Eq. 1}$$

Where:

P_t = an nx1 vector of n price variables;

$$\Delta P_t = P_t - P_{t-1}$$

Δ = the difference operator, so
ε_t = an nx1 vector of error terms;
α = an nx1 vector of estimated parameters that describe the trend component;
Π = an nxn matrix of estimated parameters that describe the long-term relationship and the error correction adjustment; and
rk = a set of nxn matrices of estimated parameters that describe the short-run relationship between prices, one for each of q lags included in the model.

The model tests for the effect of each variable on each other under the law of one price. In the context of this study, the two-variable VECM tested the effect of price from leading or large consuming markets to follower or producing regions markets prices. In addition, tests automatically indicate that the 12 months lagged term was generally sufficient for carrying out price transmission analysis. Since the analysis is not concerned with international price transmission to domestic markets, only one portion of the VECM was sufficient for analyzing domestic price transmission. This portion can be simplified as follows:

$$\Delta P_t^d = \alpha + \theta\{P_{t-1}^d - \beta_{t-1}^s\} + \delta\Delta P_{t-1}^s + \rho\Delta P_{t-1}^d + \varepsilon_t \quad \text{..... Eq. 2}$$

Where:

P_t^d = the log of leading market price converted to US/MT;

P_t^s = the log of follower market price of the same commodity in real US/MT:

Δ = the difference operator, so

$$\Delta P_t = P_t - P_{t-1};$$

$\alpha, \beta, \theta, \delta, and\ \rho$ are estimated parameters; and ε_t is the error term.

The data were tested for stationary series using unit root based on Equation 3.

$$\Delta P_t = \propto + \delta P_{t-1} + \varepsilon_t \quad \text{…….....} \text{ Eq. 3}$$

Where:
P_t = the crop price in a given market;
t = the time index and in this study data were recorded on monthly basis;
Δ = the difference operator;
α = a constant term;
ε = the error term; and
δ = unit root test.

In this model, a unit root was estimated and tested when δ is equal to zero (where δ = p-1) (Ravi, 2011). Since the test is done with presence over residual data it is impossible to use t-distribution to provide critical values. Therefore, ADF test was used with the help of e-views. The hypothesis statement was as follow:

Ho: δ = 0 (Unit root)
H1: δ ≠ 0

The decision rule is, if t>ADF critical value, do not reject null hypothesis, i.e. unit root exists; and if t>ADF critical value, reject null hypothesis i.e. unit root does not exist. Testing for Granger causality (GC) plays an important part in many VECMs to understand the direction of causality particularly to integrated markets. Therefore, P^1 prices can be said to be granger caused P^2 prices if P^2 helps in the prediction of P^1 or equivalently, if the coefficient on the lagged P^1 are statistically significant. However, the two-way causation frequently occurs, i.e. P^1 prices in market X granger cause P^2 prices in market Y, and P^2 prices in market Y granger cause P^1 prices in market X. It is important to note that the statement P^1 prices in market X granger cause P^2 prices in market Y does not imply that P^2 prices in market Y is the effect or result of price P^1. Granger causality measures precedence and information content, but does not by itself indicate causality in the more use of the term (Ravi, 2011; Worako, 2012).

E-view was used and it runs bi-variate regression in the form as shown in equation (4) and (5):

$$P_t^{2Y} = \propto_0 + \propto_1 P_{t-1}^{2y} + \cdots + \propto_t P_{t-1}^{2y} +$$

$$\beta_t P_{t-1}^{1x} + \ldots + \beta_t P_{-t}^{1x} + \varepsilon_t \quad \ldots\ldots\ldots\ldots \text{Eq. 4}$$

$$P_t^{1x} = \propto_0 + \propto_1 P_{t-1}^{1x} + \ldots + \propto_t P_{t-1}^{1x} +$$

$$\ldots + \beta_t P_{-t}^{2y} + \varepsilon_t \quad \ldots\ldots\ldots\ldots \text{Eq. 5}$$

Where:

t = time, P^{2y} = price in market Y, P^{1x} = price in market X, α = intercept, ε = the error term and β = coefficient. For all possible pairs of prices in market X and Y or (P^{1x}, P^{2y}) series in the group, the reported F-statistics were the Wald statistics for the joint hypothesis such that:

$$\beta_1 = \beta_2 = \cdots \beta_1 = 0 \quad \ldots\ldots\ldots\ldots \text{Eq. 6}$$

Therefore, for each equation, the null hypothesis is that price P^1 in market X does not granger cause price P^2 in market Y in the first regression and *vice versa* in the second regression equation.

Interpretation of model variables. The coefficients in the error-correction model were interpreted as follows:

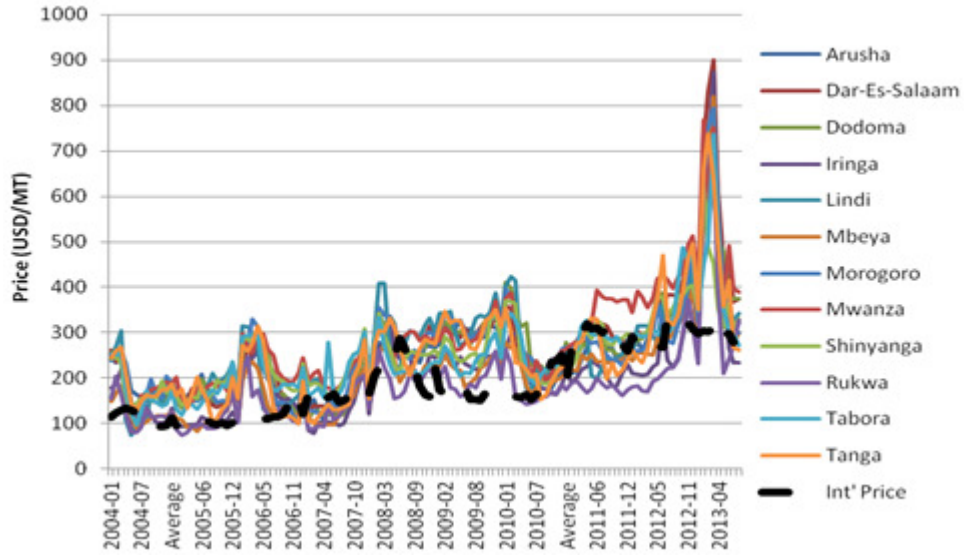
a) Since the prices are expressed in logarithms, the co-integration factor (ß) measures long-run elasticity of the follower market price with respect to the leading market price of the same commodity. Thus, ß is the long-run elasticity of price transmission. The expected value for commodities traded between leading and follower market is 1>ß>0;
b) The error-correction coefficient (θ) reflects the speed of adjustment. It is expected to fall in the range of -1<θ<0. As θ gets closer to -1, the more quickly the leading/larger market price will return to the value consistent with its long-run relationship to the follower/smaller market prices;
c) The coefficient on change (d) is the short-run elasticity of the leading market price relative to the follower price market. In this case, it measures the percentage adjustment of leading market prices by months after 1 percent shock in follower market price. The expected value is 0<d<ß.

The coefficient on the lagged change in the leading market price (p) is the autoregressive term, reflecting the effect of each change in the leading market price on the change in the follower market price in the next period. The expected value is -1<p<1.

RESULTS AND DISCUSSION

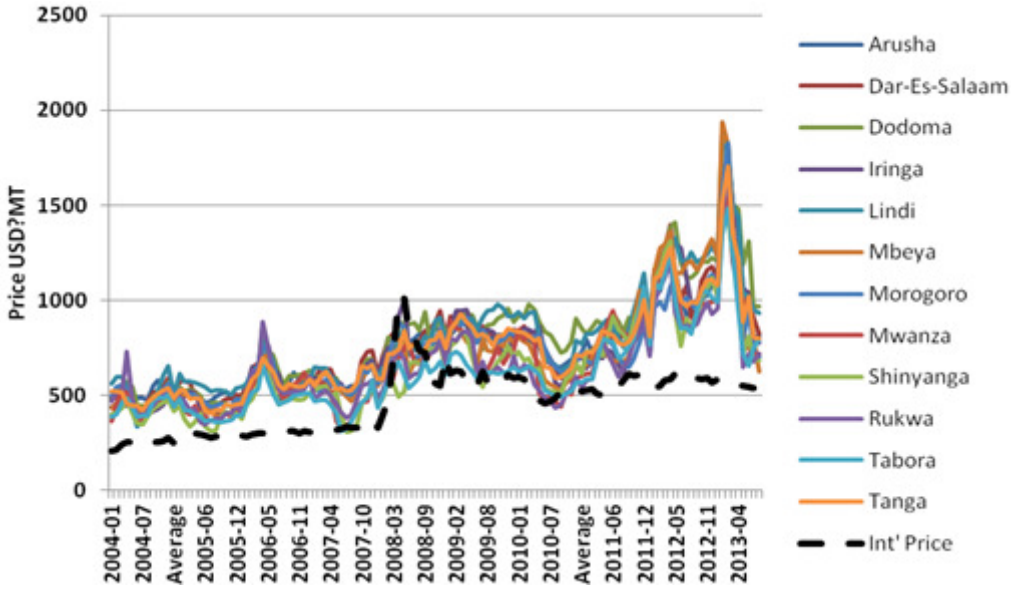
The price trends. The price surge since 2004 (except in 2007/08) for rice and maize at the beginning of 2012 when the international prices were low (Figs. 1 and 2) suggests domestic price movement and other drivers particularly at national level. For example, from January 2010 to August 2013, the margin between local and international prices for rice prices increased from 26 to 52 percent, with the local market having higher prices. On the other hand, the maize price difference between domestic and international prices, more than doubled (15 to 39%) with domestic prices being higher. The fluctuation of the supply between the harvest seasons as a result of unbalanced trade flows led to even wide variation in prices as well as food insecurity as farmers were unable to store their own production. However, the price of maize went down in the last year across certain markets in Togo, Kenya, Chad, and Uganda (between 28 and 38%) because of good supplies, and in Uganda because of reduced export pressures (World Bank, 2013).

Unit root test. The results of the unit root test are presented in Table 1. ADF test, calculated and critical values, suggest insufficient evidence to reject the null hypothesis of unit roots at the 5% level, suggesting that all the series were stationary processes and integration of the same order, except for maize prices in Lindi and Mtwara markets.



Source: Ministry of Industry and Trade (MIT), Tanzania

Figure 1. Maize price trend in markets in Tanzania during 2004 to 2013.



Source: Ministry of Industry and Trade (MIT), Tanzania

Figure 2. Rice price trend in markets in Tanzania during 2004 to 2013.

Maize co-integration. All other maize markets showed long run relationships, except for Dar es Salaam *versus* Dodoma, Arusha *vs.* Iringa, Arusha *vs.* Mbeya, and Mwanza *vs.* Rukwa (Table 2). Dar es salaam is the largest consuming region and attracts supplies from many surplus regions in the country. Dodoma is a maize auction market for eastern and southern Africa.

Dodoma *vs* Dar es Salaam did not integrate because both are large markets and compete for maize supplies from surplus regions in the country. This implies that the two markets (Dar es Salaam *vs* Dodoma) did not have a constant long-term trade flow due to reliable connectivity with other regions. Prices in Dodoma market were higher, thus it was unprofitable for traders to

TABLE 1. Unit root tests results for maize and rice monthly prices from 2004 to 2013 in Tanzania

Market	Test	Calculated values	Critical values at 0.05	
			Maize	Rice
Arusha	ADF	2.88	1.70	2.38
Bukoba	ADF	2.88	2.25	2.81
Dar es Salaam	ADF	2.88	2.23	1.89
Dodoma	ADF	2.88	1.79	2.25
Iringa	ADF	2.88	2.25	2.22
Lindi	ADF	2.88	2.09**	2.14
Mbeya	ADF	2.88	1.93	1.622
Morogoro	ADF	2.88	2.36	2.06
Moshi	ADF	2.88	1.65	1.94
Mtwara	ADF	2.88	2.57**	2.85
Musoma	ADF	2.88	1.76	2.23
Mwanza	ADF	2.88	2.39	1.91
Rukwa	ADF	2.88	2.56	3.09
Shinyanga	ADF	2.88	1.96	2.12
Singida	ADF	2.88	1.92	2.06
Songea	ADF	2.88		
Tabora	ADF	2.88		
Tanga	ADF	2.88		

ADF = Augmented Dickey Fuller Test; ** = non-stationary data

TABLE 2. Maize market co-integration data for various paired markets in Tanzania during 2004 to 2013 period

Market pair	Eigen value	Trace statistic	Critical value	P-values
Dar - Dodoma	0.09	14.55	15.49	0.07*
Dar - Iringa	0.13	18.26	15.49	0.02
Dar - Mbeya	0.14	19.47	15.49	0.01
Arusha - Iringa	0.09	15.49	15.49	0.05*
Arusha - Mbeya	0.09	12.37	15.49	0.14*
Arusha - Morogoro	0.12	18.42	15.49	0.02
Lindi - Dodoma	0.18	27.97	15.49	0.00
Lindi - Iringa	0.20	29.53	15.49	0.00
Lindi - Mbeya	0.16	23.17	15.49	0.00
Mwanza - Iringa	0.12	17.46	15.49	0.03
Mwanza - Rukwa	0.09	13.2	15.49	0.11*

* = No co-integration. Deriodr various paired markets in Tanzania during ...tion between site graphs

frequently supply Dar es Salaam market. Instead they traded more with Lindi, where prices were relatively higher than those in Dar es Salaam.

Arusha market was both a high maize producing area and a transit route for the crop to Nairobi. Significant amounts (17,916 metric tonnes) of maize in the region were exported to Kenya *via* Namanga (FEWS NET/FAO/WFP, 2011). The same route was used for export of maize produced from other regions such as Manyara, a major maize producing area in northern Tanzania. During peak deficit periods in Kenya, transit of maize through the Tanzania-Kenya border could reach 1,000 tonnes per day (Mashindano *et al*., 2012). Overall, it was relatively a shorter distance for traders in Arusha to procure maize from Manyara than from Iringa or Mbeya, although the road connecting these regions is tarmac. Arusha - Manyara is about 118 Km compared with 686 Km Arusha-Iringa or 905 Km Arusha-Mbeya (TANROADS, 2012).

Rice co-integration. Generally, rice markets co-integration was concentrated in regions which were closer to each other (Table 3). For example, Dar es Salaam *vs*. Shinyanga, Rukwa *vs*. Morogoro, Rukwa *vs.* Mbeya, and Rukwa *vs.* Iringa were not co-integrated. Rice deficit regions such as Lindi had price co-integration with surplus Morogoro, Mbeya and Iringa. Implying long term trade relation and over dependence of Lindi for rice supplies from those regions.

Despite Lindi's co-integration with many suppliers, rice prices were higher than in many other regions. Poor connectivity was a major factor affecting food prices in southern regions of Tanzania. This translates into high transaction costs, which affect the price to the final consumers. World Bank (2009) found that transport prices per metric tonne per kilometre from farm-gate to primary markets were 3-5 times larger than those from secondary to wholesale markets located in the east African capitals. As a result, about 45 percent of average transport charges were transferred to final consumers.

Maize price transmission. Table 4 represents follower markets transmitting more than 65 percent of maize prices to leading markets. Dodoma transmitted relatively small percentages to Dar es Salaam market. This was because Dodoma was also a major auction centre in eastern and southern Africa, which makes price margin to those of Dar es Salaam very small. Similarly, it was established that surplus maize had been diverted to neighbouring countries from Dar es Salaam and central regions markets like Dodoma and Singida which are semi arid and have chronic

TABLE 3. Rice market co-integration data for paired markets in Tanzania during 2004 to 2013 period

Market pair	Eigen value	Trace statistic	Critical value	p-values
Dar – Iringa	0.13	18.64	15.49	0.02
Dar - Morogoro	0.13	18.29	15.49	0.02
Dar – Mbeya	0.14	20.68	15.49	0.01
Dar - Shinyanga	0.08	12.89	15.49	0.12*
Arusha - iringa	0.15	20.96	15.49	0.01
Arusha - Morogoro	0.16	22.07	15.49	0.00
Arusha - Mbeya	0.1	15.9	15.49	0.04
Arusha - Shinyanga	0.16	22.31	15.49	0.00
Mwanza- Shinyanga	0.15	22.33	15.49	0.00
Lindi - Mbeya	0.11	16.46	15.49	0.04
Lindi – Iringa	0.13	17.82	15.49	0.02
Lindi - Morogoro	0.12	16.61	15.49	0.03
Rukwa - Morogoro	0.06	10.79	15.49	0.23*
Rukwa - Iringa	0.09	13.26	15.49	0.11*
Rukwa - Mbeya	0.09	14.18	15.49	0.08*
Tanga - Morogoro	0.09	13.17	15.49	0.11

* = no co-integration

TABLE 4. Maize markets price transmission in paired markets in Tanzania during 2004 to 2013 period

Markets	t-value	Transmission (%)	Speed of transmission
Dar – Iringa	8.27	74.2	11.24
Dar - Shinyanga	9.36	95.8	7.38
Dar – Mbeya	8.97	81.4	3.29
Dar – Rukwa	7.21	67.9	3.08
Dar - Dodoma	6.4	60.4	8.62
Arusha - Mbeya	8.99	81.4	3.29
Arusha - Rukwa	8.96	87.8	3.76
Lindi – Iringa	10.86	93.3	4.63
Lindi - Mbeya	9.28	82.9	8.77
Lindi - Rukwa	7.38	73.7	7.75
Mwanza - Iringa	11.39	98.9	3.14
Mwanza-Rukwa	9.24	81.8	3.56

TABLE 5. Rice market price transmission in paired markets in Tanzania during 2004 period 2013

Markets	t-value	Transmission (%)	Speed of transmission
Dar – Iringa	7.34	61.9	7.58
Dar – Shinyanga	8.83	81.5	4.13
Dar – Mbeya	7.24	69.5	4.74
Dar – Morogoro	7.24	57.6	6.21
Arusha – Shinyanga	9.51	86.3	3.46
Arusha – Iringa	9.5	84.1	3.98
Arusha – Morogoro	9.51	78.1	3.06
Rukwa – Mbeya	6.61	65.3	12.35
Rukwa – Iringa	7.68	75.4	4.15
Rukwa – Morogoro	8.18	75.7	9.71
Tanga – Morogoro	7.83	60.2	4.56
Lindi – Morogoro	8.07	72.4	5.91
Lindi – Mbeya	7.37	72.9	4.79
Mwanza – Shinyanga	7.17	63.3	5.89

maize deficit due to better price margins (World Bank, 2009).

Rice price transmission. Table 5 presents follower market or small market transmissions to leading or larger consuming markets. The only exception was Morogoro market which transmitted 57 percent of prices in Dar es Salaam market. Dar es Salaam and Morogoro are much closer about (198 Km) than other major rice producing regions, but it takes more than 6 months for the prices to be transmitted from the latter to the Dar es Salaam market. Regions like Mbeya and Shinyanga take less than 4 months to transmit prices to Dar es Salaam. Arusha on the other hand, is very far but it takes 3 months to respond to prices from smaller markets from Shinyanga, Iringa and Mbeya. This is due to being close to a major export market of Nairobi. Therefore, demand in Nairobi pushes higher rice prices in Arusha, consequently affecting net buyers. However, it is not clear whether farmers benefit from the premium prices which traders get by exporting to Kenya.

Granger causality outputs. Table 6 depicts results of the granger causality and in this analysis Dar es Salaam, Arusha, Lindi and Mwanza were considered as reference markets or leading markets. Results show only maize prices of Mbeya markets depended on maize prices prevailing in Dar es Salaam market; while Iringa, Rukwa and Dodoma maize prices did not. In Ethiopia, results from similar analysis showed different results where, Addis Ababa which is equivalent to Dar es Salaam had fully bi-directional maize prices with other markets. This implies that Addis Ababa maize prices did not granger cause any markets or surplus maize regions. Maize prices in Arusha markets did not depend on prices from Mbeya and Rukwa due to the fact that Arusha was both a producing region, transit route and larger market. Lindi, unlike Arusha and Dar es Salaam, depended heavily on prevailing prices from Dodoma, Iringa and Mbeya. Also, Mwanza maize prices depended on prevailing prices in Iringa markets.

The analysis shows that there was a limitation for leading maize markets to influence prices in follower markets. This implies that maize producers did not set prices based on prices prevailing in leading markets. Van Campenhout (2007) observed slow price transmission signals to farmers due to lack of good infrastructures, as a results they were incapable of reacting to increased prices in leading markets (Kilima *et al*., 2008).

Rice prices for Dar es Salaam market were found to granger cause prices, but with a weak effect, in Mbeya and bi-directional price

TABLE 6. Granger causality tests results for selected maize and rice markets from 2004 to 2013

Crop	Leading market	Null hypothesis	Follower market	F-statistic	Probability	Causality from follower market to leading market
Maize	Dar es Salaam	Maize prices in Dar market does not Granger Cause	Mbeya	4.54	0.01	Yes, at 5% significance level
			Iringa	16.93	0.00	No, at 5% sig level
			Rukwa	5.08	0.01	Yes, at 5% significance level
			Dodoma	9.97	0.00	Yes, at 5% significance level
	Arusha	Maize prices in Arusha market does not Granger Cause	Iringa	12.77	0.00	Yes
			Mbeya	12.79	0.00	No
			Rukwa	6.11	0.00	No
	Lindi	Maize prices in Lindi market does not Granger Cause	Dodoma	10.14	0.00	Yes
			Rukwa	7.34	0.00	No
			Mbeya	8.83	0.00	Yes
			Iringa	11.44	0.00	Yes
	Mwanza	Maize prices in Mwanza market does not Granger Cause	Iringa	7.20	0.00	Yes
Rice	Dar es Salaam	Rice prices in Dar market does not Granger Cause	Iringa	13.40	0.00	Yes
			Shinyanga	2.48	0.09	Bi-directional
			Mbeya	3.82	0.02	No
			Morogoro	9.92	0.00	Yes
	Arusha	Rice prices in Arusha market does not Granger Cause	Shinyanga	4.78	0.01	Yes
			Iringa	9.89	0.00	Yes
			Morogoro	7.60	0.00	Yes
	Lindi	Rice prices in Lindi market does not Granger Cause	Morogoro	9.72	0.00	Yes
			Mbeya	2.84	0.06	No
	Mwanza	Rice prices in Mwanza market does not Granger Cause	Shinyanga	9.61	0.00	Yes

movement with Shinyanga market. Shinyanga rice market depended lightly on prices prevailing in Arusha market (Table 6). However, Iringa and Morogoro markets depended on Arusha market prices more than Mbeya. Lindi prices had an effect on Mbeya rice prices, but with limited effect in Morogoro prices.

The analysis implies that many domestic markets for rice and maize had limited dependency on price situation in major leading markets such as Dar es Salaam and Arusha. Marketing arrangements for maize and rice in Tanzania were complex and multi-layered. Infrastructure connecting these markets were underdeveloped, causing slow price transmission (Zorya and Mahdi, 2009). However strengthening market information systems at different levels of markets in rural and urban areas is essential to improve price signal flow and producers response to higher prices.

ACKNOWLEDGEMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 941 - 950 ISSN 1021-9730/2014 $4.00

ENHANCING RESPONSE FARMING FOR STRATEGIC AND TACTICAL MANAGEMENT OF RISKS OF SEASONAL RAINFALL VARIABILITY

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ABSTRACT

Seasonal rainfall variability, particularly the uncertainty with respect to the direction and extent that variability will assume in a given season, forms the greatest source of risk to crop production in semi-arid areas of Ethiopia. Equipping vulnerable communities, in advance, with the expected date of onset of a cropping season, is crucial for smallholder farmers to better prepare to respond and manage the uncertainties. Therefore, rainfall prediction, particularly development of models that can foretell the date of onset of next cropping season is crucial in facilitating strategic agronomic planning and tactical management of in-season risks. A twenty-four-year climatic data study was conducted for Melkassa Agricultural Research Centre (MARC) in semi arid Ethiopia, to develop onset date prediction models that can improve strategic and tactical response farming (RF). A sequential simulation model for a build up of 15 to 25 mm soil water by April 1st, was conducted. Simulation results revealed a build up of soil water up to 25 mm, to be the most risk-wise acceptable time of season onset for planting of a 150-day maize crop. In the context of response farming, this was desirable as it offers the opportunity for farmers to consider flexible combination production of maize (*Zea mays* L.) varieties of 120 and 90 days in the event of failure of earliest sown 150-day maize crop. Thus, to allow for flexible combination production of the three maize varieties, predictive capacity was found crucial for April onset of the next crop season. Accordingly, based on the consideration of pre-onset rainfall parameters, the first effective rainfall date varied considerably with the date of onset of rainfall. Regression analyses revealed the first effective rainfall date to be the best predictor of the date of onset (R^2 = 62.5%), and a good indicator of the duration of next season (R^2 = 42.4%). The identified strategic predictor, the first effective rainfall date, enabled prediction of time of season onset and season length by a lead time of two to three months. This markedly improved Stewart's RF. The date of onset of the next crop season was also found to be a useful predictor of season duration (R^2 = 87.3%). Strategic agronomic planning should be adjusted according to the first effective rain date, and tactically according to what date of rainfall onset informs us about expectations in the duration and total season water supply.

Key Words: Ethiopia, semiarid, strategic predictor, *Zea mays*

RÉSUMÉ

La variabilité saisonnière de la pluviométrie, particulièrement l'incertitude en rapport avec la direction et l'ampleur de cette variabilité au cours d'une saison donnée est un grand risque à la production agricole dans les zones semi-arides de l'Ethiopie. La provision à l'avance d'information sur les dates correspondantes aux débuts des saisond culturales s'avère cruciale pour que les communautés dans des zones vulnérables puissent gérer les risques liés à la variabilité saisonière de la pluviométrie Par conséquent, la prédiction de la pluviométrie, en particulier le développement des modèles pouvant prévoir à l'avance la date du début de la prochaine saison culturale est cruciale pour faciliter une planification stratégique de la saison culturale et une gestion tactique des risques au cours de la saison culturale. Une étude des données climatiques de vingt quatre années était menée au Centre de

Recherche Agricole de Melkassa situé dans la zone semi-aride de l'Ethiopie afin de développer des modèles de prédiction des débuts de saisons culturales pouvant améliorer la réponse stratégique et tactique aucours des saisons culturales. Un modèle de simulation séquentiel pour une accumulation de 15 à 25 mm d'eau dans le sol au 1er Avril était développé. Les résultats de cette simulation ont révélé qu'une accumulation de 25mm d'eau dans le sol constitue le niveau de risque le plus acceptable pour le début de la saison culturale et le semis d'une culture de maïs à maturité de 150 jours. Dans le contexte de développer une agriculture adaptée aux variabilités saisonnières, cette strratégie est appropriée car elle offre aux agriculteurs une opportunité d'être flexible et d'envisager de semer des combinaisons de 3 variétes de maîs pouvant inclure des variétés à 90, 120 et 150 jours de maturation pour s'assurer d'avoir une récolte satisfaisante en cas d'échec de la variété à 150 jours. Ainsi, pour permettre une combinaison flexible de production de ces trois variétés de maïs, la capacité de prédire le début de la prochaine la saison culturale d'Avril était jugée cruciale. Par conséquent, sur base des paramètres pré-pluviométriques, la date de la première pluie différait considérablement avec la date effective du début de la saison des pluies. Les analyses de régression ont révélé cependant que la date de la première pluie est le meilleur prédicateur de la date du début de la saison culturale (R^2=62.5), et un bon indicateur de la durée de la prochaine saison culturale (R^2=42.4%). L'indicateur stratégique identifiée qu'est la date de la première pluie permet de prédire la date effective du début de la saison culturale et de la longueur de la saison culturale 2 à 3 mois à l'avance. Ceci a amélioré remaquablement le modèle d'adaptation de la saison culturale à la variabilité climatique de Steward (modèle RF de Steward). La date du début de la prochaine saison culturale s'est aussi avéré être un prédicateur utile de la durée de saison culturale (R^2=87.3%). Cette étude montre que la planification stratéqique de la saison culturale devrait être ajustée sur base de la date de la première pluie, et tactiquement, ajustée sur base des informations que la date effective du début de la saison des pluies donne en rapport avec la durée de la saison et la pluviométrie totale au cours de la saison.

Mots Cles: Ethiopie, semi-aride, prédicateur stratégique, *Zea mays*

INTRODUCTION

Seasonal rainfall variability and its uncertainty with respect to the direction and extent that variability will assume in any given season, form the greatest source of risk to crop yield in Ethiopia's semiarid lands (Admassu *et al*., 2011). The high risk of low rainfall and the associated poor crop yields have been major disincentives to adoption of yield improving recommendations in Ethiopia (Admassu *et al*., 2010). This, together with farmers' reliance on traditional farming practices have resulted in acute shortage of food and pasture and depletion of assets contributing to enhanced societal vulnerability, mass migration and loss of life (Fujisaka *et al*., 1996; Admassu *et al*., 2013).

Under this condition, the need for dynamic cropping strategies that utilise climate forecasts is critical (Sadras *et al*., 2003). Thus, the prediction capacity for the onset of next crop season assumes key importance for vulnerable communities to better prepare, respond and manage the uncertainties presented by highly variable rainfall. Without such practical actions to reduce crop failure and improve the capacity to adapt, the gradual and sudden changes associated with climate change will increase vulnerability in many areas (Admassu *et al*., 2012; 2013). The objective of this study was to predict the date of onset of the next cropping season and other seasonal rainfall parameters for improving strategic planning and tactical RF under the semi-arid agricultural systems of Ethiopia.

MATERIALS AND METHODS

The study area. This study was conducted at the Melkassa Agricultural Research Centre (MARC) in the Central Rift Valley of Ethiopia. The Centre is located at Latitude 08°.1' N and Longitude 39°.3' E; lying at an altitude of 1578 m above sea level. The area is characterised by erratic and undependable rainfall (Reddy and Kidane, 1993), making crop production a risky enterprise.

Research procedure

Establishing date of onset to be predicted. The World Hunger Alleviation, through Response Farming (WHARF) Computer Programme was used for iterative simulation analyses of 24 years

(1977-2000) of daily rainfall (Stewart *et al*., 1995) in order to determine the most risk-wise acceptable dates of onset for which predictive capacity was required. Based on a detailed season by season study of daily rainfall for the study area by Admassu (2004), and analysis of farmers perceptions by Fujisaka *et al.* (1996), WHARF Simulation Programme analytical inputs used designated the first day of January as the first acceptable date of soil water accumulation; the first day of April as the first acceptable onset; the 15th of April as the first normal onset; and 31st August as the last acceptable onset. The last search date for final rainfall was set at 15th October; a final rainfall criterion was set at 70 mm and a minimum season-end intensity index of 2 mm day^{-1}, based on the final days rainfall intensity in the study area (Admassu, 2004).

The study soil was a sandy loam texture (predominant in the study area) with water holding capacity at field capacity of 100 mm (Admassu, 2004). Simulation analyses accepting three onset criteria (maintaining the above input factors) were separately conducted (15, 20 and 25 mm). The analyses based on designation of 15 and 20 mm soil water build up as onset criteria resulted in a higher failure rate to a 150-day maize crop, and denied sufficient lead time and maximum possible flexibility desired for consideration of the growing of three maize varieties during early to median onset seasons. The outputs from the simulation designating 25 mm onset criterion was found desirable as it offered maximum flexibility.

WHARF rainfall analytical outputs, based on the 25 mm onset criterion, were exported to MINITAB statistical software, version 16 (MINITAB Incorporated, 2008) for determination of historical variability in various pre-onset rainfall parameters. Predictors were selected from among pre-onset rainfall parameters based on exhibits of extreme inter-seasonal variability. The date of onset then was regressed on the most variable pre-onset rainfall parameters using MINITAB. Assessments of model capability in predicting the onset of next crop season was done using MINITAB version 16 that applies a one-year-out cross validation technique. Graphical outputs to determine the goodness-of-fit of the observed and predicted observations were developed to confirm the findings.

RESULTS AND DISCUSSION

Establishing the date of onset and onset criterion for next crop season. Of all the simulations, a buildup of 25 soil water was found the most risk-wise acceptable date of rainfall season. The results presented in Table 1 summarise the characteristics of pre-onset and date of onset and other seasonal rainfall characteristics at Melkassa during 1977 - 2000 as limited by date of onset and the 25 mm onset criterion. The probability for onset for the month of April was the greatest (33%). This implies considerable potential for growing high yielding drought tolerant medium maturing crops in early seasons switching to lower yielding shorter maturing cultivars in late seasons (Admassu, 2010). Thus, development of predictive capacity for April onset to maximise the benefits from higher yield during April onset (during early seasons), and reduce failure during late season by bringing into play a 120-day and 90 day maize during median and late season was evident.

Predicting the date of onset for next crop season. Figure 1 presents a scatter diagram of individual years bounded by a prediction interval giving a

TABLE 1. Characteristics of pre-onset and date of onset and main season rainfall at Melkassa Research Centre in Ethiopia during 1977 – 2007

Variable	Mean	Median	SD	C.V (%)	Minimum	Maximum	Range
First effective rain date (Julian day)	109	105	61	55	18	194	176
Pre-onset rain (mm)	107	88	68	63	33	263	231
Season duration (days)	122	124	38	31	69	185	116
Total season water (mm)	590	553	139	23	339	966	626
Date of onset (Julian)	145	149	38	26	91	197	106

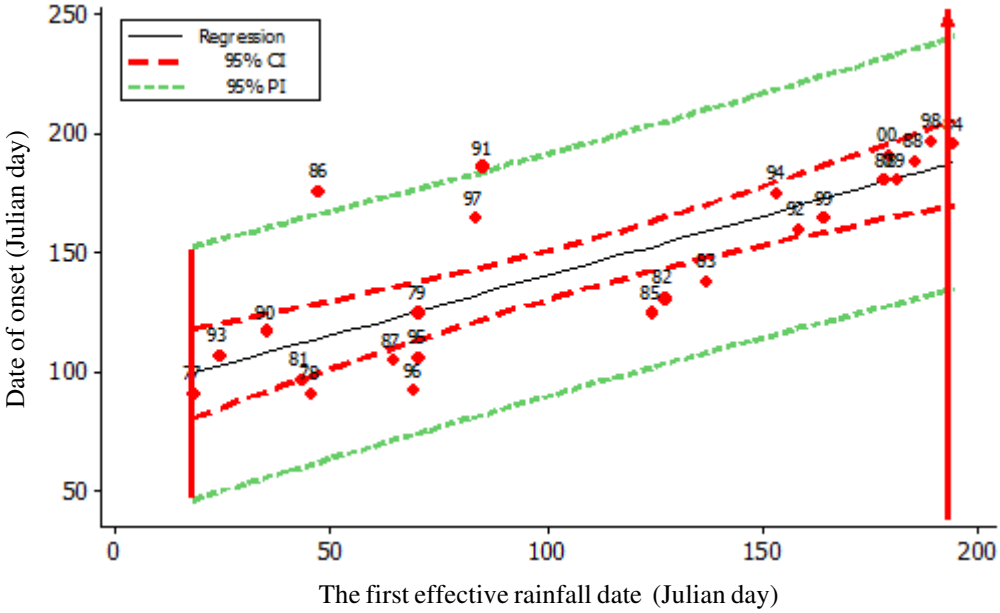

Figure 1. Twenty four seasosns relationship between the date of onset and the first effective rainfall date at Melkassa (1977 – 2000).

flag-like picture that droops away from the flag pole to the left. The R^2 value of 62% implies that the slightly more than 62% of the likely variation in the date of onset is explained by the variation in the first effective rainfall date ($P < 0.001$). At the Research Centre (MARC), on average, the date of onset is extended by 12 hours per day that passes without its first effective rainfall (slope = 0.5013). The developed prediction model is:

Date of onset (Julian day) = $90.53 + 0.5013x$

Where:

x = the first effective rainfall date in Julian day.

Cross validation results, relating the observed and the predicted date of onset has a correlation coefficient (r) of 0.75 ($P < 0.001$, Fig. 2). This suggests that the model is good in predicting the dates of onset and has potential application for strategic agronomic planning purposes in reducing risk of variable season onset dates. The standard error of the developed prediction model for the date of onset using the prediction equation above is ±24 days. Taking the 24-seasons mean date of onset of 145 Julian days into account, the estimation error would have been close to17% either above or below it. This implies that the prediction model is acceptable.

As has been shown, the date of onset significantly varies with the first effective rainfall date (Table 1). The above relationship between the first effective rainfall date and the date of onset can be attributed to the fact that the dates when the first effective rainfall having significant contribution for onset are received are highly variable, making the date of onset considerably dependent on the first effective rainfall date.

The above observation clearly contradicts the conclusion by Mamo (2004), who reported a near complete unpredictability of the date onset under semi-arid conditions. The first effective rainfall date as the predictor of the date of onset makes it possible to get good insights into the expected season dates of onset at a lead time of two to three months. This can lay a foundation for strategic selection of crop types to emphasise during the up-coming season and credit to be sought for purchase of desired production inputs. This study has revealed for the first time the use of the first effective rainfall date as a predictor of the date of onset of next season.

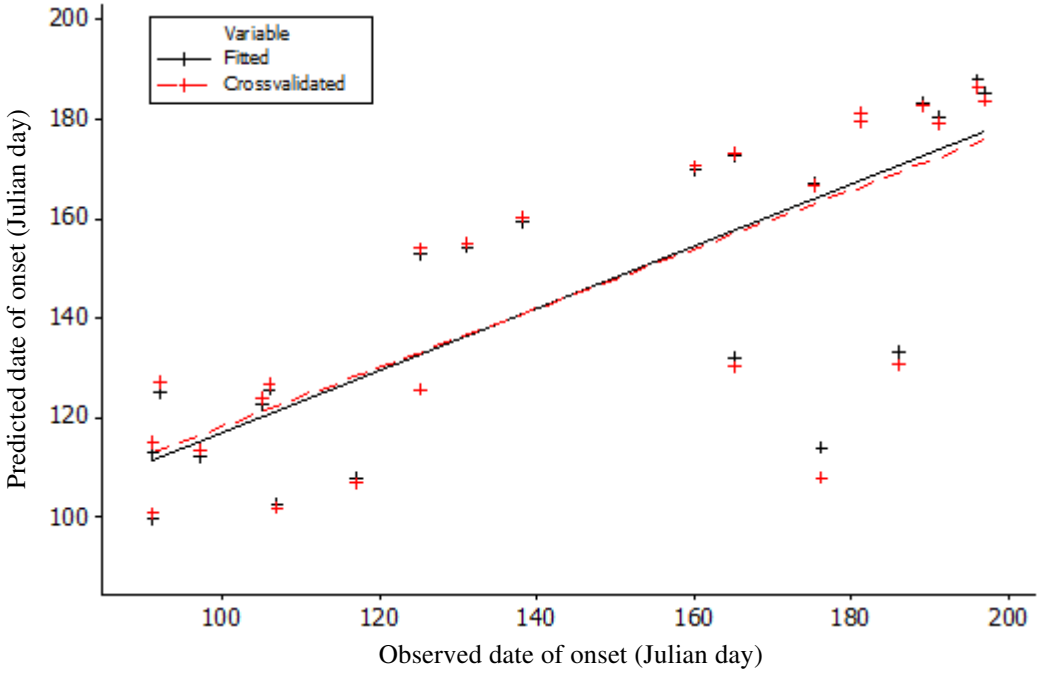

Figure 2. Observed *versus* predicted date of onset using the first effective rain date as a predictor of the date of onset.

Predicting season duration using the first effective rainfall date. Results for regression of season duration on its respective first effective rainfall date during the past 24 seasons (Fig. 3) have a R^2 value that indicates slightly more than 42% of the likely variation in the season duration with the variation in the first effective rainfall date. The developed prediction model is:

Season duration (days) = 167.2 – 0.4124*x*

Where:

x = the first effective rainfall date in Julian day.

Analysis of variance showed the R^2 to be significant ($P < 0.0001$). A flag like picture (Fig. 3) droops away from the pole to the right. At MARC, on average, the season duration is foreshortened by nearly half day per day that passes without its first effective rainfall (slope = 0.41).

The SE for predicting season duration using regression equation is ±30 days. Taking the 24 seasons mean season duration of 122 days, the estimation error is about 24% either above or below it.

Cross validation results relating both the observed and the predicted date of onset has r value of 0.65 (Fig. 4). This suggests that the model is fair in capturing future dates of onset and promise its operational use for strategic agronomic planning purposes.

At MARC, significant delay in the first effective rainfall date would result in shorter season duration. The apparent reason for such relationship is that the dates for receiving the first effective rainfall are highly variable, making season duration dependent on them. Similarly, as the first effective rainfall date is delayed, the date of onset is delayed implying shortening tendency in season duration. The variation expected in season duration is lower than that of the date of onset because of the precedence of the first effective rainfall date in time of occurrence compared to season duration.

Predicting season duration using the date of onset for next crop season. For tactical management of seasonal rainfall variability, regression analyses to predict seasonal rainfall characteristics using the date of onset revealed the date of onset to be the surest predictor of

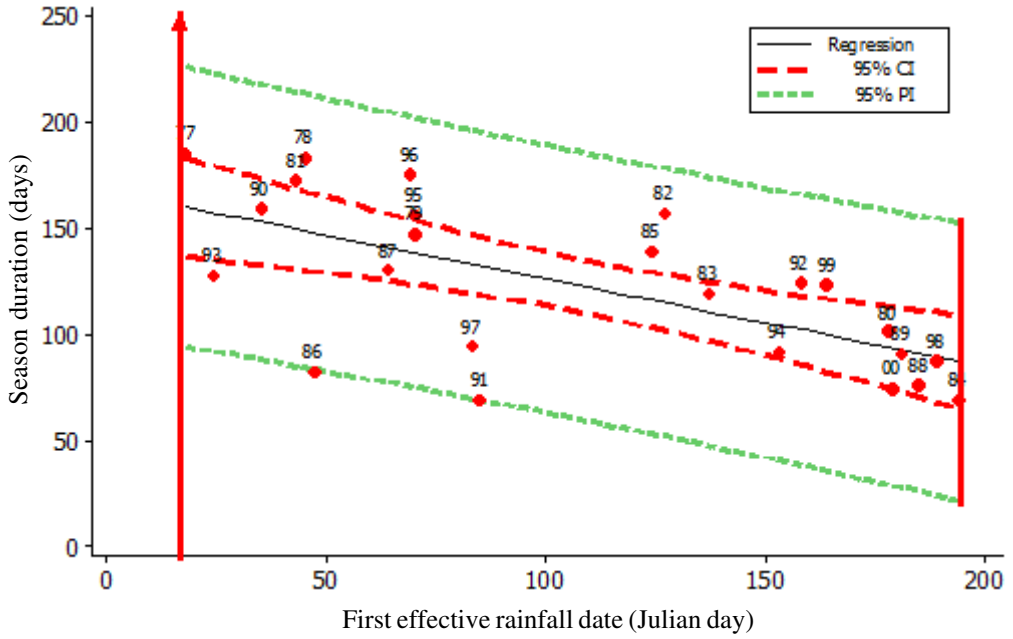

Figure 3. Twenty four years relationship between the season duration and the first effective rainfall date at Melkassa Research Centre in Ethiopia (1977 – 2000).

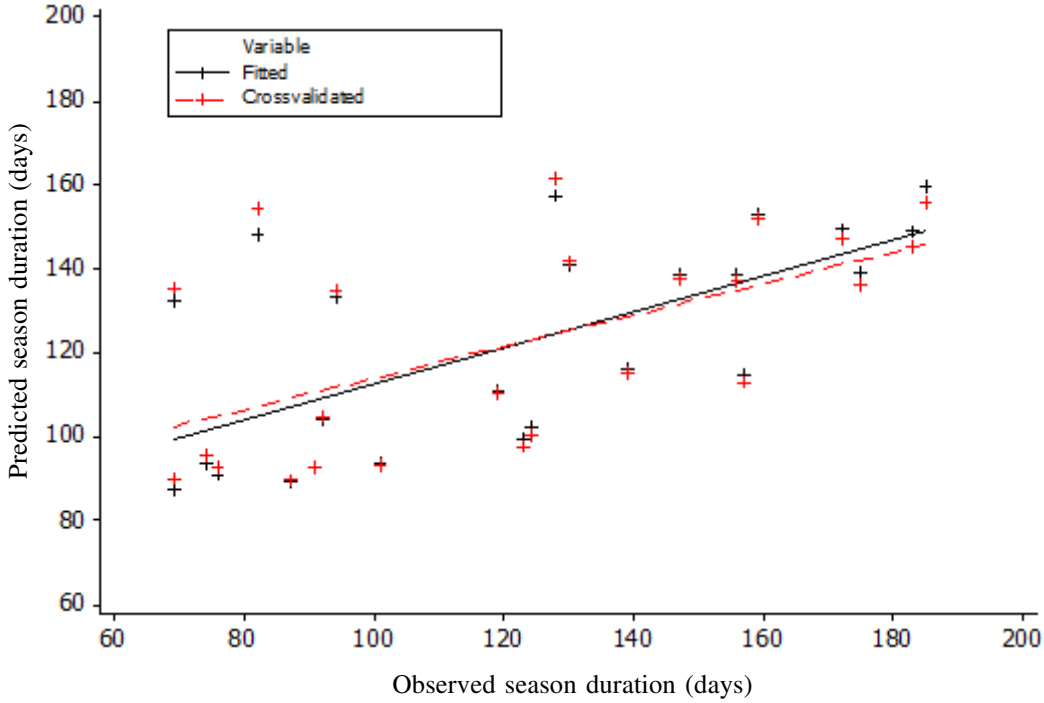

Figure 4. Observed *versus* predicted season duration using the first rain date as a predictor.

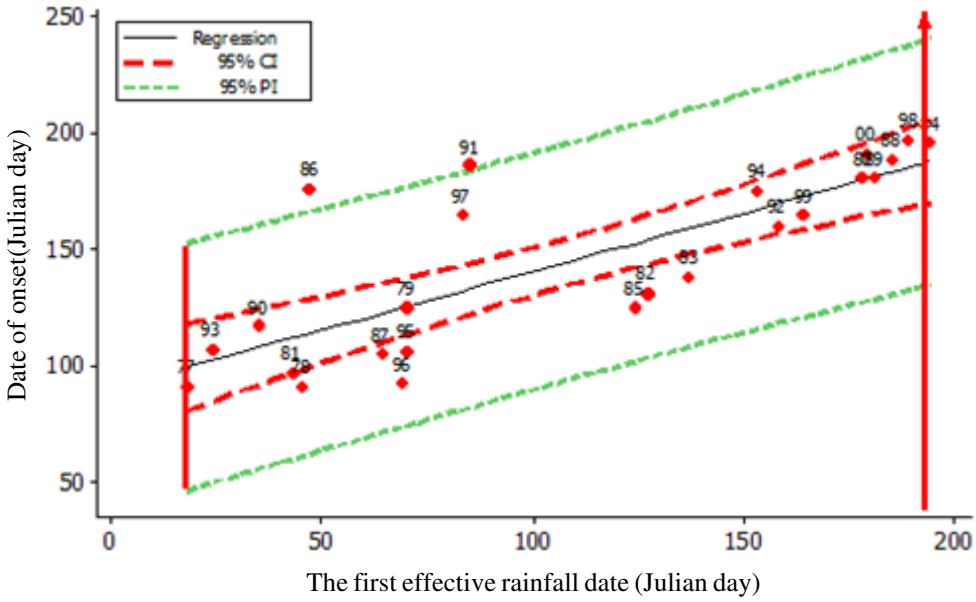

Figure 5. Twenty four years relationship between the date of onset and the duration of rainy period at MARC.

season duration (Fig. 5) as explained by the R^2 value of 87.3% ($P < 0.001$). The result shows that for every day that passes without onset, the duration of rainy period is foreshortened by nearly one day. The developed regression model is:

Season duration (days) = $257.7 - 0.9327x$

Where:

x = the date of onset in Julian day.

Cross validation results relating the predicted against the observed season duration has r = 0.93 (Fig. 6). This indicates that the model is good for predicting the duration of the next crop season. Stewart (1988) and Sivakumar (1990) found a similar relationship for many semi-arid areas in Africa. Sivakumar (1988) earlier used such a relationship and developed relay cropping recommendation for Sahel region of West Africa. The findings from this study promise potential application for developing seasonally flexible agronomic package that will minimise cropping season during seasons that vary in their season duration.

Historical relations of the amounts of total season water (TSW) with the date of onset of rainy seasons. Total season water was regressed on its respective date of onset at MARC. The resulting regression equation is:

TSW (mm) = $823 - 1.60x$

Where:

x = the date of onset in Julian day.

The R^2 relating to both TSW and the date of onset is small (20%), but statistically significant ($P < 0.030$). Moreover, the regression coefficient for the constant intercept was also statistically significant ($P < 0.001$). Although the very low R^2 value indicates that total seasonal rainfall bears little relationship with the date of onset, the large intercept indicates that seasons with earliest onset dates would have significant amount of TSW. On the other hand, the slope of the predictor was also statistically significant ($P < 0.030$); indicating a good example of the dichotomy, which can occur between the practical application and the statistical significance in that a slope of

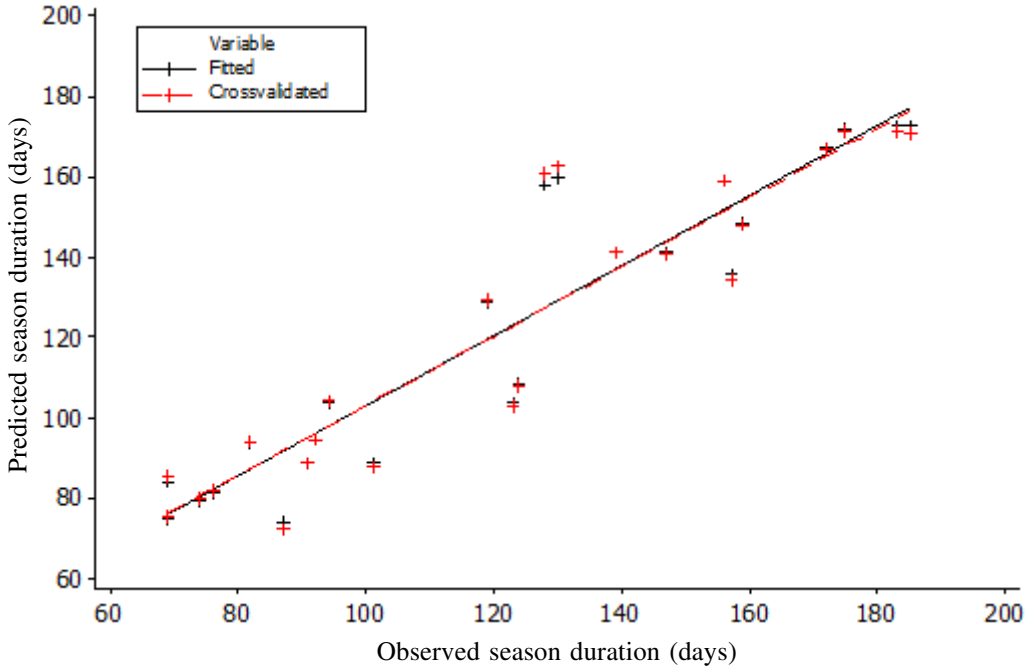

Figure 6. Comparison of predicted *versus* observed season duration based on model developed using date of onset as a predictor.

close to -2 means that rainfall expectation, is reduced by about 2 mm per day that passes without onset. Thus, this equation can be used to gain initial insight into TSW expectation.

The developed predictive capacity has good potential for localised strategic agronomic planning and decision making purposes compared to the crude down-scaled forecasts that are issued by meteorological service agencies today. In order to make use of the predictors, portable rain gauges can be locally installed and monitored to detect the first effective rainfall dates. These are economically feasible and are less demanding knowledge wise.

The developed predictive capacity encourages resource poor households to look for sources of credit in advance and prepare well to exploit the advantages inherent in early seasons. It also encourages lenders to give credits to farmers, and input suppliers too to deliver the required inputs (seed, fertiliser, herbicides and pesticides) in a very good time. In forecast of very delayed onset which bear high risk of too short season and too low water supply, farmers can be advised early enough to wait and sow lower water demanding short duration crops. In forecast of extremely delayed onset, they can also be advised to look for other off-farm remittances.

The scientific community concerned with rainfall prediction using numerical indices and other indicators often have implied a near total unpredictability of date of onset in semi-arid areas (Mamo, 2004). Reviewed literature shows no evidence of success in developing predictors for onset for localized agronomic planning of farm operations and decision making purposes. What is evident in literature is some exhibit of capability for detection of onset at regional scales (Ati *et al*., 2002; Tadros *et al*., 2005). Thus, the major challenge of the lack of site specific predictors for the date of onset as well as the problem of time of prediction which usually starts at onset (Stewart, 1988; Tadros *et al.*, 2005) has been successfully addressed through this study.

CONCLUSION

The first effective rainfall date as a predictor for the date of onset markedly improved our

predictive capability for the date of onset by advancing time of prediction by a lead time of 3 months. This has several practical advantages: first, it is generated for decision making for local level using the data from the location where it is intended for use. This makes it site specific and, hence relevant. The first effective rainfall date turned the good predictor for date of onset onset. This is useful for strategic advance planning of farm operations. Moreover, the ability to predict the duration of next crop season is useful in tactical terms this is good to enable initial decision on types of varieties to sow at or following onset. The date of onset was also proved best predictor of duration of rainy period, and fair indicator of total season water. These are useful as they can facilitate rapid changes in on-farm tactics leading to reduction of risks. Hence, key agronomic risk management decisions need to be organised in a multi-staged decision array: first strategically using first rain effective rainfall date, and second tactically according to what date of onset of the current season informs us. Field validation and calibration of the predictors' performance, and further research to sharpen the predictions and possibly advance time of prediction using off-season rainfall are recommended. Wider application of RF warrants further investment decisions by governments to improve the overall low crop productivity and ensure food security in the semi-arid areas.

ACKNOWLEDGEMENT

The WHARF Foundation provided the software used for analysis. The Climate Change Adaptation in Africa (CCAA) Program, a joint initiative of Canada's International Development Research Centre (IDRC) and the United Kingdom's Department for International Development (DFID) funded this study. The Ethiopian Institute of Agricultural Research provided the climatic data used in this study. The Natural Resource Management and Bio-diversity Programme of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) partially sponsored the research.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 951 - 957 ISSN 1021-9730/2014 $4.00

EVALUATION OF EARLY CALVES' WEANING DIET AS MILK REPLACER FOR SMALLHOLDER DAIRY PRODUCTION SYSTEMS IN KENYA

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ABSTRACT

Small-scale dairy farmers in Kenya are interested more in selling milk to earn income, especially during dry seasons when milk prices hike. This results in depressed calves' growth rates, high calf mortality rates, late maturity and general economic losses in the smallholder dairy production systems. Innovative development of early calves weaning formulae, as milk replacers, would offer a solution in the calves' nutrition and household income in the long run. A study was conducted to determine the effectiveness and economic returns to replacing milk with formulated early calf weaning diets (EWDs) on the survival and general performance of dairy calves in Kenya. Treatments included milk feeding up to 105 days (Control) and with milk (28 days) + EWD, fortified or not fortified with effective microorganisms (EM), diamond-V or Diatomite (DT), up to 105 days. There was no ($P>0.05$) differences in average daily weight gain of the calves as a result of the treatments. However, the EM-treatment had significantly ($P<0.01$) higher calve dry matter (DM) intake (g kg^{-1} day) than in the other treatment groups. Due to feeding with EWD, total milk saved for the farmer was 9 $kg^{-1}cow^{-1}day^{-1}$; equal to 945 kg for the 105 period, valued at US$614. For the conventional milk feeding (control), total milk saved was 5 kg^{-1} cow^{-1} day^{-1}; equal to 525 for the 105 period, valued at US$ 341. Significant incidences of diarrhea were observed in the control (milk) and the Diamond-V fortified treatments. Signs of hair loss and discolorations were observed in DT-fortified EWDs. EM- fortification reduced disease incidences, thus, EWD fortified with this microbial feed additive can be an effective milk- replacer in smallholder dairy production systems to wean dairy calves at 28-35 days with good economic and performance results.

Key Words: Diarrhea, dairy calves, hair loss, Diatomite

RÉSUMÉ

Les petits fermiers agricoles au Kenya s'intéressent plus à la vente du lait pour générer des revenues, spécialement durant les saisons sèches lorsque le prix du lait est élevé. Ceci résulte en une inhibition du taux de croissance des veaux, des taux de mortalités élevés, retard de maturité et pertes économiques dans les systèmes de production laitier des petits fermiers agricoles. Le développement des formules innovées de sevrage précoce des veaux en remplacement au lait pourrait offrir une solution dans la nutrition des veaux et à la longue améliorer le revenu des ménages. Une étude était faite pour déterminer l'efficacité et le bénéfice du remplacement du lait par une alimentation formulée de sevrage précoce des veaux (EWDs) pour la survie et la performance des veaux au Kenya. Les traitements comportaient l'alimentation par le lait jusqu'à 105 jours (témoin) et le lait (28 jours) + EWD, fortifié ou non par des microorganismes efficaces (EM) , le diamant-V ou le Diatomite (DT), jusqu' à 105 jours. Il n'y avait pas de différences significatives ($P>0.05$) des traitements sur la moyenne du gain quotidien de poids des veaux. Par ailleurs, le traitement de fortification avec EM avait significativement ($P<0.01$) induit une ingestion de la matière sèche la plus élevée (DM) (g kg^{-1} day) par rapport autres traitements. Par l'alimentation à l'EWD, les fermiers ont pu gagner 9 kg $vache^{-1}jour^{-1}$ équivalant à 945 kg pour toute la période de 105 jours et évalués à US$614. Pour l'alimentation conventionnelle en lait (témoin), le total épargné était de 5 kg par vache jour-1

équivalent à 525 kg d'une valeur d'US $ 341. Des incidences de diarrhée étaient observées dans le control (lait) et le traitement EWD fortifié avec Diamond-V tandis que les signes de perte et décoloration des poils étaient observés dans l'EWD fortifié de DT. La fortification avec les microorganismes EM a réduit les incidences de maladies. Dès lors EWD fortifié avec les microorganismes EM peut constituer un remplacement efficace du lait dans les systèmes de production laitières pour sevrer les veaux de 28-35 jours avec des résultats économiques et des performances satisfaisants.

Mots Clés: Diarrhée, veaux, perte de poils, Diatomite

INTRODUCTION

In an attempt to maximise milk sales to cope with the rising immediate costs of living, bull calves on smallholder farms in Kenya, suffer neglect and in most cases die of malnutrition. For this reason, farmers incur high rates of calf mortality of between 15-20% compared with approximately 5% or less in well managed farms and low calf growth rates (growth rates of less 300 g per day compared with more than 500 g per day (Odongo and Njuho, 1990). Small-scale dairy farmers in Kenya are more interested in milk sale to earn more income, especially during dry seasons when milk prices are high (Land O' Lakes, 2003). This results in depressed calves' growth rates, high calf mortality rates, late maturity and general economic losses in the smallholder dairy production systems.

Innovative development of early calves weaning formulae as milk replacers would offer a solution to poor calves' nutrition and household income in the long run. A cost effective milk replacer feeding systems can increase both the welfare of dairy calves and dairy profitability (Kehoe *et al.*, 2006). Such feeding technologies include utilisation of locally available feed resources as ingredients in early calves' weaning diets. According to Khan and Azim (2000) and Khan *et al.* (2002), early weaning reduces the amount of milk consumed by the calves. This, not only releases more milk for human consumption, but also increases cash income for the farmer through increased milk sales, and also reduces the cost of rearing the calves during their nursing period.

Feed fortification with feed additives such as probiotics and yeast cultures have been reported to manipulate the rumen environment for efficient utilisation of fibrous feeds, especially in neonate ruminants which possess little cell-wall and starch degrading enzyme activity (Anjum *et al.,* 2006). Effective microorganisms (EM) and Diamond-V, which are available in Kenya, are such microbial feed additives, which can influence early establishment of fibrolytic, amylolytic and proteolytic capacities influential for the early expansion of the reticulo-rumen epithelia in calves (Hagg *et al.*, 2012). Such an early development in reticulo-rumen fermentation will enable a timely hepatic adaptation to volatile fatty acids assimilation (Silva *et al.,* 1986). Therefore, this early nutrient release in the reticulo-rumen can facilitate early weaning, reduce labour costs, save milk and lessen health issues associated with late weaning. On the other hand, mineral clays such as diatomite, which is negatively (-ve) charged, is capable of trapping ammonia, a positively (+ve) charged gas, therefore, enhancing efficient utilisation of ammonia-N. The objective of this study was to evaluate the performance and economic efficacy of an early calves weaning formula as a milk replacer for small-holder dairy production systems.

METHODS AND MATERIALS

Study area. The study was conducted on-station at the Kenya Agricultural Research Institute (KARI) Muguga South Research Station in Kenya from October 2012 to January 2013. KARI Muguga South is located approximately 26 Km from Nairobi, along the Nairobi-Naivasha highway.

Test diet formulation. The chemical composition of the experimental diet is presented in Table 1. Feedsoft, a computer software package was used in formulation of the test diet. Mixing of the ingredients and pelleting (Table 2) was done at Unga farm Care Ltd., Nairobi, Kenya.

TABLE 1. Formula composition of test milk replacer diet

Parameter/unit	Value
Energy (Mj kg^{-1})	11
Crude protein (%)	23
Crude fibre (%)	9.10
Calcium (%)	0.90
Total phosphorus (%)	1.50
Crude fat (%)	3.05

TABLE 2. Inclusion rates of ingredients in the test diet (%)

Ingredients	Kilogrammes
Maize	14
Maize germ and bran meal	30.0
Pollard	20
Soya bean	15.8
Omena	3
Cotton seed cake	13.6
Extracted sunflower seed meal	2
Stockfeed lime	1
Salt	0.4
Vitamin and mineral premix	0.2
	100

A**nimals, diets and experimental design.** Twenty friesian (*Bos taurus*) bull calves with average age of 7-10 days and body weight 37.01±3.52 kg were divided into five groups of four animals in each group, based on their body weight. The 7-10 day old calves were obtained both from KARI Muguga South Research Station and farmers fields in Limuru and Githunguri districts of Kiambu County in Kenya. At one week post-colostrum, calves were assigned to one of the 5 treatments in a randomised block design. The treatments were: (i) milk feeding (up to 105 days (control), (ii) milk feeding (28 days) + Early Weaner Diet (EWD) (77 days), (iii) milk feeding 28 days + EWD (77 days) + Effective microorganisms (EM), (iv) milk feeding 28 days + EWD (77 days) + Diamond-V (DV), and (v) milk feeding 28 days + EWD (77 days) + Diatomite (DT). Where fortification was a treatment, early weaner diet was fortified with either effective microorganisms (EM) at the rate of 1 ml l^{-1} EM, Diatomite, 4 g, or Diamond-V, one teaspoonful. All feed additives were administered in the mornings' milk feeding at 7-28-day old, and in drinking water from 29 to 105 days.

All calves received water and basal diets *ad libitum.* The basal diet consisted of 50% good quality Napier grass (harvested at the recommended 6-8 weeks of maturity stage), Rhodes grass hay (20%) and *Leucaena leucocephala* (20%). Basal diet and EWDs were fed separately to individual calves twice daily at 0830 and 1530 hours.

The Control group which represented a standard well managed farm, received milk twice a day at the rate of 6 kg per calf per day; while the EWD test group received either fortified or non-fortified diets at 1-4 kg per day, as the animals grew. Calves were introduced to the test diets during the 2nd week of age for acclimatisation to the new feed before milk withdrawal.

Animal housing and management. The calves were housed in individual roofed pens measuring 3 m x 4 m, with open side walls. Three sides of the pens were covered with a long polythene sheet to minimise extreme weather conditions such as cold and rain during the experimental period. The animals were ear-tagged for identification and de-wormed once a month using Nilzan Plus at a rate of 25 to 50 ml per animal, depending on the live weight at the time. The active ingredient of this de-wormer (Nilzan) is 1.5% w/v levamisole hydrochloride B. P, 3.0% w/v Oxyclozanide B. P and 0.38% w/v Colbalt Sulphate.

Data collection. The parameters evaluated included general animal health observations, growth rates, basal feed intake and economic data (gross margins). In determination of growth rates, live weight was taken at the beginning of the study and then on weekly basis throughout the experimental period. Calves were denied access to feed and water overnight prior to weight measurement. Data collection on feed intake started at 21st day, preceded by 14 days acclimatisation period. Milk withdrawal started at 28th day and gradually up to 35th day of age. Feed provided to and refused by the calves was recorded daily, and 0.5 kg samples of the fresh and refusals were collected and oven-dried at 60 °C.

Data on economic performance were captured from the gross margins calculated from the differences of the cost of inputs and that of outputs and prevailing procurement price in least-cost feed formulations of the test diets and that of milk.

Statistical analysis. Data were subjected to analysis of variance (ANOVA) using GenStat version 14th edition. Significant differences were detected at P<0.05. Significant differences among treatment means were separated using Least Significant Difference (LSD). Economic data were determined from gross margins calculations (costs of output minus input costs).

RESULTS

General animal health observations. While incidences of diarrhea were observed in the control (milk) and Diamong-V fortified treatments, there were no cases of disease symptoms in the EM-fortified EWDs. Signs of hair loss and discolorations were observed in calves fed DT-fortified EWDs.

Animal performance. Data on the growth rates of the experimental animals and dry matter (DM) intake of the basal diet are presented in Table 3. There were no significant (P>0.05) difference in daily weight gains of the calves due to treatments. However, significant (P<0.01) differences in DM intake of the basal diet across treatments were recorded. The highest DM intake was registered in the EM fortified EWDs; while the other treatments had similar DM intake values as the control.

TABLE 3. Growth rates (g kg^{-1} day) of the experimental animals and dry matter (DM) intake of the basal diet (kg day^{-1})

Treatment	Growth rates (kg day^{-1})	DM intake (kg day^{-1})
Milk (control)	0.87	1.04
EWD +0	0.86	1.11
EWD + EM	0.84	1.30
EWD +DV	0.85	1.06
EWD + DT	0.90	1.13
P-value	NS	**
S.e.d	0.086	0.074

**P<0.01
EWD = Early weaner diet, EM = Effective microorganisms, DV = Diamond-V, DT = Diatomite, DM = Dry matter, LSD = Least significant differences of means, TR = Treatments, NS = Not significant

Economic performance. The average total cost of rearing one dairy calf on the formulated test diet as a milk substitute from day 28-35 up to 105 days was US$173, while the total cost of calf rearing using the conventional methods of milk feeding up to the same age was US$407 (Table 4). The highest gross margins were registered with EM-fortified EWD, while the lowest (negative gross margin) was in the control treatment (milk). Farmers can save approximately 9 kgs of milk per cow per day when EWD is used for calf rearing, as compared to only 5 kgs of milk are saved per cow per day for the control.

As a result of feeding EWD, the total milk saved during the 105 day-calf rearing period is 9 kg cow^{-1} day^{-1} multiply by105 days = 945 kg (milk savings). At US$ 0.65 per kg of milk, the total savings would be valued at 945 kg milk multiply by 0.65 = US$614. For conventional milk feeding, the total milk saved is 5 kg cow^{-1} day^{-1} (Table 4). For a 105-day calf rearing period, the total milk saved in the control group would be 5 kg cow^{-1} day^{-1} multiply by 105 days=US$525. This is equivalent to 525 kg milk multiply by US$ 0.65 = US$ 341.

DISCUSSION

General animal health observations. There were no cases of disease incidences in calves on the EM-fortified EWDs. EM is said to have beneficial microorganisms which suppress the harmful ones such as salmonella (Cremonini *et al.,* 2002). The high incidences of diarrhea observed in Diamond-V treatments was possibly due to a rapid intake of the early weaner diets. Diamond-V consists of yeast cultures and their metabolites, with a sweet aroma which may have served as an appetiser in this treatment group, thus the rapid feed intake.

According to Kehoe *et al.* (2006), the nature of neonatal calves' diet plays a role in frequency

TABLE 4. Gross margin (US$) accruing from milk replacer diets of early weaned bull calves in Kenya

T1 (Control)	Inputs (A)	Rate of inputs (kg) (milk consumed by calves (B)	Unit cost of input (C) US$	Total cost of input (D) BxC	Outputs (milk produced/ cow (10*105d) minus milk consumed by calves (milk saved) (E)	Unit cost of output (F)	Value of output (G) ExF	Gross margin (H) G-D
	Milk	520	0.65	336.5	530	0.65	344.5	-63.2
	Drugs	3	23.5	70.6				
				407.1				
T2	Milk	64	0.65	41.4	986	0.65	640.9	453.72
	EWD	180	0.4	75.2				
	Drugs	3	23.5	70.6				
				187.2				
T3	Milk	64	0.65	41.4	986	0.65	640.9	520.2
	EWD	180	0.4	75.2				
	E M	1	4.1	4.1				
				120.7				
T4	Milk	64	0.65	41.4	986	0.65	640.9	447.9
	EWD	180	0.4	75.2				
	DV	2	2.9	5.9				
	Drugs	3	23.5	70.6				
				193.1				
T5	Milk	64	0.65	41.4	986	0.65	640.9	452.0
	EWD	180	0.4	75.2				
	DT	1	1.8	1.8				
	Drugs	3	23.5	70.6				
				189.0				

Assumptions: Average milk production in the first three and half months of lactation is 10 kg cow^{-1} day^{-1}. Total EWD intake in the whole feeding trial period is 180 kgs. Experimental animals fell sick at least 3 times during the trial period. 1 US$= Kes 85. Other factors held constant

of occurrence of calf scours. Early calves' weaning with dry feeds has been reported to reduce calf scours, compared to milk (liquid) feeding. Signs of hair loss and discolorations observed in DT-fortified EWDs, were possibly associated with copper deficiency due to mineral interactions. EM utilisation as a feed additive in the neonatal diets has been reported to reduce incidences of disease occurrence such as diarrhea (Anjum *et al.,* 2006). Our findings are in agreement with those of D'Souza *et al.* (2002), Fuller (1987) and Cremonini *et al. (* 2002), who reported cases of reduced disease incidences in both humans and animals when a commercial probiotic product was used.

Animal performance. Feeding of a formulated early weaner diet as a substitute for milk (up to 105 days) had similar results with milk feeding to calves without compromising growth rates (Table 3). There were no significant (P>0.05) differences between treatments implying that the formulated test diet (with CP 23% and ME approximately 11 Mj kg^{-1}) was comparable to milk feeding up to 105 days period. All calves in the experiment attained the expected daily weight gain of more than 0.5 kg^{-1} day recommended for well managed dairy farms (Odongo and Njuho, 1990).

However, there were differences (P<0.05) in DM intake of the basal diet (Table 3). The highest DM intake was registered in the EM fortified EWDs, while the other treatments had similar values as the control. The calves on this treatment appeared healthy, and thus feed intake was not reduced, unlike in other treatments. However, the observed increase in feed intake in this treatment did not result in increase in weight gains.

Economic performance. Adopting the early weaning technology using EWD up to 105 days, reduced the cost of rearing a dairy calf by approximately threefold (Table 4). Farmers can save 9 kg of milk per cow per day, compared to 5 kg in the control group (Table 4). Therefore, for a 105-day calf rearing period, the total milk saved (due to feeding of EWD) is 9 kg $cow^{-1}day^{-1}$ multiplied by 105 days = 945 kg of milk savings. At US$ 0.65 per kg of milk, the total savings would be valued at 945 kg milk multiply by 0.65 = US$614. For conventional milk feeding, the total milk saved is 5 kg cow^{-1} day^{-1} (Table 4). For a 105-day calf rearing period, the total milk saved in the control group would be 5 kg cow^{-1} day^{-1} multiply by 105 days = 525 kg. The monetary equivalent is = 525 kg multiply by US$ 0.65 = US$ 341. According to Staal *et al (*2001), farmers usually offer 4 kg of milk to calves per day in the smallholder dairy production systems. This mode of feeding releases more milk to the farmer for sale at the expense of the calf health, which may later die of malnutrition. A standard farm offers 6 kg of milk to calves per day. However, use of EWD allows the farmers to share milk equally with the calves during the first phase of lactation.

From the current study the use of early calves' weaning technology gives two major benefits; (i) an increase in available milk for sale home consumption and/or for sale; and (ii) positive performance of calves without any adverse effects. These findings are in agreement with those by Odongo and Njuho (1990) who reported 20% increase in household incomes when maize/ bean gruel was used to replace milk for dairy calves.

ACKNOWLEDGEMENT

This study was funded by East African Agricultural Productivity Project (EAAPP). The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 959 - 968 ISSN 1021-9730/2014 $4.00

L'UTILISATION DE LA LUTTE CHIMIQUE ET DE LA RÉSISTANCE VARIÉTALE CONTRE LE MILDIOU DE LA POMME DE TERRE À MADAGASCAR

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RÉSUMÉ

La culture de la pomme de terre (*Solanum tuberosum* L.) au Madagascar a sévèrement été affectée par l'épidémie du mildiou (*Phytophtora infestans*) au cours des années 2007 - 2008. La plupart des variétés étaient affectées, ce qui fait appel à l'évaluation des produits anti-mildiou et la résistance au sein des germoplasmes dans le pays. Cette étude avait pour objectif de déterminer l'efficacité des fongicides en terme de capacité protectrice et systémique, ainsi que la résistance inhérente de quelques variétés cultivées au Madagascar. Parmi les produits testés, le mélange des fongicides protecteurs et systémiques ont été les plus efficaces et plus économiquement bénéfiques. Les meilleurs traitements étaient 1.5 kg ha^{-1} de dithane à base de mancozèbe plus 1.5 kg ha^{-1} d-athlète à base de fosétylaluminium, et 1.5 kg ha^{-1} de dithane plus 1.5 kg ha^{-1} de ridomil à base de metalaxyl plus le manèbe. L'application de ces produits a donné un rapport bénéfice-coût de 3. Les variétés qui ont manifesté une résistance considérable sont entre autre CIP 395 015.6, CIP 395 111.13 et CIP 396 236.20, toutes avec un rendement >20 t ha^{-1}. Cependant, leurs niveaux de résistance nécessitent un suivi régulier.

Mots Clés: Clones, fongicide, mildiou, pomme de terre

ABSTRACT

Potato (*Solanum tuberosum* L.) production in Madagascar was severely affected by the epidemic infestation of mildew (*Phytophtora infestans*) during the the years 2007-2008. Most of the potato varieties were severely affected. This calls for evaluation of anti-mildew products and resistance in the potato germplasm in the country. This study aimed at determining the efficicacy of fungicides in terms of protectiveness and systemic actions; as well as inherent resistance of some potato varieties grown in Madagascar. Among the products tested, the mixture of protectant and systemic fungicides presented good efficacy level and higher economic returns. The best treatments are 1.5 kg ha^{-1} of mancozebe based dithane plus 1.5 kg ha^{-1} of fosetylaluminium based d-athlete, and 1.5 kg ha^{-1} of dithane plus 1.5 kg ha^{-1} of metalaxyl based ridomil plus manebe. Application of these products resulted in a benefit cost ratio of 3. Varieties which showed considerable resistance included CIP 395 015.6, CIP 395 111.13 and CIP 396 236.20, all yielding >20 t ha^{-1}. However, their resistance levels need to be monitored regularly.

Key Words: Fungicide, *Phytophtora infestans, Solanum tuberosum*

INTRODUCTION

Depuis son introduction dans l'île de Madagascar, la production de la pomme de terre connaît une augmentation assez régulière de la production (environ 285.000 t/an) d'après la dernière statistique de l'année 2004. Cette situation s'explique par son rôle dans l'alimentation, substitut du riz en période de soudure, et comme source de revenu. La possibilité de trois saisons de plantation dans l'année, surtout sur les hautes terres, favorise aussi l'expansion de sa culture. Cependant, bien que le mildiou existe dans l'île depuis des années

rapportée par Rakotondramanana (1978), cette maladie a atteint un niveau épidémique en 2007 - 2008 à cause de cyclones successifs. Depuis l'année 1980, le mildiou n'a pas été rapporté avoir atteint une pression aussi élevée qu'elle a actuellement. Ainsi, les parcelles de pomme de terre ont été attaquées ou même complètement détruites, d'où la perte considérable de récolte jusqu'à 80% selon les variétés. La plupart des variétés cultivées par les agriculteurs se sont avérées sensibles (Meva, Spunta, Menamaso, Garana…). Par conséquent, on s'est basée sur des études déjà entreprises pour contrôler cette maladie. D'abord , la lutte chimique par l'utilisation de fongicides de contact et à action systémique (EPPO – Bulletin, 1994) cité par C.D van Loon *et al.*, 2004. Il y a aussi la combinaison de ces deux produits pour améliorer leur efficacité (KARI - PRAPACE, 2004) , Et puis la résistance horizontale au mildiou pour réduire l'application de produits anti-mildiou. A la suite de cette épidémie, le traitement anti-mildiou est devenu systématique, surtout avec le mancozèbe, plus accessible par les producteurs, pour obtenir de récolte assez satisfaisante, sinon des agriculteurs ont opté pour l'abandon de la culture. Par ailleurs, la quantité de semences pour des variétés plus ou moins résistantes est insuffisante pour satisfaire les demandes. Donc, en plus de la lutte basée sur la pratique culturale l'étude de la lutte chimique par les produits disponibles sur le marché s'impose dans l'immédiat. Cette pratique est pourtant limitée par la possibilité financière des agriculteurs. En même temps, la considération de l'aspect économique du traitement chimique fait partie de l'étude. La contribution du matériel végétal fourni par le Centre International de la Pomme de terre (CIP) possédant un certain niveau de résistante au mildiou pourrait constituer un moyen de lutte pour les paysans avec des moyens limités et afin de réduire autant que possible l'utilisation de produits chimiques. Le matériel végétal introduit possède une résistance horizontale au mildiou effective contre les races de l'agent pathogène. Au niveau de l'étude de l'évolution de l'incidence et de la sévérité du mildiou, la constitution d'une banque de gènes constituée de variétés à divers niveau de résistance a été réalisée. Comme cette série de variétés/clones ne subit aucun traitement chimique anti-mildiou au cours de la végétation, la résistance au mildiou observée en comparaison avec le témoin sensible Meva peut être attribuée à la résistance variétale. La mise à profit de la résistance variétale sert à convaincre les paysans à planter la pomme de terre en saison pluviale afin de posséder au moins de semences pour la contre saison, sur rizières après le riz, durant laquelle le problème du mildiou n'est pas aussi important qu'en saison pluviale.

MATERIELS ET METHODES

Trois niveaux d'études, donc de tests, sont prévus dans cette section, d'abor sur l'importance de l'utilisation de produits chimiques , ensuite la mise à l'épreuve de la résistance des nouvelles variétés du CIP et leur adaptabilité dans les différentes conditions de culture. Enfin , on pourra indique quel serait le résultat attendu en fonction des niveaux de résistance de 16 clones/variétés de pomme de terre testés en l'absence totale de traitement enti-mildiou.

Evaluation de l'efficacité des produits anti-mildiou. Le dispositif expérimental est du type bloc complet randomisé à 3 répétitions avec 60 tubercules par parcelle élémentaire : soit 6 billons de 3 m. Les 11 traitements testés comprenant des produits à action protectante (dithane à base de mancozèbe) ou systémique (athlète : à base de fosétyl-aluminium, le ridomil à base de métalaxyl+manèbe - et le gold à base de carbendazime) sont les suivants avec leurs modes et fréquences d'application

1. Témoin absolu (sans traitement)
2. Athlète 2,5 kg ha^{-1} : toutes les 2 semaines
3. Athlète 2,5 kg ha^{-1} et dithane 2,5 kg ha^{-1} (en alternance) toutes les semaines
4. Athlète (1,5 kg ha^{-1}) + dithane (1,5 kg ha^{-1}) en mélange toutes les semaines
5. Ridomil (2,5 kg ha^{-1}) toutes les 2 semaines
6. Ridomil 2,5 kg ha^{-1} et dithane 2,5 kg ha^{-1} (en alternance) toutes les semaines
7. Ridomil 1,5 kg ha^{-1} + dithane 1,5 kg ha^{-1}) (en mélange) toutes les semaines
8. Gold (0,5 l ha^{-1}) toutes les 2 semaines
9. Gold 0,25 l ha^{-1} et dithane 1,5 kg ha^{-1} en alternance toutes les semaines

10. Gold 0,25 l ha^{-1} + dithane 1,5 kg ha^{-1} en mélange toutes les semaines
11. Dithane 2,5 kg ha^{-1} toutes les semaines.

Variété – test : Spunta : sensible au mildiou avec un cycle de 105 jours. Ces tests ont été conduits en station Mimosa située à 1600 m d'altitude

Evaluation des clones résistants au mildiou. Le dispositif expérimental est du type bloc complet randomisé à 3 répétitions avec 60 tubercules par parcelle élémentaires, soit 6 billons de 3 m.

Les 10 traitements sont constitués de nouveaux clones et des témoins résistant Diamondra 2 et sensible Spunta :

Variétés/clones	N° CIP (clones)	Nature de matériel végétal issu du CIP
1-W3	393.077 54	B3C2
2-W4	393.280.64	B3C2
3-W5	395.011.2	B3C2
4-W6	395.096.2	B3C2
5-W7	395.015.6	B3C2
6-W8	395.111.13	B3C2
7-W9	396.236.20	B3C2
8-W12	396.027.29	B3C2
9-Spunta	800.923	-
10-Diamondra 2	800.946	-

B3 C2 : Population B issue du croisement uniquement du type tuberusum avec gènes de résistance horizontale au mildiou en deuxième cycle

Les sites pour les tests :

Sites	Altitude (m)	Types de sol
Alakamisy - Anativato	1.450	Volcanique récent
Mandritsara/ Ankabahaba	1700	Volcanique récent
Station Mimosa	1.600	Dépôts volcano-lacustres

Suivant les conditions climatiques, 1 à 4 traitements contre le mildiou ont été effectués avec du mélange de 1,5 kg ha^{-1} de dithane et de 1,5 kg ha^{-1} de ridomil.

Evaluation des performances des variétés/clones résistantes au mildiou par infection naturelle. Cette évaluation permet également de suivre l'incidence, la sévérité de la maladie dans l'espace et dans le temps, ainsi que la stabilité de leurs niveaux de résistance. Le dispositif expérimental comprend 16 clones/variétés de pomme de terre anciennement, nouvellement diffusées ainsi que des variétés prometteuses identifiées, sans répétition, avec 5 tubercules par billon. La parcelle est entourée de bordures infestantes composée de variétés Spunta et Meva sensibles au mildiou et à cycle relativement court.

Les variétés/clones évaluées sont les suivantes:

Variétés/clones	N° CIP	Niveau de réaction au mildiou
Meva	377.957.5	S
Spunta	800.923	S
Marevaka	-	S
Diamondra 1	800.946(1)	MR-MS
Avotra	381.381.13	MR-MS
Pota	720.084	MR-MS
Maneva	392.797.22	MR-MS
Voaloboka	-	MR-MS
Diamondra 2	800.946(2)	R-MR
Maharevo	381.381.20	R-MR
S6	394.905.6	R-MR
Jengy	720.118	R-MR
Bemanga	394.904.17	R
W8	395.111.13	R
W9	396.236.20	R
K14	575.049	R

L'analyse du comportement de ces clones/ variétés par rapport au mildiou s'est basée seulement sur des données de deux ans après l'épidémie de la maladie. Il faut dès lors suivre leurs évolutions. L'infection s'est produite donc d'une manière naturelle, et la bordure infestante

a servi de sources assez homogènes de spores de mildiou pour les différentes variétés/clones.

Les sites pour les tests sont les suivants :

Sites	Altitude (m)	Types de sol
Alakamisy - Anativato	1.450	Volcanique récent
Ambohidranandriana	1650	Dépôts volcano-lacustres
Station Mimosa	1.600	Dépôts volcano-lacustres

Pratiques culturales pour les trois types de test La technique culturale, les entretiens et les observations à effectuer et relatives aux 3 essais sus-mentionnés sont comme suit : 70 cm entre billons et 30 cm entre les tubercules avec comme fertilisation 80 N- 66 - P2O5 – 48 K2O ha^{-1} sous-forme de N-P-K (11-22-16) et de l'urée plus 20 t ha^{-1} de fumier . Le buttage se fait quand les plantes atteignent la hauteur de 15 à 20 cm précédé de l'application de l'urée de couverture. et les récoltes au mois de Mars. Des traitements insecticides à base de pyrethrinoïdes ont été appliqués .contre les insectes foliaires

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Collecte de données - Notation. La notation sur le mildiou a été effectuée 7 à 10 jours après l 'émergence et sur les 2 lignes centrales de chaque parcelle élémentaires dans le cas des tests de traitement et de variétés. Cette notation s'effectue tous les 7 à 10 jours et avant d'appliquer les produits anti-mildiou pour les tests de traitement contre le mildiou. A la récolte, les 2 lignes centrales de chaque parcelle élémentaire sont récoltées, les tubercules sont séparés en trois catégories à savoir les tubercules de consommation (calibre < 50 mm), les tubercules de semences (de calibre compris entre 28 mm et 55 mm) les tubercules des écarts (de calibre < 28 mm). Les tubercules dans chaque catégorie sont comptés et pesés séparément.

Traitement des données. L'analyse statistique des résultats par l'utilisation des logiciels MSTAT C et Genstat pour traiter l'analyse de variance. L'attaque du mildiou est exprimée en courbe d'évolution ou par Area Under Disease Progress Curve (AUDPC) ou la surface au-dessous de la courbe d'évolution de maladie tel que recommandé par le CIP.

L'équation pour calculer l'AUDPC est présentée ci-après :

$$AUDPC = \sum_{i=1}^{n} [(X_{i+1} + Xi) / 2^* (Di+1 - Di)]$$

où

(i) Xi = pourcentage de feuilles infectées au temps t (jours) après la plantation

(ii) Xi+1 = pourcentage de feuilles infectées au t + 1 (jours) après la plantation

(iii) Di + 1 – Di = le nombre de jours entre la première et la seconde notation.

L'analyse économique des résultats par le calcul du Rapport Valeur/ Coût (RVC). Le calcul d'indice de rendement par rapport au témoin exprimé en %.

RESULTATS

Evaluation de l'efficacité des traitements chimiques contre le mildiou. L'effet des traitements par différents produits anti-mildiou appliqués par différentes méthodes est significatif, sur la moyenne de 2009 à 2012, en comparaison avec le témoin absolu (Tableau 1). En effet, 2,5 kg ha^{-1} de dithane ou bien1,5 kg ha^{-1} de dithane mélangé avec 1,5 kg ha^{-1} de ridomil ou bien 1,5 kg ha^{-1} de dithane mélangé avec l'athlète appliqués toutes les semaines ont donné les meilleurs résultats . Les rendements obtenus ont presque doublé en comparaison avec celui du témoin (216 %). L'efficacité de la combinaison de fongicide de contact et de fongicide systémique a été mentionnée (KARI - PRAPACE, 2004) pour optimiser l'application de produits anti-mildiou. En se référant à l'AUDPC, traduisant la surface foliaire attaquée par le mildiou, sa valeur est inférieure à 1000 avec les meilleurs traitements

TABLEAU 1. Rendement en t/ha sur test de traitement contre le mildiou (moyenne sur 3 ans, 2010 à 2012) en saison pluviale

Traitements	Mimosa 2009-2010	Mimosa 2010-2011	Mimosa 2011-2012	Moyenne 3 ans	Indice de rendement/ témoin	Nombre de tubercule/plante	AUDPC	RVC
1. Témoin	8,1	7,8	11,9	9,31	100	4,4	2122	-
2. Athlète	13,3	13,0	17,0	14.1	151	5,6	1374	15,8
3. Athlète- dithane	13,9	12,3	23,3	16,57	177	5,6	1239	11,5
4. Athlète+ dithane	13,9	14,1	24,6	17,58	186	5,6	1056	12,3
5. Ridomil	14,6	13,0	11,6e	13,15	141	4,4	1302	7,9
6. Ridomil- dithane	12,7	12,5	19,3	14,89	159	4,8	917	6,3
7. Ridomil+ dithane	16,7	16,9e	26,5a	20,12	216	5,1	944	10,6
8. Gold	9,2	10,6	10,7	10,22	109	4,5	1878	10,2
9. Gold- dithane	7,6	12,5	13,9	11,39	122	4,6	1645	5,8
10. Gold+dithane	12,6	13,1	21,4	15,13	162	5,4	1268	7,3
11. Dithane	20,7	17,2	24,3	20,18	216	5,5	905	19,6
CV % =	17	23	2 0	21		14		
Alpha =	0,05	0,05	0,05	0,05		0,05		
Prob de S =	S	S	S	S		S		
Ppds =	4,0	5,4	6,3	2,9		171		

Base de calcul : - Dithane 14.000 Ar/kg Ridomil : 25.000 Ar/kg. Athlète : 15.000 Ar/kg Gold : 20.000 Ar/kg. 1 USD = 1.900 AR

ci-dessus contre 2122 avec le témoin absolu non traité (Fig. 1). Généralement , le RVC (rapport valeur-coût) dégagé par les traitements est supérieur à 10. Toutefois, le traitement avec du dithane seul présente le meilleur RVC = 16,3 grâce au coût moins élevé du dithane. L'alternance toutes les semaines du dithane avec les produits systémiques athlète ou ridomil a donné également de bons résultats. Les produits systémiques appliqués seuls toutes les deux semaines tels que l'athlète, le ridomil et le gold ne présentent pas de résultats aussi intéressants que les traitements précédents. Cela peut rejoindre les observations citées par van Loon *et al*. (2003), selon lesquelles l'intervalle de traitement plus serré peut être nécessaire en présence de souches plus virulentes.

Evaluation des variétés par rapport à leur résistance au mildiou. Les 3 nouveaux clones W 7 (CIP 395 015-6), W 8 (395 111-13) et W 9 (CIP 396 033 112) présentent un niveau de rendement total en tubercules plus élevé que le témoin Diamondra 2 (22-26 t ha^{-1}) sur différents sites : Tableau 2. De même, leurs rendements en tubercules commercialisables varient entre 20 à 24 t ha^{-1} contre 15 t ha^{-1} pour

Diamondra 2, soit une augmentation de rendement de 30 à 60 %. Cette performance se confirme aussi par leur adaptation dans différentes conditions écologiques sur trois ans. Ils ont également une proportion de gros tubercules supérieure à 20%. Il faut souligner que le clone 395 111 13 tend à donner le meilleur rendement sur les trois années. Par ailleurs, la courbe d'évolution du mildiou convertie en terme de l'AUDPC en comparaison avec le témoin sensible Spunta et même avec le témoin résistant Diamondra 2 peut également expliquer leurs niveaux de rendement (Fig. 2). Les valeurs de leurs AUDPC sont comprises entre 595 et 680 alors que celles de Diamondra 2 et Spunta atteignent respectivement 1134 et 3616. La Figure 2 révèle que la plupart des clones de la série B3C2 montrent un niveau de résistance au mildiou relativement plus élevé que le témoin résistant. Mais comme il s'agit de résistance (Landeo, 2004), quatre traitements anti-mildiou ont été appliqués pour contrôler la maladie.

Evaluation des variétés par rapport à leur résistance au mildiou. Sans aucun traitement chimique anti-mildiou, les variétés présentant de niveaux différents de résistance réagissent différemment à l'attaque du mildiou. Cette différence est évaluée d'une part par le rendement exprimée en g/plante (Tableau 3) et d'autre part, par la courbe d'évolution de l'attaque du mildiou (Fig. 3) et par l'AUDPC, en se référant à celle du témoin sensible Spunta/ Meva (Fig. 4). Les clones avec de rendement relativement élevé (exprimé en g/plante) sont ceux à réactions résistantes ou moyennement résistantes (W 8, W 9, Bemanga, Maneva …). C'est-à-dire un rendement de 390 g à 600g/plante contre 194 g/ plante pour le témoin sensible Meva Leurs indices de rendement sont compris entre 200 et 300 % par rapport au témoin Meva. La Figure 3 présente

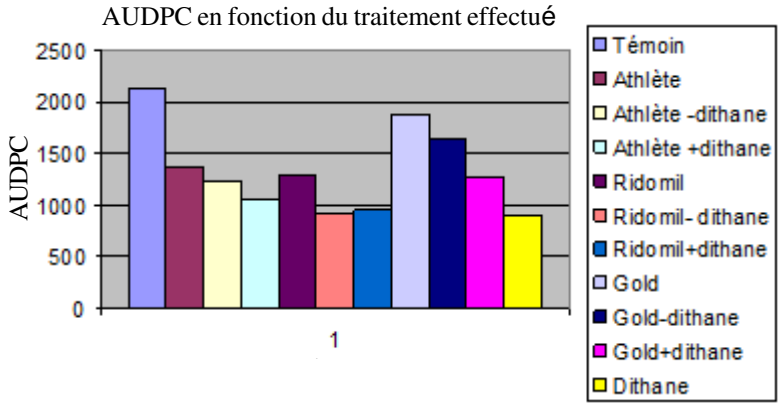

Figure 1. AUDPC en fonction des traitements effectués sur 3 ans (2010 – 2012) en station Mimosa, saison pluviale.

TABLEAU 2. Rendement moyen en t/ha sur test variétal de pomme de terre pour 3 ans (2010-2012) en saison pluviale

Variétés/ Clones	2009-2010 2 sites	2010-2011 4 sites	2011-2012 3 sites	Moyenne (tubercules totaux)	% gros tubercules	% tubercules moyens	% petits tubercules	Moyenne (tubercules commercialisables)	UDPC 2012 station
1-W3	19,5	19,8	12,8cd	17,3	30,7	61,6	7,6	15,8	1049
2-W4	16,6	13,1	14,7	14,8	17,3	71,8	10,9	13,1	629
3-W5	17,7	22,6	19,4	19,9	24,8	67,0	8,0	18,2	534
4-W6	16,3	13,0	14,1	14,4	17,3	73,6	9,1	13,0	1500
5-W7	24,0	21,8	21,3	22,3	21,1	70,5	8,2	20,4	680
6-W8	25,1a	25,7	28,4	26,4	24,7	68,0	7,1	24,4	618
7-W9	25,1a	20,6	27,9	24,5	29,7	64,1	6,1	22,8	595
8-W12	13,9a	15,6	10,8	13,4	22,4	64,8	12,8	11,6	611
9-Spunta	23,0abc	15,2	12,4	16,6	28,0	62,9	9,0	15,0	3616
10-Diamondra 2	15,6d	06,8	19,4	17,2	21,3	67,9	10,7	15,3	1134
CV % =	20	18	21,5						
Alpha =	0,05	0,05	0,05						
Prob de S =	S	S	S						
Ppds =	6,7	2,9	3,6						

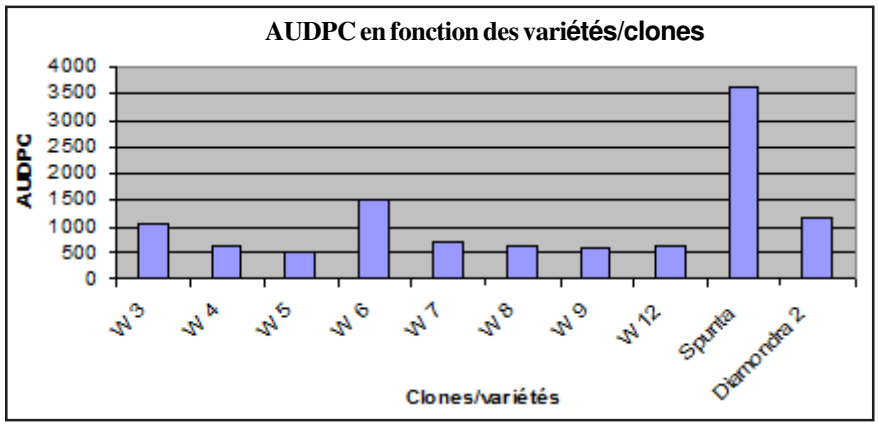

Figure 2. AUDPC en fonction des variétés/clones sur 2 ans (2011-2012) -Saison pluviale.

TABLEAU 3. Performance des variétés résistantes au mildiou sous infection naturelle (moyenne de 3 sites en saison pluviale 2011-2012)

Variétés/clones	N° CIP	Niveau de réaction au mildiou	Valeur AUDPC	Poids de tubercule g/plante	Indice de rendement/ Meva
Meva	377.957.5	S	3323	194	100
Spunta	800.923	S	3305	206	106
Marevaka	-	S	3435	156	80
Diamondra 1	800.946(1)	MR-MS	1354	391	201
Avotra	381.381.13	MR-MS	1831	406	209
Pota	720.084	MR-MS	2466	313	161
Maneva	392.797.22	MR-MS	2071	430	221
Voaloboka	-	MR-MS	2294	306	157
Diamondra 2	800.946(2)	R-MR	1131	326	168
Maharevo	381.381.2	R-MR	1862	393	202
S6/S5	394.905.6	R-MR	1000	274	141
Jengy	720.118	R-MR	1070	284	146
Bemanga	394.904.17	R	934	440	226
W8	395.111.13	R	544	603	310
W9	396.236.20	R	827	480	247
K14	575.049	R	1024	350	180
CV% :			26	40	
Alpha			0,05	0,05	
Prob de S :			S	S	
Ppds			732	208	

R : résistant, MR : moyennement résistant, MS : moyennement sensible, S : sensible

des courbes d'évolution du mildiou sur des variétés à trois types de niveau de résistance. Celles-ci indiquent que le degré d'infection du mildiou à 20 % est atteint plus rapidement environ 2 semaines après la première notation ou trois semaines après l'émergence (Meva, Spunta). Alors que ce même niveau n'a été atteint pour les variétés/clones moyennement résistantes et résistantes qu'à environ 4,5 semaines (Pota, Maneva) et 6 semaines (W 8, W 9) respectivement après l'émergence. L'AUDPC peut donner une indication sur la sévérité du mildiou en fonction

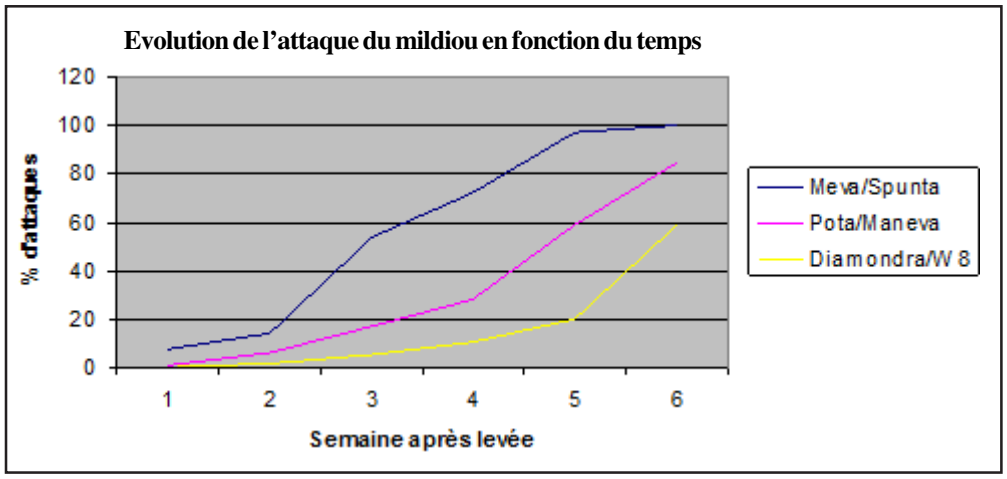

Figure 3. Evolution de l'attaque du mildiou sur variétés/clones avec des niveaux différents de résistance au mildiou (sensible : Meva/Spunta, moyennement résistantes : Pota, Maneva et résistante : Diamondra 2/W8).

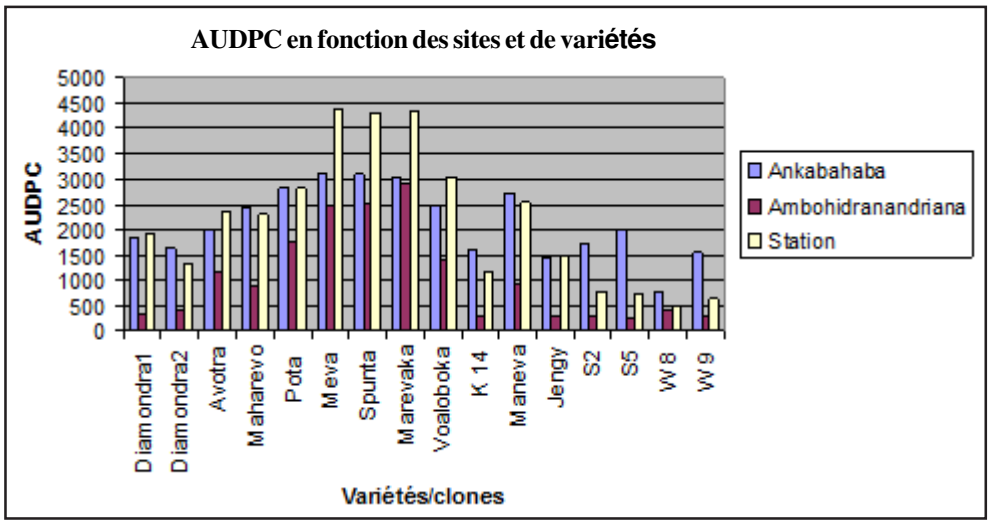

Figure 4. AUDPC mildiou en fonction des sites et des variétés/clones.

des localités. En effet, la Figure 4 montre que le niveau d'infection paraît plus élevé en station Mimosa puis à Ankabahaba et enfin à Ambohidranandriana à partir de la réaction de chaque variété /clone. Dans les conditions de cette évaluation, les variétés W 8 et W 9 à résistance horizontale donne tout de même de rendement satisfaisant sans aucun traitement contre le mildiou.

DISCUSSIONS ET CONCLUSIONS

Ces tests menés pour contrôler le mildiou ont permis de déterminer la contribution de la lutte chimique et de la résistance variétale. En effet, l'utilisation des variétés sensibles (Spunta, Meva …) exige du traitement anti-mildiou au moins une fois par semaine pour rentabiliser aussi bien la culture que l'application de produits chimiques.

Cette dernière est justifiée par le rapport valeur coût supérieur à 3. L'emploi du mancozèbe à la dose de 3 kg ha^{-1} ou bien le mancozèbe mélangé avec des produits chimiques soit le ridomil, soit l'athlète à la dose de 1,5 kg ha^{-1} de mancozèbe plus 1,5 kg ha^{-1} de l'un des deux produits, présente presque les mêmes efficacités et rentabilités économiques. Aussi, la combinaison du produit de contact et du produit systémique est recommandée afin d'optimiser l'emploi du produit systémique est recommandée par le afin d'optimiser optiimiser l'emploi de fongicide surtout sur les variétés sensibles (KARI - PRAPACE , 2004). Cependant, la fréquence d'un seul traitement par semaine ne pourrait pas suffire en saison pluviale et durant la période de développement rapide de la plante (van Loon *et al*., 2003). Parmi les variétés résistantes issues du CIP (population B3C2), les variétés W7 : CIP 395015.6, W8 : 395111.13 et W9 : 396236.20 ont prouvé leurs résistances au mildiou et leur adaptabilité et productivité dans les conditions de culture pluviale. Trois à quatre traitements ont pu suffire pour contrôler le mildiou aulieu de huit traitements au minimum dans le cas du test conduit précédemment avec des variétés sensibles. Ces résultats correspondent aux observations par J. Landeo sur les variétés à résistance horizontale (Landeo, 2004). Ce qui permettrait aux producteurs de réduire significativement le coût relatif à l'application de fongicides et d'augmenter la productivité avec un rendement supérieur à celui du témoin résistant Diamondra 800 946). Avec la série de 16 variétés/clones de pomme de terre et en l'absence totale de traitement fongicide, l'indice de rendement des variétés plus ou moins résistantes donnent une indication sur le niveau de rendement attendu (20 t ha^{-1}) en comparaison avec celui du témoin sensible (< 10 t ha^{-1}) dans les conditions de ces tests. Ce qui confirme la contribution de la lutte génétique (résistance variétale) contre cette maladie, surtout pour les producteurs avec de moyens financiers limités et surtout pour préserver l'environnement dans la tendance d'utiliser abusivement de produits chimiques après l'épidémie du mildiou. Cette même série de clones/variétés pourrait aussi contribue à donner une indication sur la sévérité du mildiou à partir de la valeur de l'AUPDC en fonction des zones concernées. Finalement, cette étude contribuera à établir des recommandations sur les méthodes de lutte contre le mildiou qui a découragé les producteurs dans la production de pomme de terre, il y a environ cinq ans dans le pays.

REMERCIEMENT

Nous remercions vivement le CIP de sa contribution à la fourniture de matériel végétal qui joue un rôle important dans l'amélioration de la productivité de la pomme de terre dans le pays et pour lutter contre le mildiou (surtout le matériel végétal envoyé par Dr. J . Landeo. La convention entre le Gouvernement Malgache et le Gouvernement de la Norvège a été fortement appréciée pour le financement ayant contribué à la réalisation de cette étude relative à la lutte contre le mildiou de la pomme de terre donc à la redynamisation de la production nationale. Cette publication est le résultat d'un projet financé par l'Association pour le Renforcement de la Recherche Agricole en Afrique Orientale et Centrale (ASARECA). Les considérations exprimées ne sont pas nécessairement celles de l'ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 969 - 977 ISSN 1021-9730/2014 $4.00

EFFET DU MAIS A FORTE TENEUR EN PROTEINE SUR L'ÉLEVAGE DES POULETS DE CHAIR DANS LA PROVINCE DU BAS-CONGO ET L'IMPACT SUR SA PRODUCTION EN RÉPUBLIQUE DÉMOCRATIQUE DU CONGO

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RÉSUMÉ

Le coût élevé des provendes constitue un facteur limitant au développement de l'aviculture. Bien que le maïs (*Zea mays* L.) soit l'ingrédient majeur dans la formulation des rations de poulets de chair, sa déficience en lysine et tryptophane limite sa valeur nutritionnelle. Cette étude avait pour but d'évaluer l'impact de la valeur nutritionnelle du maïs à forte teneur en protéine (QPM) sur les performances zootechniques des poulets de chair en vue de remplacer l'aliment commercial onéreux. Quatre vingt dix-neuf poussins de chair non sexés de souche Cobb 500 ont été soumis à trois rations dont l'aliment commercial (R0), l'aliment à base de QPM (R1) et l'aliment à base de maïs normal (R2). Chaque lot comportait 11 sujets répétés trois fois chacun. Les poids vifs obtenus à 7 semaines d'âge ont été de 0,896 kg, 0,791 kg et 0,450 kg respectivement pour les sujets soumis aux R0, R1 et R2. Les consommations alimentaires individuelles ont été de 923 g, 907 g et 812 g, avec des indices de conversion de 1,03; 1,15 et 1,80 respectivement pour les aliments R0, R1 et R2. Pour ces paramètres zootechniques, les tests statistiques ont montré une différence significative entre les différents traitements au seuil de 5% ($P<0,05$). Cette étude a démontré que l'aliment à base de QPM peut efficacement remplacer l'aliment commercial dans la ration des poulets de chair tout en générant des bénéfices supérieurs d'environ 2 %, ce qui contribuera à une grande demande en QPM et ainsi à l'augmentation de la production du maïs à qualité protéique en République Démocratique du Congo.

Mots Clés: poulet de chair, INERA, ration, RD Congo, QPM

ABSTRACT

High cost of feeds constitutes a limiting factor to poultry development. Although maize (*Zea mays* L.) is the major ingredient in the formulation of chicken feeds, its nutritional value is limited by maize lysine and tryptophan deficiencies. This study was conducted to assess the impact of the quality protein maize (QPM) on chicken performance as a replacement to the commercial expensive feeds. Ninety nine non-sexed broiler chicks from Cobb 500 breed were subjected to 3 different rations, namely, commercial feed (R0), QPM based feed (R1) and normal maize based feed (R2). Each lot was made of 11 chicks replicated three times. The weight obtained from seven weeks old chickens were 0.896, 0.791 and 0.450 kg, for those subjected to R0, R1 and R2, respectively. Feed intake per chicken were 923, 907 and 812 g, with conversion indices of 1.03, 1.15 and 1.80, respectively, for feeds R0, R1 and R2. For these performance parameters, statistic tests showed significant differences ($P<0.05$) between the different treatments. From this study, it appeared that QPM based feed can efficiently replace commercial feeds in rations of broilers, while generating higher returns by about 2%. This will contribute to QPM high demand and thus increase of its production in the Democratic Republic of Congo.

Key Words: Broiler, INERA, ration, RD Congo, QPM

INTRODUCTION

La filière avicole, plus particulièrement l'aviculture moderne, est apparue au cours de ces dernières années comme une solution attractive pour satisfaire la demande de plus en plus croissante en protéines animales et une source de revenu de la population africaine (Zaman *et al*., 2004; Ayssiwede *et al*., 2009).

Cependant, le coût élevé des provendes limite le développement de l'aviculture; l'alimentation des poulets de chair représentant 60 à 70% du coût total de production (Tandonkeng *et al*., 2009). Les sources conventionnelles des protéines végétales utilisées dans l'alimentation de la volaille sont nombreuses. Le tourteau de soja présente les meilleures caractéristiques alimentaires et occupe par conséquent la première place dans le commerce mondial des protéagineux et oléagineux. Cependant, les coûts élevés de production de soja et sa transformation en tourteau sont les principaux facteurs qui limitent leur utilisation et de ce fait affaiblissent le développement de l'aviculture (Tandonkeng *et al*., 2009). Etant donné que le coût de l'aliment représente 60 à 70% du coût total d'un poulet de chair, une conversion correcte de l'aliment consommé en kilogramme de poids vif est essentielle pour la rentabilité d'un lot de poulets de chair (Tandonkeng *et al*., 2009). Une légère différence sur l'indice de conversion peut avoir un impact important sur la marge bénéficiaire (Ross, 2012).

Dans la formulation des rations, le maïs constitue l'ingrédient majeur du fait qu'il est de grande valeur énergétique et est dépourvu de substances anti-nutritionnelles (Bornstein et Lipstein, 1971; Douglas *et al*., 1993; Mitaru *et al*., 1985). Il est incorporé généralement de 50 à 70% dans les rations des poulets de chair comme source d'énergie (Salami et Odunsi, 2003; Teguia *et al*., 2004; Ukachukwu, 2005). Cependant, une des principales limites nutritionnelles du maïs normal est son pauvre profil nutritionnel dû au déficit en acides aminés essentiels, la lysine, le tryptophane et la méthionine (Mbuya *et al*., 2010). Le maïs à qualité protéique développé par le Centre International d'Amélioration de Maïs et Blé (CIMMYT) vers les années 1990, contient deux fois plus de lysine et de tryptophane, comparativement au maïs normal (Villegas *et al*., 1992, cité par Millan-carillo, 2007) et lui confèrent une haute valeur nutritive. La substitution des ingrédients protéiniques conventionnels souvent coûteux comme le soja par le QPM dans la ration des poulets de chair peut s'avérer intéressante en ce qu'elle réduirait le coût de fabrication des rations (FAO, 1992).

L'objectif de ce travail était d'étudier les performances du QPM dans le gain en poids des poulets de chair et son coût correspondant afin d'envisager la possibilité de substituer les ingrédients protéiniques conventionnels par le QPM dans la ration de finition des poulets de chair.

MATERIEL ET METHODES

Site expérimental. L'étude a été conduite d'Août à Novembre 2012 au laboratoire de l'Antenne Elevage du Centre de Recherche de l'INERA Mvuazi situé à 470 m d'altitude et à 14°54' de longitude Est et de 5°21' latitude Sud. Les précipitations varient entre 800 et 1200 mm, et les températures oscillent entre 20 et 28°C. Les poussins destinés à l'étude ont été élevés dans des loges de 1m x 1m pendant sept semaines. Chaque loge grillagée était munie de deux mangeoires de 2000 ml de capacité chacune et de deux abreuvoirs de 1000 ml de capacité chacun. Les poussins étaient élevés sur une litière en copeau de bois et une ampoule de 75 watt servant de source de lumière et de chaleur : la température et humidité dans les cages étaient de 28°c et 75% respectivement.

Animaux d'expérimentation et aliment. Le dispositif expérimental utilisé était un plan complètement randomisé avec 3 traitements en trois répétitions. L'étude a porté sur 99 poussins non sexés de souche Cobb 500, originaire des Etats Unis d'Amérique. Cette souche est actuellement produite sur place en RDC et est en diffusion auprès des éleveurs de volailles. Les poussins étaient vaccinés contre les maladies de Newcastle et soumis à un programme préventif et prophylactique rigoureux.

A leur arrivée au Centre de Recherche de l'INERA Mvuazi, les poussins d'une semaine d'âge étaient pesés et bagués individuellement

puis repartis en trois lots de 33 sujets correspondant à trois traitements alimentaires : un aliment commercial (R0), un aliment à base de QPM (R1) et un aliment à base de maïs normal (R2). Chaque traitement comportait trois répétitions de 11 sujets chacune. La mise en lot en fonction de traitement a été faite de manière à respecter un poids moyen identique, avec une densité de 10 sujets par m^2 en fin de production.

Les différents sous lots ont été répartis de façon homogène dans les cages de manière à réduire les variations dues à l'environnement. A partir de ce moment, les sujets soumis aux différents traitements alimentaires étaient nourris à volonté de 0 à 2 semaines, et trois fois par jour à partir de la 3ème semaine jusqu'à la 7ème semaine d'âge. Les quantités d'aliment par individu en fonction de l'âge ont été celles présentées dans le Tableau 1 des spécifications minimum recommandées pour le besoin nutritionnel de la souche Cobb 500. Il est à noter que l'aliment commercial (témoin) doit être nécessairement acheté à Kinshasa, soit 200 Km de Mvuazi.

Pour minimiser le coût de fabrication d'aliments locaux seuls les ingrédients disponibles dans les environnements des éleveurs ont été pris en considérations. Les proportions en ingrédients disponibles sur le marché et les valeurs alimentaires estimées de trois aliments (commercial, à base de QPM et à base de maïs normal) sont présentées au Tableau 2 ci-dessous.

La pesée des animaux était hebdomadaire et la quantité d'aliments consommés (servis – refus) était relevée quotidiennement. L'évaluation économique a été faite sur base du coût de production alimentaire de R1 et R2, à partir du prix des ingrédients relevés sur le marché local et du coût d'achat de R0. Le coût de production d'un kilogramme de poids vif a été obtenu en multipliant l'indice de consommation (IC) par le coût du kilogramme d'aliment.

Analyses statistiques. La statistique descriptive et l'analyse de variance du modèle linéaire général univarié (ANOVA), ont été effectuées avec le logiciel Statistical Package for the Social Sciences version 12 (SPSS 12) pour l'analyse de gain de poids, consommation alimentaire, et l'indice de consommation. Le model linéaire général a été utilisé pour tester les effets des facteurs sur les variables, les différences ont été considérées

TABLEAU 1. Recommandations nutritionnelles

	Démarrage	Croissance	Finition 1	Finition 2
Quantité d'aliment/animal	250 g	1000 g	1000g	1000g
Période d'alimentation (jours)	0 - 10	11 - 22	23 - 42	43 +
Présentation de l'aliment	Miettes	Granulés	Granulés	Granulés
Protéine brute %	21 - 22	19 - 20	18 - 19	17 - 18
Energie métabolisable MJ kg^{-1}	12.70	13.00	13.30	13.40
(AMEn) Kcal kg^{-1}	3035	3108	3180	3203
Lysine %	1.32	1.19	1.05	1.00
Méthionine %	0.50	0.48	0.43	0.41
Met + Cis	0.98	0.89	0.82	0.78
Tryptophane %	0.2	0.19	0.19	0.18
Thréonine %	0.86	0.78	0.71	0.68
Arginine digestible %	1.24	1.10	1.03	0.97
Valine %	1.00	0.91	0.81	0.77
Calcium %	0.90	0.84	0.76	0.76
Phosphore disponible %	0.45	0.42	0.38	0.38
Sodium %	0.16 - 0.23	0.16 - 0.23	0.15 - 0.23	0.15 - 0.23
Chlore %	0.17 - 0.35	0.16 - 0.35	0.15 -0.35	0.15 - 0.35
Potassium %	0.60 - 0.95	0.6 - 0.85	0.6 - 0.8	0.6 - 0.8
Acide linoléique %	1.00	1.00	1.00	1.00

Source : Cobb 500 Edition Avril 2012

TABLEAU 2. Composition et valeurs alimentaires des rations d'expérimentation

	Aliment commercial	Aliments expérimentaux	
	R0	R1	R2
Matières alimentaires utilisées			
Maïs normal (%)	59.00	0.00	58.00
QPM (%)	0.00	58.00	0.00
Son de blé (%)	7.00	11.00	11.00
Tourteau palmiste (%)	10.00	0.00	0.00
Farine de soja (%)	19,80	23.00	23.00
Farine de poisson (%)	0.00	5.00	5.00
Huile de palme (%)	1.00	1.00	1.00
A.A. de synthèse (%)	0,10	0.00	0.00
Phosphate bicalcique (%)	1.00	0.00	0.00
CMV (%)	1,10	1.00	1.00
Sel (%)	1.00	1.00	1.00
Total	100.00	100.00	100.00
Valeurs bromatologiques calculées (%)			
Matière sèche	88,30	84,71	84,71
Protéine brute	20.00	20.00	20.00
Matière grasse	5,01	7,20	7,20
Cellulose brute	4,37	3,76	3,76
Lysine	0,80	1,15	1,03
Méthionine	0,53	-	-
Tryptophane	-	0,63	0,40
Calcium	0,83	0,30	0,30
Phosphore	0,70	0,52	0,52
EM (Kcal kg^{-1})	3.240.40	3.180.00	3.072.30

CMV : Complément minéral et vitamine, A.A : Acide Aminés

comme significatives avec un risque d'erreur de 5%.

RESULTATS ET DISCUSSION

Effet de l'aliment sur la consommation. L'effet de l'aliment sur la consommation alimentaire moyenne par jour en fonction de l'âge est présenté dans la Figure 1.

Il ressort de la Figure 1 ci-dessus qu'à partir de la 4e semaine, on a observé une consommation égale entre les rations R0 et R1. De manière générale, la consommation alimentaire la plus élevée au cours de l'essai est observée avec la ration R0 (923,50gr/jr) à la 7è semaine. L'analyse de la variance a révélé une différence significative ($P< 0,05$) entre les traitements. Cette différence significative existe entre R0 et R2, ainsi qu'entre R1 et R2.

La faible consommation de R2 peut s'expliquer par l'hypothèse d'Agbede et Teguia (1996) selon laquelle le rapport énergie/protéine détermine le niveau de consommation alimentaire, car ils fixent ce rapport dans une fourchette comprise entre 155 et 165 pour les poulets de chair. Par conséquent la préférence de R1 serait due à la teneur élevée du tryptophane influant sur de nombreuses fonctions biologiques comme la régulation de l'appétit (Ajinomoto, 2005).

Effet de l'aliment sur le poids vif des animaux en fonction de l'âge. L'effet des aliments sur l'évolution des poids vifs des animaux en fonction de l'âge est présenté sur la Figure 2.

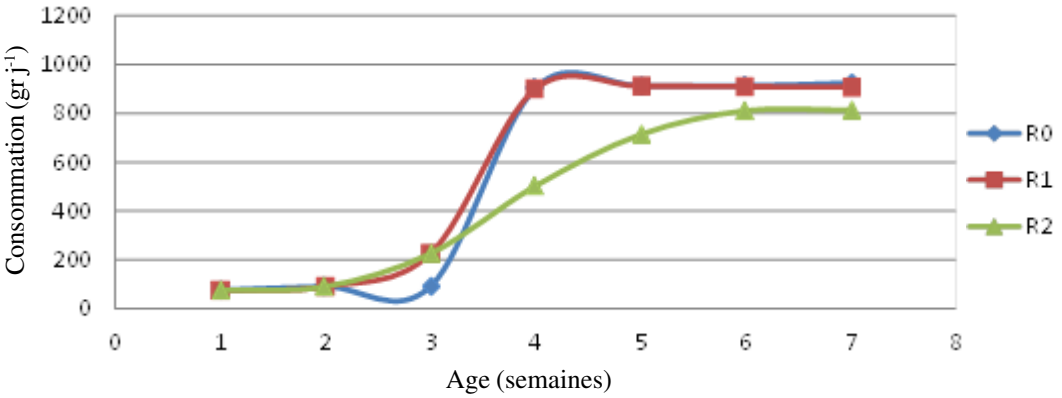

Figure 1. Effet de l'aliment sur la consommation alimentaire moyenne par jour en fonction du temps

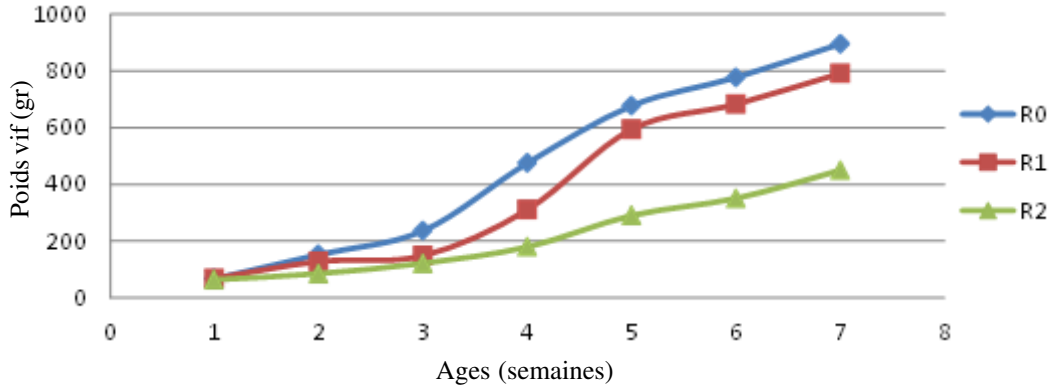

Figure 2. Evolution du poids vif (gr/jour) en fonction de l'âge.

Il ressort de cette figure que les poids vifs des animaux, pour chaque type de ration, ont évolué de manière croissante dès la 1ère semaine. A partir de la 4ème semaine on a observé une différence significative entre les rations. Les allures de R0 et R1 se sont écartées considérablement de R2. A la fin de l'essai, l'aliment R0 a permis d'obtenir le poids vif moyen le plus élevé (896,00 gr) suivi de l'aliment R1 (791,00 g) pendant que l'aliment R2 a présenté le poids vif le plus faible (450,00 gr). L'analyse de la variance a révélé une différence significative ($P < 0,05$) entre les poids vifs des animaux en fonction de la ration, à la fin de l'essai. Les poids obtenus dans cet essai sont inférieurs à ceux de Mbakop (2003) et à ceux recommandés par Cobb (2007) le sélectionneur de la souche.

Effet de l'aliment sur le gain de poids en fonction de l'âge

L'effet de l'aliment sur le gain de poids est représenté sur la Figure 3. Comme présenté à la Figure 3 ci-dessus, on a observé jusqu'à 2semaines d'âge, une augmentation constante du gain de poids pour les trois rations. Au cours de la 3ème semaine, le gain de poids pour R0 et R1 ont connu une baisse. Cette situation serait due au changement du rythme d'apport alimentaire de trois fois par jour. A la 4ème semaine R0 et R1 ont présenté une forte augmentation atteignant le maximum à la 5ème semaine avec R1 > R0. A la 6ème semaine, on a constaté également une baisse du gain de poids. Cette situation est similaire à celle de la fiche technique des performances et

recommandations nutritionnelles (Cobb, 2012), proposée par le sélectionneur de la souche Cobb500. A la 7ème semaine, la ration R0 a obtenu un gain de poids (118,31 gr) supérieur à celui de la R1 (108,62gr). L'analyse statistique a montré une différence significative ($P< 0,05$) entre les moyennes de gain de poids en fonction d'aliment et de l'âge. S'agissant du gain de poids cumulé, la ration R0 était la meilleure. La différence en gain de poids entre R1 et R2 serait due à la valeur nutritionnelle élevée du QPM dont la digestibilité avoisine 80 à 90% celle du lait (FAO, 1992).

L'effet de l'aliment sur l'évolution hebdomadaire de l'Indice de Conversion

L'effet de l'aliment sur l'évolution de l'indice de conversion est présenté à la Figure 4. On peut observer sur Figure 4 que l'allure de l'indice de conversion de l'aliment R0 reste basse comparée à celles de R2 et R1. Se référant aux résultats obtenus par Tandonkeng *et al*. (2009) l'indice de conversion de R0 est resté le meilleur durant toute la période de l'essai suivi de celui de R1. L'analyse statistique a montré une différence

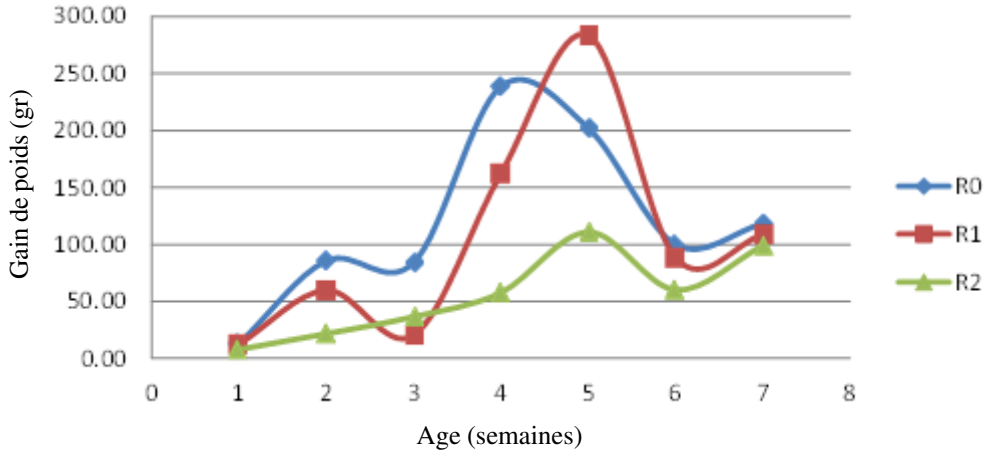

Figure 3. Evolution du gain de poids.

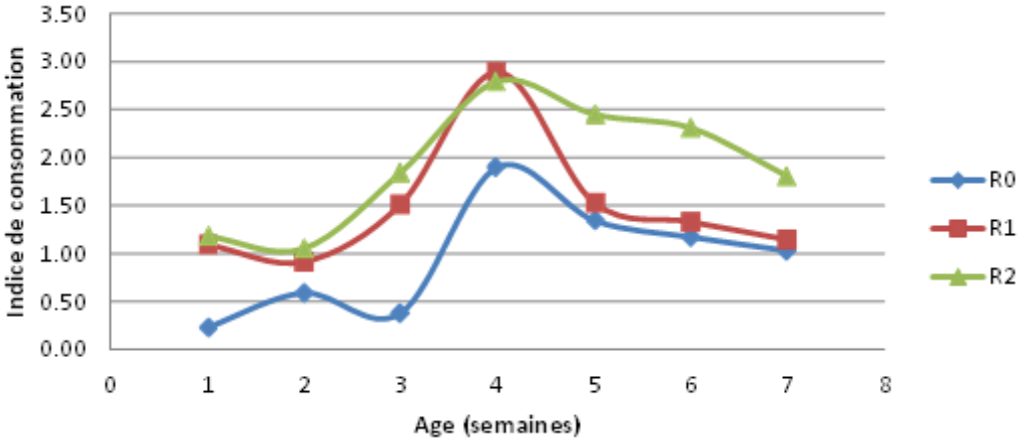

Figure 4. Indice de conversion en fonction de l'âge.

significative (P<0,05) entre les lots d'animaux pour l'indice de conversion. A la fin de l'essai, l'indice de conversion pour R1 est inférieur à 2 (soit 1,21), similaire à celui proposé par le sélectionneur de la souche (Cobb, 2007).

Analyse économique. L'analyse économique a concerné le coût de revient de l'aliment ayant permis l'obtention d'un kilogramme de poids vif et le bénéfice brut réalisable par kilogramme de poids vif. Il a été également question d'évaluer les indices de consommation des lots des poules en fonction des rations.

Le coût d'aliments locaux, aliment commercial sont repris dans les Tableaux 3 et 4. Le Tableau 5 illustre les coûts totaux par aliment. La différence entre le coût de l'aliment pour produire un kilogramme de poulet et le prix de vente local fournit la marge brute de bénéfice par poulet sur pied (Tableau 6).

Au regard de ces résultats ressortant des Tableaux 3 et 4, on constate que le coût d'approvisionnement en aliment commercial est plus élevé comparé aux aliments locaux (R1 et R2) soit 154.500,00 FC pour l'aliment commercial et 129.789,60 FC pour les aliments locaux (Tableau 5). Une différence de près de 25.000,00 FC entre l'aliment commercial et local couvrirait pratiquement le coût du transport de l'aliment commercial.

A l'issue de cette analyse, on constate que le prix de l'aliment à base de QPM est inférieur à celui de l'aliment témoin (R0) d'environ 1,7 %. La marge bénéficiaire brute alimentaire est plus élevée avec l'aliment R1 que celles obtenues avec les aliments R0 et R2. Cette situation confirme l'hypothèse d'Aviagen (2012) selon laquelle de légères différences d'indice de conversion peuvent avoir un impact sur la marge financière. En comparaison avec la marge bénéficiaire brute de l'aliment témoin, les aliments expérimentaux R1 et R2 engendrent respectivement un bénéfice d'environ 26 FC et un déficit d'environ 750 FC/ kg de poids sur pieds sur leurs marges brutes.

TABLEAU 3. Coût d'ingrédients locaux pour 100 kilogrammes d'aliments

Ingrédients	Prix Unitaire (FC)*	Quantité (kg)	Prix Total (FC)		
			R0	R1	R2
Maïs	1.000.00	58.00	-	58.000.00	58.000.00
Son de blé	112.00	11.00	-	1.232.00	1.232.00
Farine de soja	1.800.00	23.00	-	41.400.00	41.400.00
Farine de poison	2.500.00	5.00	-	12.500.00	12.500.00
Huile de palme	1.000.00	1.00	-	1.000.00	1.000.00
CMV d'essai	500.00	1.00	-	500.00	500.00
Sel	500.00	1.00	-	500.00	500.00
Total		100.00	0.00	115.132.00	115.132.00

* : Franc Congolais

TABLEAU 4. Main d'œuvre, transport et achat d'aliment commercial

Coût de main d'œuvre /100 kg Aliment (FC)	R0	R1	R2
Transport et manutention d'ingrédients	25.000.00	4.657.60	4.657.60
Coût fabrication d'aliment	0.00	10.000.00	10.000.00
Coût d'achat aliment	129.500.00	0.00	0.00
Total	154.500.00	14.657.60	14.657.60

TABLEAU 5. Coûts totaux pour 100 kilogrammes d'aliment

	R0	R1	R2
Total coût ingrédient	0.00	115.132.00	115.132.00
Total main d'œuvre	154.500.00	14.657.60	14.657.60
Coût total /100 kg d'aliment	154.500.00	129.789.60	129.789.60

TABLEAU 6. Indice de consommation, coût aliment par kg de poids vif, prix de vente et marge brute de bénéfice

Observations	R0	R1	R2
Indice de conversion	1.03	1.21	1.80
Coût d'aliment/kg gain de poids vif	1.592.42	1.565.62	2.341.79
Prix de vente d'1kg de poids sur pied (local)	7.666.00	7.666.00	7.666.00
Bénéfice brut alimentaire/kg de poids sur pied	6.073.58	6.100.38	5.324.21
Bénéfice brut /kg par rapport à R0	0.00	26.79	-749.37

Ces résultats peuvent être justifiés par le coût élevé d'approvisionnement en aliment commercial et le faible rendement de l'aliment R2. De même, l'indice de conversion élevé obtenu pour les poulets de chair nourris à l'aliment R2 a contribué à une augmentation du coût de l'aliment nécessaire pour produire un kilogramme de poids vif.

CONCLUSION

Les résultats obtenus au cours de cette étude de comparaison de trois aliments commercial à base de maïs à qualité protéique et de maïs normal dans la ration des poulets de chair ont permis de montrer que l'aliment commercial (R0) était plus performant en termes de gain de poids et d'indice de conversion tandis qu'en termes économiques, les aliments à base de maïs à qualité protéique donnent les meilleurs résultats. Le maïs à qualité protéique peut ainsi devenir un ingrédient de base dans la formulation des aliments pour poulet de chair en remplacement de l'aliment commercial qui est importé et dont le prix sur le marché est croissant. La promotion de ce remplacement contribuera à la promotion de la production du maïs à qualité protéique en République Démocratique du Congo. Pour les aviculteurs, le maïs à qualité protéique constituera une porte de sortie pour résoudre les problèmes alimentaires en quantité et qualité.

REMERCIEMENT

Nous remercions également le Centre de Recherche de l'INERA(Institut National pour l'Etude et la Recherche Agronomiques) Mvuazi pour nous avoir accordé un bon cadre de travail. Cette publication est le résultat d'un projet financé par l'Association pour le Renforcement de la Recherche Agricole en Afrique Orientale et Centrale (ASARECA). Les considérations exprimées ne sont pas nécessairement celles de l'ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 979 - 986 ISSN 1021-9730/2014 $4.00

PERFORMANCE OF LOCALLY FORMULATED FEEDS FOR REARING OF AFRICAN CATFISH IN TANZANIA

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ABSTRACT

Fisheries is an important food production sub-sector, providing almost 20% of the world's protein supply; however, the trend in fish production from capture fisheries has reached its limits due to overfishing. A study was conducted to evaluate the performance of two locally formulated feeds as possible replacements for an imported costly commercial feed (CMF) commonly used in rearing of African catfish (*Clarias gariepinus* Burchell) in Tanzania. Two feed types, namely TAF 1 and TAF 2, denoting TAFIRI feed type 1 and 2 were formulated from fish meal (*Rastrineobola argentea*) and soybean (*Glycine max* L.), respectively. Nine concrete tanks of 12 m3 each were stocked with 320 catfish fry each, and fed with formulated feeds at 5% of their mean body weight for four months. Water in the tanks was wholly flushed out on a weekly basis and fish sorted for the fast growers to reduce cannibalism. On a monthly basis, fish were randomly sampled for body length and weight. The mean values for temperature, dissolved oxygen and pH ranged from 21.62±0.04 to 25.16±0.05 oC, 5.43±0.05 to 5.7±0.07 mg O2 L-1, and 6.5±0.05 to 6.61±0.03, respectively. Feed TAF 1 was the best performer with weight gain of 33.72±0.89, average daily gain of 0.28±0.01, FCR of 1.35±0.05 and specific growth rate of 4.61±0.04. Fish fed on the commercial feed performed the poorest, with weight gain of 6.17±4.8, average daily gain of 0.05±0.004, FCR of 1.56±0.11 and specific growth rate of 2.98±0.05. Results from this study suggest that locally formulated feeds can cost effectively be used for the rearing of African catfish in Tanzania.

Key Words: *Clarias gariepinus,* dissolved oxygen, *Glycine max*

RÉSUMÉ

La pêche et l'aquaculture constituent un sous secteur important de production alimentaire, fournissant environ 20% des besoins en protéines mondiales ; par ailleurs, la tendance de la production des poissons à partir de la pêche dans les lacs et les océans a atteint ses limites par suite d'une trop forte pression sur les resources halieutiques. Une étude était menée pour évaluer la performance de deux aliments locaux formulés afin de remplacer les aliments commerciaux chèrement importés couramment utilisés dans la nutrition des poissons (*Clarias gariepinus* Burchell) en Tanzanie. Deux types d'aliments TAF 1 et TAF 2, aussi appelés aliments TAFIRI type 1 et 2 étaient formulés à partir des aliments de poissons (*Rastrineobola argentea*) et du soja (*Glycine max* L.), respectivement. Neuf réservoirs de 12 m^3 chacun étaient approvisionnés chacun avec 320 clarias, et nourris avec des aliments formulés sur base de 5% de leur poids corporel moyen pendant quatre mois. L'eau dans les réservoirs était renouvelée une fois la semaine et ainsi le triage des grands poissons pour réduire le cannibalisme. Chaque mois, les poissons étaient aléatoirement échantillonnés pour les mesures de la longueur du corps et du poids corporel. Les valeurs moyennes de la température, de l'oxygène dissous et du pH variaient de 21.62±0.04 à 25.16±0.05oC, 5.43±0.05 à 5.7±0.07mg O_2 L^{-1}, et 6.5±0.05 à 6.61±0.03, respectivement. L'aliment TAF 1 était le meilleur et a induit un gain de poids de 33.72±0.89, un gain quotidien moyen de 0.28±0.01, un FCR

de 1.35±0.05 et un taux de croissance spécifique de 4.61±0.04. Les aliments de poissons importés ont induit une performance inférieure à celle des aliments locaux avec un gain de poids de 6.17±4.8, un gain de poids quotidien moyen de 0.05±0.004, un FCR de 1.56±0.11 et un taux de croissance spécifique de 2.98±0.05. Les résultats de cette étude montrent que les aliments localement formulés peuvent remplacer efficacément et de manière économiquement compétitive les aliments importés pour l'élevage du poisson-chat en Tanzanie.

Mots Clés: *Clariasgariepinus,* oxygène dissous, *Glycine max*

INTRODUCTION

Fisheries is an important food production sub sector, providing almost 20% of the world's protein supply. However, trends have shown that fish production from capture fisheries has reached its limits, which calls for an increase for fish supply from aquaculture (FAO, 2012). It is hoped that aquaculture production will increase fish supply and bridge the ever increasing gap between fish supply and demand. Aquaculture currently produces about 50% of the world supply of fisheries products for direct human consumption (Boyd, 2012). However, the contribution of aquaculture from Africa to the global aquaculture production was only 2.2% in 2010, of which 39.9% came from freshwater fish farming (FAO, 2012).

Tanzania, like other east African countries, has identified aquaculture as an alternative livelihood for fish supply, which requires special development consideration to reduce national dependency on the capture fisheries. African catfish (*Clarias gariepinus*) is one of the commonly cultured species in Lake Victoria basin in east Africa. The demand for the African catfish as food, for control over-population in tilapia ponds (''police fish'') and as bait for the Nile perch fishery poses a threat on its stocks in the water bodies.

Although farming of fish in east Africa started during the colonial *era* (i.e. since 1940s), it has remained undeveloped ever since. The major obstacles in this respect is the unavailability of quality feed for the different fish production systems (Adebayo and Popoola, 2008; Ndimele *et al*., 2011; Shoko *et al.,* 2011a). This problem has driven most fish famers into making their own feeds, by using some locally available food materials like maize (*Zea mays* L.) and rice (*Oryza sativa*) bran, food remains and garbage from their farms. Nevertheless, commercial feeds are recognised for their high value, although they are expensive for most local fish farmers (Bureau *et al.*, 2009; Marithumu *et al.*, 2011). Most fish farmers who use imported commercial feeds incur more than 60% of the total farm production investments in these feeds (Gabriel, 2007; Aderolu, 2010; Himadri *et al.,* 2012).

The most important barrier towards fish feed development in Tanzania is lack of simple technology for developing feed from locally available ingredients. The objective of this study was to evaluate the performance of two locally formulated feeds as possible replacements for an imported costly commercial feed commonly used on rearing of African catfish.

METHODOLOGY

The experiment was carried out from April to August, 2013 in nine concrete tanks of 2 m x 4 m x 1.5 m (12 m^3 capacity), located at Tanzania Fisheries Research Institute (TAFIRI), Mwanza centre. The tanks were filled with fresh water flowing by gravity from a filtration overhead tank which received water from Lake Victoria. The chemical and biological qualities of the water were determined for suitability to fish prior to stocking with fish fry, and the same was repeated after stocking fish before water replacement. Each tank was stocked with 320 catfish fry of three weeks old obtained from TAFIRI hatchery, stocked in replicates of three tanks per feed treatment. Prior stocking, the fry were treated with 1mg L^{-1} potassium permanganate ($KMnO_4$) to remove external parasites.

Even though the fry were from a single batch, they varied much in size (0.17 - 0.56 g), thus necessitated sorting into three size categories to reduce cannibalism. Therefore, the mean initial weights of fry used in the experiment were 0.30±0.01, 0.29±0.03 and 0.24±0.02 g for CMF (commercial feed), TAF 1 (TAFIRI made feed one)

and TAF 2 (TAFIRI made feed two) feed treatments, respectively. TAF 1 and TAF 2 were made at TAFIRI - Mwanza centre; while the commercial feed was imported from Uganda. All the three feeds contained 35% crude protein. The feed ingredients for TAF 1 comprised of fish meal "Dagaa" (*Rastrineobola argentea*), cotton seed cake, maize bran, multivitamins and fish oil; while TAF 2 feed comprised of soybean, rice bran, fish oil and multivitamin. Fish meal and cotton seed cake were used as sources of protein for TAF 1 and soybean for TAF 2. The CMF was made up of fish meal as the source of protein. Maize and rice bran were locally available in the study area and were commonly used in animal feed formulation in the country. The proximate analysis of TAF 1, TAF 2 and CMF feeds were done at Sokoine University of Agriculture in Morogoro, Tanzania.

The fish in tanks were fed at 5% of their body weight per day. The feeds were divided into two rations as fish were fed twice a day at 10.00 a.m. and 4.00 p.m. The amount of feed was adjusted monthly basing on the total weight of the fish calculated from the mean weights. Water quality was monitored for pH and temperature twice a week at 09.00 a.m. and 03.00 p.m. using portable pH-Temperature meter (HI 991300 pH/EC/TDS/ Temperature, USA). Concurrently, dissolved oxygen was monitored using an Oxygen meter (HI 9143 Microprocessor Oxygen meter HANNA, USA). Debris at the bottom of the tanks was washed out while replacing water with fresh water from the filtration tank on weekly basis.

For the purpose of measuring growth parameters, 30 fish were taken from each experimental tank and measured for total length and weight. The length was measured using 30 cm ruler; while weight was measured using 220 g capacity weighing balance (model Scout Pro SPU 2001, China). After each sampling, survival (%), specific growth rate (SGR), food conversion ratio (FCR) and growth rate (GR) of the fish were calculated by using the formula given by Aderolu *et al.* (2010):

$$Percentage\ Survival = \frac{N_h}{N_s} x100 \quad \text{.... Eq. 1}$$

Where:

N_h = Total number at harvested; and

N_s = Total number of fish stocked.

$$SGR = \frac{\ell n\, W_f - \ell n\, W_i}{t} x\,100 \quad \text{..... Eq. 2}$$

Where:

W_f = Final mean weight (g); and

Wi = Initial mean weight (g).

$$FCR = \frac{TFC}{TWG}$$

Where:

TFC = Total feed consumed (dry) (g); and
TWG = Total weight gained by fish (wet) (g).

Two-way analysis of variance (ANOVA) was used to evaluate any significant differences in growth performance among different feeds tested. All statistical analyses were performed using SPSS 13 for Windows (Landau and Everit, 2004). Post hoc Turkey's pairwise multiple comparisons were used to detect significant differences between the means (Zar,1999). Significant differences were judged at a probability level of $P<0.05$.

RESULTS

Composition of the feeds. The chemical composition of the selected locally available feed ingredients is presented in Table 1. Fish meal had the highest crude protein, followed by soybean and lastly cotton seed cake. The lowest values were recorded in maize and rice brans. For the crude fibre, the highest values were recorded in rice bran and cotton seed cake; while the lowest was in fish meal. Ether extract was the highest in cotton seed cake and lowest in rice bran. Ash content varied greatly among the ingredients, with the highest values recorded in the fish meal.

The proportions of different ingredients and the proximate analysis of the formulated TAF 1 and TAF 2 feeds are as shown in Tables 2 and 3, respectively. Both feeds had 35% crude protein

TABLE 1. Proximate composition of selected feed ingredients (% dry matter) formulated to TAF 1 and TAF 2 feeds used in the experimental study

Feed ingredient	Dry matter (DM)	Crude protein (CP)	Crude fibre (CF)	Ether extract (EE)	Ash
Fish meal	90.53	61.86	0.75	13.00	22.51
Soybean	91.44	32.35	4.18	6.84	5.52
Cotton seed cake	92.44	33.12	16.44	12.40	7.55
Maize bran	91.60	12.20	8.94	6.63	5.16
Rice bran	92.43	5.50	20.21	1.23	19.91

TABLE 2. Proportions of ingredients (%) of the formulated TAF 1 and TAF 2 feeds used in an aquaculture study

Feed ingredients	Percentage in diet	
	TAF 1	TAF 2
Fish meal	32.21	-
Soybean	-	59.57
Cotton seed cake	32.21	-
Rice bran	-	39.71
Maize bran	35.43	-
Vitamin/mineral premix	0.08	0.37
Oil	0.07	0.36

TABLE 3. Proximate analysis (%) of the formulated TAF 1 and TAF 2 feeds used in the experimental study.

Feed type	Dry matter	Crude protein	Crude fibre	Ether extract	Ash
TAF 1	93.0	35	7.6	12.4	10.0
TAF 2	93.0	35	7.0	13.2	6.6

with almost, the same values of crude fibre and ether extract. The exception was with ash content whereby a higher value was recorded in TAF 1.

Bio-physical conditions of the tanks. Mean temperature, pH and dissolved oxygen in the rearing tanks are presented in Table 4. There was significant ($P<0.05$) increase in temperature from morning to the evening in the three treatments. On the other hand, dissolved oxygen decreased significantly ($P<0.05$) from the morning to the evening. There was no significant variations in pH level ($P>0.05$).

Catfish growth rates. African catfish fed on Feed TAF 1 attained the highest growth rate (33.72±0.89 g), followed by TAF 2 (22.43±5.58 g) (Table 5, Fig. 1). Catfish fed on CMF resulted in the lowest growth rate (6.17±0.48 g). Food conversion ratios among the three feed treatments were not significantly different ($P>0.05$).

Survival rate. The highest percenatge survival was recorded in fish fed on the commercial feed (Table 5). There was no natural mortality in all the tanks and it was noticed that all the mortalities were due to cannibalism.

DISCUSSION

Bio-physical conditions of the tanks. The levels of temperature, pH and DO recorded from the culture tanks in the present study were within the appropriate range for catfish culture (Ayinla

TABLE 4. Water quality parameters (pH, temperature and dissolved oxygen) as measured in the tanks used in the experimental study

Parameter	Feed type	Morning	Evening
pH	CMF	6.56±0.03	6.61±0.03
	TAF 1	6.51±0.05	6.60±0.03
	TAF 2	6.59±0.04	6.61±0.03
T (°C)	CMF	21.62±0.04	25.16±0.05
	TAF 1	21.63±0.04	25.14±0.08
	TAF 2	21.67±0.04	25.10±0.09
DO (mg L^{-1})	CMF	5.59±0.06	5.44±0.07
	TAF 1	5.57±0.04	5.43±0.05
	TAF 2	5.70±0.07	5.60±0.08

TABLE 5. Growth and survival rates of African catfish (*C. gariepinus*) fed with different feeds used in the experimental study

Growth parameters	Feed treatments		
	CMF	TAF 1	TAF 2
Initial average weight (g)	0.30±0.01^a	0.29±0.03^a	0.24±0.02^a
Final weight (g)	6.42±0.48^a	34.19±0.89^b	22.43±5.58^c
Weight gain (g)	6.17±0.48^a	33.72±0.89^b	22.86±1.92^c
Initial length(mm)	35.92±0.65^a	34.95±0.44^a	32.63±0.88^c
Final length(mm)	105.23±6.52^a	180.62±34.39^b	146.53±2.00^c
Average daily weight gain	0.05±0.004^a	0.28±0.01^b	0.21±0.01^c
Specific growth rate (%)	2.98±0.05^a	4.61±0.04^b	4.47±0.08^b
Food conversion ratio	1.56±0.11^a	1.35±0.05^a	1.45±0.08^a
Survival rate (%)	69.1	52.2	49.1

Values with the same superscripts in the rows are not significant different ($P<0.05$)

et al., 1994). The findings imply that there was no influence of these parameters on catfish growth. Monitoring water quality parameters in culture systems is very important as the variables influence fish physiological processes. Feed wastes may lead to water deterioration, thus bringing significant changes in ecosystem structure and functioning (Da, 2012). However, in African catfish, negative impacts of low water quality are quite rare, as adults are quite tolerant to a range of environmental parameters as opposed to its juveniles.

Composition of the feeds. It is clear that fish meal had higher crude protein content than cotton seed cake and soybean based feeds (Table 1). The fact that fish meal had high crude protein favours its use in the manufacture of most animal feeds; however, its increased use poses a challenge due to competition by alternative human needs for the same (Shoko *et al*., 2011b). Worldwide, it is highly discouraged to use feeds needed by humans for making animal feeds, and thus the move is on the use of animal protein. Currently, there is increased search for various plant sources for the purpose of replacing the use of fish protein and fish oil. In this regard, any effort towards using plant by-products as a replacement on the use of fishmeal and fish oil will be appreciated. From this study, locally available materials such as cotton seedcakes and soybean have a potential for replacing fish meal

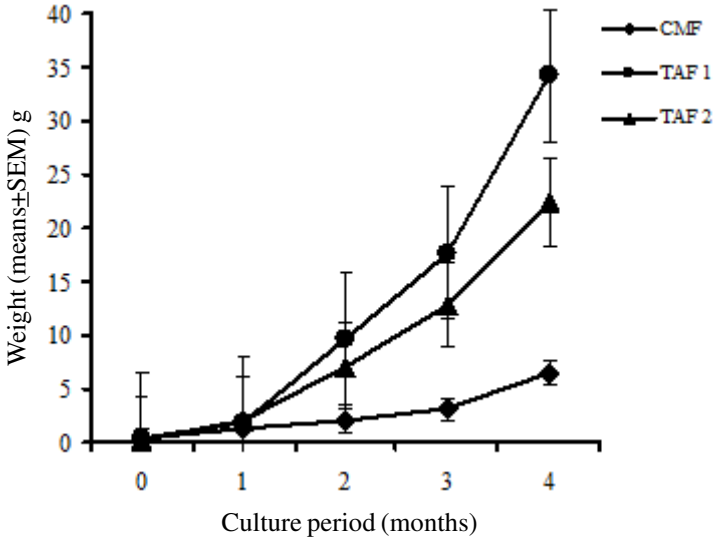

Figure 1. Growth trends showing change in mean weights of *C. gariepinus* fed on CMF, T AF 1 and TAF 2 feeds used in the study. (Error bars show ±SE).

in feeding African catfish. This finding is supported by Shoko *et al*. (2011) who reported similar findings on Tilapia *O. variabilis*.

Cost of production of the feeds. The cost of producing 1 kg of the formulated TAF 1 feed (US$ 1.00 kg^{-1}) and TAF 2 feed (US$ 1.70 kg^{-1}) was much lower than the imported commercial feed (US$ 2.00 kg^{-1}). The use of locally available materials is advantageous in that it reduces the costs of production of the feeds and it impacts on the economy of the country. The use of local ingredients also has a possibility to impact on the innovations and growth of micro-technologies as most farmers had already indicated making different trials on their farms for increased outputs. For example, some catfish fry producers used boiled chicken egg yolk to feed fry, the phenomenon which inspired researchers to conduct search on the same. Currently, there is an increasing number of catfish growers, who use bi-products from poultry industry as feed, and in fact, their farms are doing quite good.

Catfish growth rates. TAF 1 fed showed the highest weight gain and average daily gain, followed by TAF 2 feed (Table 5). The better performance of TAF 1 than TAF 2 could mainly be attributed to the inclusion of fish meal in the feed, which might have led to the acceptability and efficient utilisation by fish. Generally, fish meal bears high nutritional quality and biological value, and is well-balanced in amino acid profile, yet lacks anti-nutritional factors. As such, it is the most loved protein source by most aqua feed producing industries (El-Sayed, 1998; 2005; FAO, 2010; Aanyu *et al.,* 2012). Fish meal is a more readily digested and assimilated ingredient than the plant source ingredients (Tacon *et al*., 2008). The fiber in plant ingredients is known to reduce feed intake, decrease the time the feed spends in the gut and, consequently diet digestibility and nutrient bio-availability (Espe *et al*., 1998; Cheng and Hardy 2002; Nyina-wamwiza *et al*., 2007). However, the heat processing method employed in soybean in the present study could be partly the cause of the digestibility of TAF 2 feed as there were no significant difference in the specific growth rate and the food conversion ratios on treatment of the two locally formulated feeds. This is in concurrence with some studies which revealed that partial or complete replacement of fish meal, with plant ingredients, did not inhibit growth performance (Lee *et al*., 2002; El-Saidy and Gaber, 2003, Amisa *et al*., 2009).

Contrary to our expectation in this study, the CMF feed performed the poorest. This can be

attributed to the possibility that the feed was a floating pellet, while African catfish are dermesal fish spending most of the time in the bottom. Although most catfish would have been expected to come and compete for food in the surface, most fish did not come. This was because African catfish tend to express different behavours depending on variation on stocking density. Generally, African catfish, when stocked in high densities tends to efficiently utilise the feed due to intra-competition (Kohinoor *et al*., 2012). Fish when stocked at lower densities tend to express territorial behaviour than competition for food. Thus, it is probable that most of the CMF dissolved completely in the surface of the waters before it could be taken by fish. Thus, it is important at all times to consider all the necessary precautions on the behavior of the cultured animal and properties of the feed used.

Survival rate. The survival percentages of both feed treatments were generally low (Table 5). This could be due to cannibalism behavior of the catfish. Cannibalism in catfish is quite significant regardless of its stage in life, and normally it is recommended that sorting of fish is done to fast growers as any differences in fish size would cause cannibalism. Water quality, to some extent, impaired on the survival of the fish at their earliest life (Table 4); however this was immediately corrected and water replacement was changed on weekly intervals.

ACKNOWLEDGEMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 987 - 995 ISSN 1021-9730/2014 $4.00

COMPARATIVE ADVANTAGE OF THE EASTERN AND CENTRAL AFRICA IN THE COFFEE EXPORT SECTOR: THE CASE OF BURUNDI

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ABSTRACT

Coffee is a major contributor to the economies of East African Community (EAC) members. However, recently, export of the crop has declined due to internal and external forces of supply and demand. This paper sheds light on the EAC's comparative advantage in this cash crop in the international coffee market, with a special focus on Burundi, whose green coffee export is a backbone to its total exports (75%). The study is based on the proposition of the trade theory that partnership in international trade is determined by the prevailing comparative advantage. An improved normalised comparative advantage index, Normalised Revealed Comparative Advantage (NRCA), was used on data of coffee exports of Standard International Trade Classification (SITC) 3 4-grade, for the period 2000-2012. In order to conduct a dynamic comparative analysis, we used a time trend regression model to detect whether a country has gained or lost its comparative advantage during the period under study. Instability analysis was also used to depict the extent of NRCA volatility when the time trend was not statistical significant. Empirical results reveal that EAC countries had comparative advantage, with Uganda and Kenya leading the group during the period under study. However, they exhibited a simultaneous reduction in competitiveness in the global market, though at different levels. For the ECA countries to remain competitive in the global market, they must strengthen their position in the market by tackling coffee price volatility at ^producer level and show willingness to revamp the coffee industry.

Key Words: East African Community, Kenya, Uganda

RÉSUMÉ

Le café est un grand support de l'économie des pays membre de la Communauté d'Afrique de l'Est (CAE). Cependant, dans les périodes récentes, les exportations de cette culture industrielle a chuté a cause des facteurs tant internes qu'externes de l'offre et de la demande. Cet article a pour but de dégager le niveau de l'avantage comparatif des exportations de cette culture industrielle dans les pays importateurs, avec un aperçu spécial sur le cas du Burundi dont les exportations dépendent principalement du café (75 percent). Cette étude se base sur l'hypothèse de la théorie de l'économie internationale selon laquelle les tendances du commerce international sont prédites par l'avantage comparatif. L'indicateur de l'analyse de l'avantage comparatif, Avantage Comparatif Révélé Normalisé (NRCA) a servi à analyser NRCA sur les données des exportations du café vert, SITC grade 3- 4, durant la période de 2000-2012. Pour mener une analyse comparative dynamique, nous avons utilisé le modèle de régression de tendance temporelle. Cette analyse nous a permis de savoir si le pays en question a gagné ou perdu son avantage comparatif durant la période considérée. L'analyse d'instabilité a été adoptée afin de trouver le dégrée de la volatilité de NRCA lorsque la régression de tendance temporelle donnait des résultats dont les différences étaient statistiquement non significatives. Les résultats empiriques ont montre que tous les pays membres de la CAE présentent un certain avantage comparatif dans ce secteur café avec le Kenya et l'Uganda à la tête du groupe des pays pendant la période considérée. Néanmoins, tous ont perdu leur avantage

comparatif dans le marché mondial du café durant la période en étude mais à des niveaux relativement différents. Cet article a recommande que si les pays de la CAE et spécifiquement le Burundi, veulent être compétitif sur le marché mondial du café, ils doivent résoudre l'épineux problème de la volatilite du prix au producteur, mais aussi avoir la ferme volonté d'accélérer les politiques de restructuration du secteur café.

Mot Clés: East African Community, Kenya, Uganda

INTRODUCTION

The export sector of most eastern and central African countries is dominated by coffee, which accounts for over 70 percent of foreign exchange earnings from total exports (USAID, 2010). However, coffee output and quality in the sub-region have declined due to internal and external factors (World Bank, 2011). More recently, it was noted that coffee production decreased by 45 percent in 2011 compared to that in 2010 in Burundi alone (USAID, 2012). This was due to the decline in coffee prices, that triggered poor coffee husbandry practices and crop over-maturity.

In 2006, market liberalisation in the sector eroded the monopoly of public agencies by allowing private enterprises to compete with it and also brought changes in the regulatory framework of coffee trade. In the global market, Burundi failed to adjust itself to the radical changes such as the collapse of International Coffee Agreement (ICA) quota system in 1989, repositioning of the leading producer (Brazil), technological innovation in coffee roasting and blending, and the entry of new players in the coffee market (Vietnam and China).

Despite these backdrops, Burundi has conducive agro-ecological condition to produce high-quality coffee and the coffee sub-sector is in the process of being revived through a comprehensive reform so that it may improve its performance in the world market. The reforms introduced in 1980 in Burundi that aimed at boosting the coffee sector did not yield the expected results. Another round of reforms introduced in 1990s shaped the organisation and management in the sector. The key reforms were the privation of the sector and the downsizing of the *Office des Cultures Industrielles du Burundi* (OCIBU), a public agency playing production and marketing roles, to a marketing board. External players were called in to boost the quality of coffee along the production value chain, and at the same time promote the price incentive to producers.

After joining the East African Community in 2007, the country needs to learn from its neighbours and at the same time seize the unique occasion to exploit the EAC Custom Union and EAC Common Market protocols put in place. The Customs Union is premised on easy access to markets, reduction of trade barriers and access to the major ports of the region, that is, Mombasa and Dar Es Salam. Comparatively, Rwanda with a highly concentrated coffee export like Burundi, has reaped a lot from coffee privatisation and coffee production efficiency introduced since 2001. Tanzania and Uganda are on the same agenda with regard to the speed and magnitude of coffee production and marketing reforms implementation in 1990s. Despite coffee sub-sector liberalisation, the Coffee Board of Kenya (CBK) remains the main player in regulation and marketing of coffee in the EAC (Nyangito, 2001).

This paper presents the level of comparative advantage of Burundi coffee in relation to the EAC countries considered as benchmarks. The paper also attempts to show the coffee comparative advantage score trend of the country; with focus on the status of Burundi coffee export.

Theory of comparative advantage. While several articles on the comparative advantage approach in recent years seem to rely on the Balassa (1965)'s framework, much less effort has been devoted to use the advanced tool of comparative advantage to correct the shortcomings of Balassa Revealed Comparative Advantage (BRCA) in Sub-Sahara Africa studies (Ndimanya and Ndayitwayeko, 2009; Makochekanwa, 2007; Shinyekwa and Othieno, 2011; World Bank, 2011, Mzumara *et al*., 2013; Chingarande *et al.* 2013). According to Bebek (2011), the major weakness of BRCA index is that it violates four statistical

properties of a true comparative advantage index, such as symmetry of the index and its demarcation, fixed effective bounds, mean stationarity and uniqueness of the index value. The proponents of comparative advantage index examined how the distribution of their indices differs from the original index (BRCA), and at the same time achieved the four mentioned statistical properties. NRCA index by Run *et al.* (2009) was born out of the desire of finding a reliable and effective index to explain both dynamic and cross-country reveal comparative advantage.

The dynamic trend of comparative advantage used to explain the Sub-Saharan Africa's coffee competitiveness has not received adequate attention and is addressed in this paper. Besides, this paper uses the novel tool known as Normalised Revealed Comparative Advantage (NRCA) by Run *et al.* (2009) in order to circumvent the limitations of BRCA and better understand the dynamics of the level of competitiveness in the coffee sector of EAC. To the best of our knowledge, no time series estimate on RCA exist for Burundi and EAC member states in general.

Profiles of the coffee export sub-sectors in the EAC member countries. Rwanda Government policy since 1994 moved towards the liberalisation and privatisation of the coffee industry. Various constraints, such as export tax, were removed so that Rwandan exporters were able to pay fully competitive prices to producers. The establishment of Rwanda Competition Board, the increase of coffee-washing stations and the improvement of coffee quality or specialty coffee, re-positioned the Rwanda coffee sector in the world market. The growth of coffee production and exports was attributed to this government policy reform that had a direct bearing on the establishment by competitive private firms and individuals of modernised coffee washing stations and huge investment in primary processing in the coffee sector.

In Uganda, according to Bussolo *et al.* (2006), the Uganda Coffee Authority Board embraced strategies aimed at improving the level of competitiveness of their coffee (second largest producer in Africa after Ethiopia), in the international market by disseminating new coffee varieties, promoting domestic coffee consumption through training in coffee roasting, brand development, market research and encouraging value addition and penetration in new and emerging coffee markets.

In Tanzania, the sale of coffee was regulated and controlled by the Tanzania Coffee Board (TCB) through two channels, namely the Moshi Coffee Auction and direct export only for quality coffee permitted by licenses issued by TCB (Mhando *et al.*, 2013). A strongly regulated coffee sector may put Tanzania at competitive disadvantage in the region as well as in the world. To the contrary, in Burundi, coffee production is in the hands of competitive private firms and individuals and this has somewhat reduced the occurrence of distorted coffee prices.

The Kenyan Government reduced the powers of Kenya Planters Cooperative Union in 1999 through a special legislative supplement of the Coffee Act Chapter 333, which was the main exporter of coffee in the country, by licensing nine new processing firms and millers. Like in Tanzania, coffee sale in Kenya was done in two ways, namely by sale directly and at the digital Nairobi Coffee Auction. However, growers continued to receive unattractive prices because of highly costly and poor service delivery done by cooperative or private enterprises (Nyangito, 2001).

East African Community coffee exports for 1980-2011. The coffee export patterns from 1980 to 2011 exhibit four features (Fig. 1). Firstly, a rise in exports registered during 1986 and 1995 resulting from the severe frost and damage to the coffee crop of the leading exporter, Brazil, the coffee shortage of which pushed the Arabica coffee price up.

This led to high volumes of coffee exports from Brasil's coffee export competitors, EAC countries being among them (Otim and Ngategize, 1993; Nestlé, 2004). Secondly, the EAC exports progressively declined up to the lowest point around 1992-1994 (Fig. 1). Again, a general fall in export was recorded in 2002; followed by a modest growth up to date. Figure 1 depicts two coffee export leaders in EAC, which are, Kenya and Uganda but with a quasi dominance of Uganda since 1995. Burundi and Rwanda were

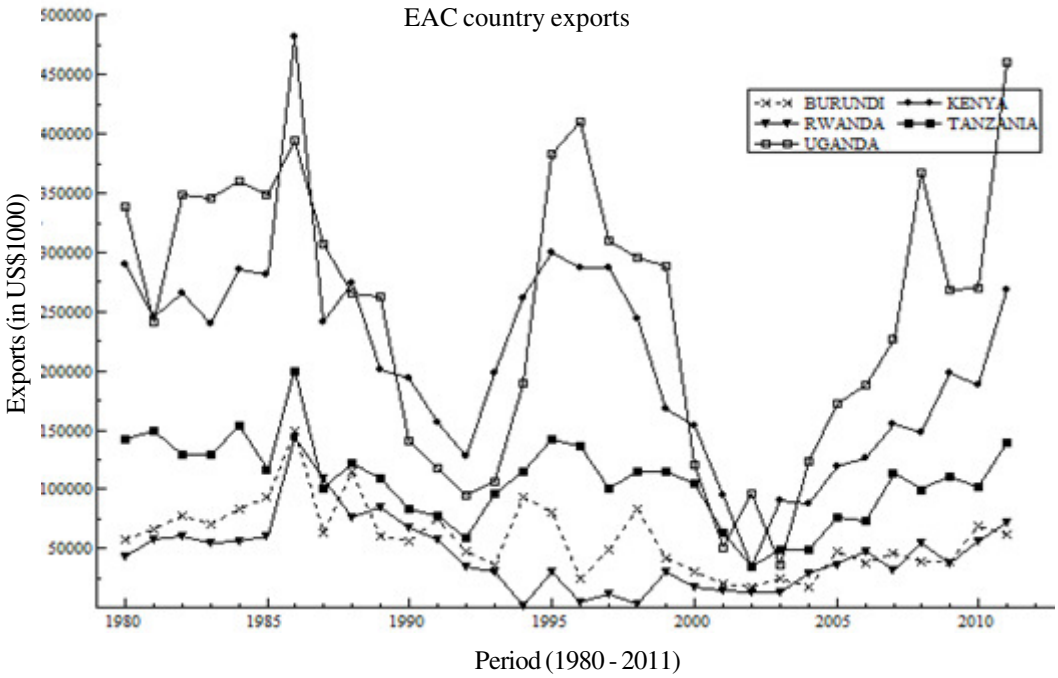

Figure 1. East African Community country coffee exports during 1980-2010.

the least coffee exporters in EAC because of limited factor endowment (land) and technology, though coffee was grown in a conducive environment and volcanic soils.

While Burundi's coffee export was greater than that of Rwanda since 1980, their export trends intertwined from 2003 onwards. The implementation of Rwanda's coffee reforms and success attracted Foreign Development Investment (FDI) which boosted its export.

Normalised revealed comparative advantage of EAC countries trend (1980-2011). On overall, the five EAC countries lost their comparative advantage in 1986, the year of great performance in the world coffee trade. The NRCA decline in trends which started 1996/1997 went even further below 0.25 because of the decline in the world coffee price which reached its trough in 2001 (Fig. 2).

Bussolo *et al.* (2006) assessed the impact of declining coffee price on coffee production by analysing the trend of world coffee price and its implications on the level of coffee growers' poverty in Uganda. The EAC countries have been facing stiff competition and losing market share to the new producers such as the Philippines and other Asian countries. Their contribution to the world market became dismal because coffee price plummeted in the global market. Nevertheless, Uganda kept pace with Kenya and both had a NRCA score above 1.0 during 1980-1987 prior to the 'lost decade' (1990-2000) due to the Structural Adjustment Programme. The drivers of their competitiveness outfit are explained by being able to contain supply chain factors, hindering production performance and also streamlining efforts to capture niche markets in developed and developing coffee consuming countries (Fairtrade, 2012; Mmri, 2012).

Burundi registered a progressive fall in its comparative advantage from a NRCA score of 0.41 in 1980-1987 to a score of 0.03 in 2004-2011, that is a 93 percent decline in comparative advantage (Table 2). However, there was an overall appreciation of the coffee competitiveness when EAC as a whole traded this commodity with the rest of the world.

The findings reported in Table 2 contradict those of Chingarande *et al.* (2013) that unroasted

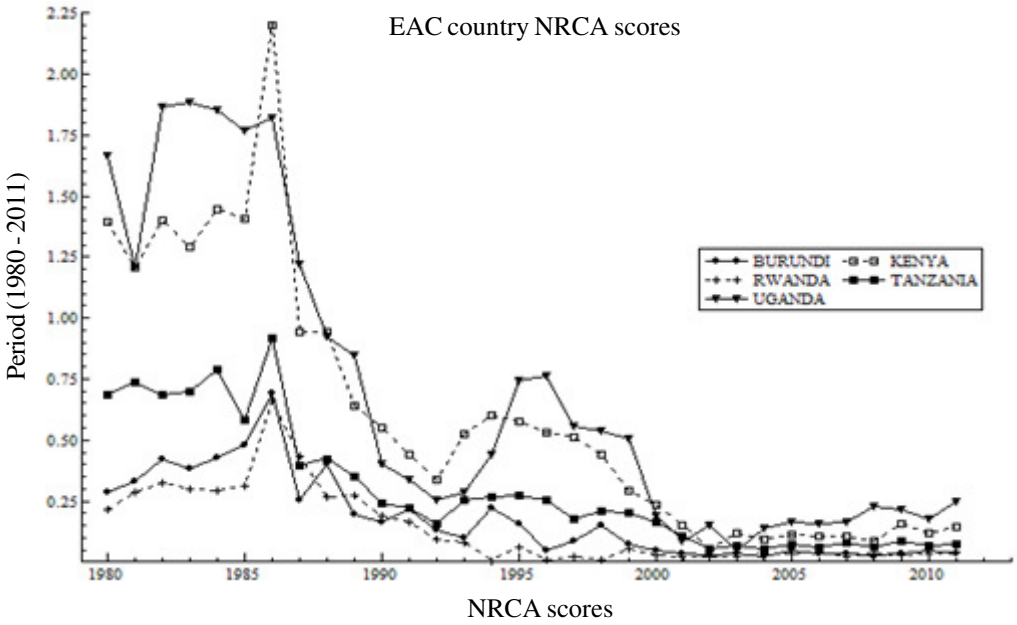

Figure 2. Normalised Revealed Comparative Advantage of EAC countries Trend (1980-2011).

TABLE 1. Burundi coffee census data (2000-2010)

Year	Yield[a] (t ha^{-1})	Production[a] (mt)	Export[a] (US$)	Farmer[b] price (US$ kg^{-1})	World[a] price (US$ kg^{-1})	Farmer earning (%)
2000	0.88	18500	30941	0.81	1.54	0.52
2001	0.88	15834	21109	0.68	1	0.68
2002	0.90	36000	18032	0.69	0.93	0.74
2003	0.91	20100	25169	0.59	1.09	0.54
2004	0.90	36000	18124	0.63	1.28	0.49
2005	0.87	7800	47056	1.07	1.75	0.61
2006	0.97	31000	38073	1.9	1.93	0.98
2007	1	29946	46895	1.76	2.21	0.8
2008	0.91	7305	39419	1.92	2.62	0.73
2009	0.97	25130	39476	1.90	2.28	0.83
2010	0.95	6821	69845	1.86	2.72	0.68

Source: [a]FAOSTAT, 10 September 2013, [b]International Coffee Organisation. (ICO), 10 September 2013

coffee emerged among the ten top product with a high BRCA. However, the BRCA as an analytical tool has shortcomings described above (static and not comparable over time). Compared to its counterparts, it ranks second last, but due to the success of Rwanda's coffee sector during this decade (2003-2013), Burundi NRCA trend followed that of Rwanda despite the privatisation reforms introduced previously in Burundi to kick-start the revival of the sector.

The results of the time trend model revealed that EAC countries exhibited a comparative disadvantage (Table 3). The variable time trend was negative (less than zero) and very statistically significant, implying that the EAC countries' coffee export competitiveness was

TABLE 2. Normalised revealed comparative advantage summary results (1980-2011)

EAC Country	1980-1987	1988-1995	1996-2003	2004-2011
Burundi	0.41	0.20	0.06	0.03
Kenya	1.41	0.58	0.29	0.12
Rwanda	0.35	0.14	0.02	0.03
Tanzania	0.69	0.27	0.15	0.07
Uganda	1.67	0.53	0.35	0.19
EAC	0.18	0.60	0.14	0.30

TABLE 3. East African Country coffee trend regression and instability index estimation (1980-2011)

Estimate	Burundi	Kenya	Rwanda	Tanzania	Uganda
Constant	0.42*	1.43*	0.35*	0.69*	1.61*
Coefficient	-0.01*	-0.05*	-0.01*	-0.02*	-0.06*
SE Coeff.	0.002	0.005	0.002	0.002	0.007
t-stat Coeff.	-7.81	-9.24	-6.21	-10.07	-8.37
F-stat	60.95*	85.45*	38.55*	101.33*	70.11*
R^2_{adj}	0.66	0.73	0.55	0.76	0.69
CV	0.97	0.91	1.14	0.87	0.92
Instability Index	0.57	0.48	0.77	0.43	0.51

* = significance at 1% level, SE = standard error, CV = Coefficient of variation

unstable, volatile and declining during the period under study. Kenya and Uganda's slopes were not as steep as those of their neighbours.

Rwanda possessed the highest instability index of 77%, followed by Burundi at 57%. This could be attributed to the recent structural and institutional reforms that shook the whole coffee production and trade system in the two countries, and spurred competitiveness in the last decade 2000-2010. However, the instability in competitiveness could also mean the degree of exposure to world shocks, specifically the price volatility due to either coffee overproduction or the existence of price asymmetry in the transmission of price changes.

Burundian coffee export sub-sector. Introduced in 1930s, the coffee industry in Burundi has undergone several re-organisations and major reforms. Burundi grows two types of coffee, *Coffea arabica* and *Coffea robusta*. *Coffea arabica* is concentrated in the northern and central parts of Burundi (Ngozi, Kayanza, Gitega and Kirundo); while the coffee robusta is largely in the northern-east region (Bubanza and Cibitoke). On the other hand, the *Coffea arabica* 'Bourbon variety' represents 96 percent and the varieties constituting coffee robusta in the country.

Coffee is grown predominantly as a smallholder cash crop; providing incomes for 600,000 households and occupying approximately 70,000 hectares, carrying about 25 millions of trees (PAGE, 2007; USAID, 2010). With the introduction of micro-credit scheme, ownership of coffee tree plantation is the means by which the smallholder farmers used as a collateral, asset presented to micro-credit institution such as Saving and Credit Cooperative (COOPEC) and others (USAID, 2010).

Despite efforts engaged by the State to revamp the coffee sector, the latter was not spared by the vagaries of shortage of coffee supply due to the domestic meager production, world coffee volatility and financial crisis. The shortage of coffee supply to the world market was due to

endogenous factors such as demographic pressure and land scarcity. Indeed, coffee is grown in the most populated regions in Burundi, that is, Ngozi, Gitega and Kayanza. The coffee price volatility in the world market has impeded the acceleration of coffee reforms. Burundi coffee farmers are viewed as the most poorly remunerated in the EAC region and sometimes below the cost of production (Table 1).

In the 1990's, Arabica coffee producers of Uganda received 76% higher price than that received by their Burundian counterparts (USAID, 2010). The fact that a low price is given to coffee producers when it is known that there is a boom in the consuming countries is what economists refer to as the 'coffee paradox'. This was explained by price asymmetries in the coffee trade, oversupply and time lag in reconstruction of world market (Kang and Kennedy, 2009). However, in the case of Burundi, the reasons given for the low prices at producer level were associated with primarily the scrupulous coffee export agents (collusion of international traders), decade of socio-political unrest within the country and state control. Low incomes generated from coffee plantation has led to either uprooting of coffee trees or intercropping with food crops. Lack of effective agricultural extension service as well as illequipped and under funded research stations have been major supply-side constraints. According to USAID (2010), OCIBU with four technical officers, lacks enough human resources to equip coffee farmers with new technologies and deliver educational programmes on good husbandry practice. This tendency has led to poor coffee production and has forced policy makers to intervene in order to seek avenues for promoting coffee productivity. This was in contrast with the expansion of coffee hectarage in 1990s with the aim of increasing coffee production (USAID, 2007).

The policy prevailing prior to coffee liberalisation of 1980s, was that of 'stick and carrot; subsidising coffee production in terms of maintaining floor producer prices in order to stimulate production (World Bank, 2011) and at the same time, forbid farmers to uproot coffee trees. But given the trend of world coffee development and the implementation of Structural Adjustment Programmes (SAPs), Burundi dropped such a policy and embraced the privatisation of the sector. This was done in three phases, namely the privatisation of management which saw the creation of private operator, the Mixed Public-private Company with Curing (SODECO) and SOGESTAL managing the de-pulping and washing stations.

The second phase was the introduction of deregulation measures with the attempt to limit State intervention in the sector. The re-structuring of the sector was the last attempt aimed at revamping it creating room for investment of the private companies in the sector.

The coffee exports fell in the hands of the private companies and Burundi Coffee Company (BCC), a State-own company. In order to strengthen their negotiation power, all private companies were regrouped in a professional association called Association of Burundi Coffee Exporters (ABEC). Coffee was sold either at auction by these companies or directly to buyers, thereby bypassing the coffee board.

Albeit all these reforms, coffee growers were sidelined and continued to receive meager revenue from their coffee. Besides, the State still had its grip on the sub-sector and there was a strong need for establishing a non-partisan coffee agency to fully regulate the coffee industry. The agency should be preferably an independent body answerable to the minister of agriculture, and enforce the laws for delivering services such as coffee processing and marketing.

With the liberalisation of the Burundi coffee industry, coffee farmers engaged with international coffee buyers for only specialty coffee, but through the facilitation of the trade regulatory body named Coffee Chain Regulatory Authority of Burundi (ARFIC). The gateways of Burundi green coffee were the sea ports of Mombasa in Kenya and Dar-Es-Salam in Tanzania. The dominant destinations were European countries, with Germany topping the list, and North American countries such as USA and Canada.

As Rwanda and Tanzania successfully reformed their coffee sector by being aggressive in coffee specialty production and adopting highly advanced marketing strategies in the world market, Burundi still lagged behind because of wrangles in the privatisation process and the

slow pace in the enforcement of decisions regarding the deregulation and privatisation of the coffee industry (USAID, 2010).

Trade policy has been designed in such a way that the export sub-sector, coffee sub-sector in particular, is promoted. The export tariff on coffee beans was abolished in Burundi by 2005 (USAID, 2007). The imports of unprocessed coffee, other than beans, attract an average tariff of 25 percent, compared with 100 per cent in 2003. The liberal coffee trade system was formed in order to allow a full participation of the coffee growers, who were organised in an association called the National Confederation of Coffee Growers (CNAC). The withdrawal of the State from coffee business enabled the growers to retain 72 per cent of the profits of 2010/2011 coffee season, ARFIC 1.68 per cent, INTERCAFE 3.5 per cent, SODECO 4.9 per cent, SOGESTAL 16.32 per cent, coffee promotion 0.4 per cent and state service only 1.2 per cent (World Bank, 2011). Besides, the existence of many players in this sub-sector ignited a stiff competition and the improvement of the coffee quality in Burundi.

In EAC, the coffee sub-sector followed the same pattern of liberalisation. In Rwanda, a national coffee strategy was drawn, with clear targets and with a sole aim of increasing the income of small scale coffee growers through scaling up their participation along the coffee value chain (Mutandwa *et al.*, 2009). The latter sold their coffee cherries to coffee-washing stations owned either by cooperative or private enterprises.

CONCLUSION

Burundi is the least competitive amongst all EAC members despite the liberalisation of the coffee sector. The declining of comparative advantage may explain the status of coffee sector of Burundi in which a large part of its production is exported to the world market. The low price paid to the producers and the asymmetries in the coffee value chain are sources of poor production and quality of Burundi's coffee. The failure to fully privatise the semi-washed, fully-washed stations and SOGESTALs has led to an unequal distribution of coffee revenues among the coffee stakeholders. Privatisation of these processing sectors is considered as the crucial determinant of coffee reforms and driver of Burundi's coffee comparative advantage in the EAC region.

ACKNOWLEDGEMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 997 - 1001 ISSN 1021-9730/2014 $4.00

RELATIVE PERFORMANCE OF STAKING TECHNIQUES ON YIELD OF CLIMBING BEAN IN HIGHLANDS OF BURUNDI

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is an important staple grain legume in the Great Lakes Region of Africa. In addition, it is a major source of proteins, energy and micro-nutrients (e.g. Fe and Zn), especially for smallholder farmers. The climbing bean is particularly more productive, an efficient land user and tolerant to environmental stresses compared to bush bean types. This study was conducted to evaluate the performance of three staking techniques, namely (i) sticks, (ii) strings, and (iii) maize intercropped with climbing beans during the cropping seasons 2010B and 2011A on 10 sites of Ngozi, Mwaro and Karusi provinces of Burundi. Staking with sticks led to the most grain yielding among the three staking techniques; however, economic analysis showed that staking with intercropped maize was the most efficient. Use of strings as staking materials can replace the use of sticks without a reduction in production.

Key Words: Great Lakes, maize intercrop

RÉSUMÉ

Le haricot commun (*Phaseolus vulgaris* L.) est une légumineuse tres importante dana la région des Grands Lacs africains. En plus, c'est une source majeur de protéines, énergie et micronutriments (ex Fe et Zn), spécialement pour les petits agriculteurs. Le haricot volubile est particulièrement plus productif, efficient en termes d'utilisation des terres et tolérant aux stress environnementaux par rapport au haricot nain. Cette étude était conduite pour évaluer la performance des techniques de tuteurage, nommément tuteurage avec (i) petits bois (ii) cordes et (iii) maïs intercalé avec le haricot, au cours des saisons culturales 2010B et 2011A, dans dix sites des provinces de Ngozi, Mwaro et Karusi au Burundi. Le tuteurage par le bois a induit un plus grand rendement parmi les trois techniques utilisées. Néamoins, l'analyse économique a montré que le tuteurage par le maïs intercalé avec le haricot est le plus rentable. L'utilisation des cordes, comme matériaux de tuteurage, peut bien remplacer le bois sans toutefois réduire la production du haricot.

Mots Clés: Grands lacs, maïs intercalé

INTRODUCTION

Due to land fragmentation, farmers need to grow climbing bean varieties in order to feed the rapidly growing population. The shortage of staking materials is ranked among the major contraints for climbing bean varieties production despite their high yielding potential. With improved agronomic practices, which include staking options, climbing beans varieties can produce up to 4 metric tonnes per hectare, while bush beans produce between 1 and 2 tonnes per hectare (CIAT, 2005). The long stems of climbing beans enable them to produce more pods as compared to the bush types.

The reduction of tree plantations associated with the high cost of stick staking explains the unavailability of sticks for staking. Indeed, staking a one hectare plot size of climbing beans requires around 25,000 sticks stakes, with a cost estimated

at US$ 350 (Ruraduma *et al.*, 2012). Besides, most farmers in the region lack sufficient knowledge on best staking options. Although staking leads to better yields, lack of appropriate staking materials is a key challenge to adoption of the technology. Wood sticks are preferred by farmers to other alternative uses; these competing needs, therefore, could lead to environmental degradation through deforestation (ISABU, 2006).

To cope with this situation, the use of strings such as banana and sisal fibres has been identified to be a potential alternative. In Burundi, for instance, where banana fibre is sufficiently available, fibres can offer the benefit of reduced utilisation of stakes.

The objective of this study was to identify the most suitable staking option of climbing beans in Burundi, targeting environmental preservation.

METHODOLOGY

This study was conducted onfarm in three provinces of the highlands of Burundi, namely Karusi, Ngozi and Mwaro. Karusi Province is located in the eastern part of Burundi, between latitude 2° 47'16' and 3° 13'78'' south and 29° 25'11'' and longitude 29° 55'95'' east (République du Burundi, 2006). The Province is characterised by highland conditions, with a temperature range of 17-20 °C. Rainfall ranges from 1200-1500 mm per annum; and the province's altitude ranges between 1600 and 1900 metres above sea level (masl).

Ngozi Province is located in the northern part of Burundi, within 2° 39'' 19'' and 3° 5'00'' latitude south and 29° 25'11'' and 29° 37'57'' longitude east (République du Burundi, 2006). It is also characterised by highland conditions, with the altitude ranging from 1800 to 1900 masl. The temperature ranges between 17-20 °C and rainfall between 1200 -1500 mm per annum.

Mwaro Province is located in the central western part of Burundi within 3° 18'' and 3° 50' latitude south and 29° 35' and 29° 51' longitude east (République du Burundi, 2006). Its altitude ranges from 1500 to 2200 masl; temperature 16-19 °C; and annual rainfall between 1300 - 2000 mm.

The field experiment was conducted during the second cropping season of 2010 (2010B) and the first season of 2011 (2011A). Treatments included bean staking using sticks, fibre strings or maize (*Zea mays* L.) stems intercropped with the beans. These treatment were evaluated using three improved climbing bean varieties (AND10, VCB 81012 and G13607), recommended for middle and highlands conditions (Ntukamazina, 2008).

On top of other agronomic practices, sole bean plots were fertilised with a pre-planting dose of diammonium phosphate (DAP) at a rate of 100 kg ha^{-1} and organic manure made from cattle (10 t ha^{-1}). Intercropped maize climbing bean plots received 20 t ha^{-1} of organic manure in addition to 100 kg ha^{-1} of DAP. All these fertilisers were applied as a single dose just before planting. The treatments were laid out in a randomised complete block design (RCBD) with six farmers as replications. Experimental plots were of 30 m^2 size.

Data were collected on grain bean yield and subjected to an analysis of variance to assess the effect of each staking technique on the three climbing bean varieties This statistical analysis was fitted using GenStat 12th Edition. Mean separation, in cases where there were significant differences among treatments, was done using Student-Newman and Keuls test (Gomez and Gomez, 1993).

For economic analysis, for each treatment, the total factor cost (TFC) was determined by multiplying its price by the total number of units used. The total value product also known as total revenue product (TRP) was calculated by multiplying the total physical product (yield) by its price. For each treatment factor, the profit was estimated by substracting the total factor from the total revenue product, i.e Profit = TRP – TFC (Hill, 2006). The profit values obtained from the three treatments were compared and the treatment with the highest profit value was considered as the most economically effiscient.

RESULTS

There were highly significant differences among the three staking techniques ($P<0.001$). Staking with sticks was the most grain yielding technique among the three studied (Fig. 1). Furthermore, the multiple comparisons of means using the

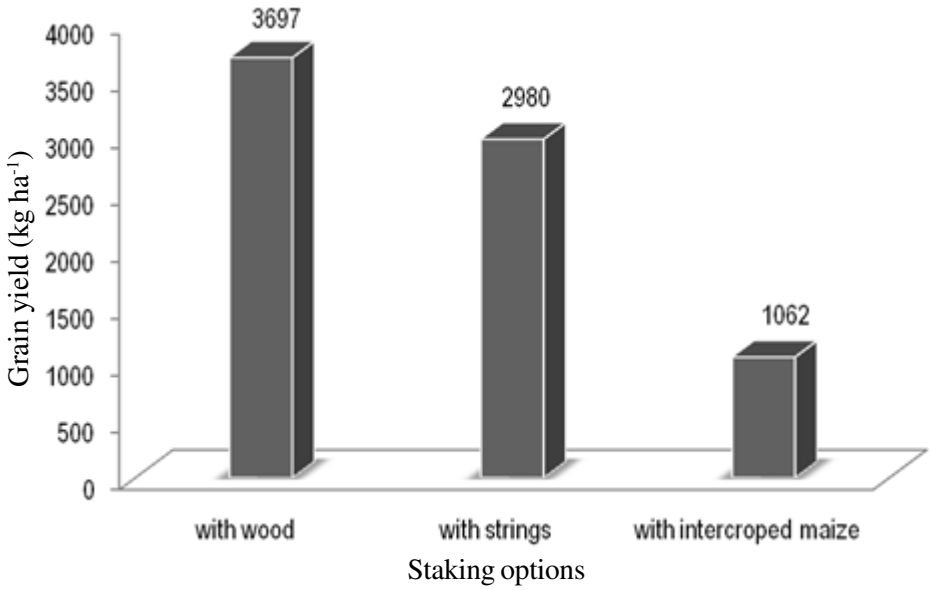

Figure 1. Effect of staking on climbing in the highlands of Burundi.

TABLE 1. Two-way grain yield means for staking types and bean varieties in the highlands of Burundi

Staking type	Grain yield (kg ha^{-1}) per site			
	Mwaro	Ngozi	Karusi	Average
Sticks	3,661	3,983	3,748	3,697a
Strings	2,691	3,064	3,185	2,980b
Maize stems	968	989	1,192	1,062c

Student-Newman-Keuls test showed that the staking technique with sticks is the most yielding, followed by staking with strings (Table 1).

In terms of economic assessment, intercropping maize stems in climbing bean had the highest gross margins, and thus was the most profitable (Table 2). Maize added value to both incomes of the associated communities. The economic profits were in the order of 1,998 US$ for intercropping maize with climbing beans; 1,086 US$ for strings and 244 US$ for sticks.

DISCUSSION

Results from this study show that climbing bean yields are influenced by the staking techniques. Staking with sticks is the most optimal technique, followed by staking with string technique (Fig. 1, Table 1). These two staking techniques could provide alternative solutions to decreasing bean yield among smallholders. In Burundi and in Eastern Africa in general, there is need to use crop production management strategies, including adoption of improved agronomic practices, to cope with gradually declining yields of bean resulting from high population pressure, and decline in arable land area caused by land fragmentation (Bekunda *et al*., 2008). In addition, there are limited opportunities for crop rotation, leading to a reduction in soil fertility and an increase inincidence of diseases.

Even though results from this study, evidently show that the climbing bean cultivars staked with sticks produced significantly higher yields (3697 kg ha^{-1}), the adoption of this technology by smallholder farmers is constrained by limited

TABLE 2. Estimated gross margins based on staking techniques used in a study in climbing beans in Burundi

Item	US$	Quantity			Total Cost = Quantity x unit cost		
		Staking with sticks	Staking with fibre strings	Staking with maize stems	Staking with sticks	Staking with fibre strings	Staking with maize stems
Labor soil preparation	1	100	100	100	100	100	100
Organic manure	33.33	10	10	20	333	333	667
Inorganic fertiliser DAP	0.47	100	100	230	47	47	107
Inorganic fertiliser KCl	0.4	50	50	50	20	20	20
Inorganic fertiliser urea	0.4	0	0	40	0	0	16
Seeds	0.8	70	70	70	56	56	56
Sowing	1	50	50	40	50	50	40
Stakes	0.05	30,000	0	0	1,520	0	0
Supporting sticks	0.08	0	3,000	0	0	245	0
Labour staking	1	50	20	0	50	20	0
Widding	1	25	20	25	25	20	25
Harvesting	1	20	10	20	20	10	20
Total production cost (TPC)					2,221	901	1,051
Yields =Sales quantity (Q)					3,697	2,980	4,574*
Price (P)					0.67	0.67	0.67
Revenue (PxQ)					2,465	1,987	30,494
Gross margin (revenue-TPC)					244	1,086	1998

The sales quantity (4,574 kg) obtained under staking with intercropped maize is obtained by adding bean yield (1,062 kg) to the maize yield (3,512 kg) on the same plot

access to sticks for staking. In this case, adoption of the fibre string staking, a technique whose average yield was 2980 kg ha^{-1}, is more applicable to the smallholder situation.

ACKNOWLEDGMENT

The authors thank Dr. Mwamburi Mcharo, Dr. Elijah Miinda Ateka, Dr. Ir Désiré Nkezabahizi, Ms. Maureen Katafiire, and Ms. Caroline Wanja Mugo for their intellectual input. This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 1003 - 1012 ISSN 1021-9730/2014 $4.00

STRENGTHENING LOCAL SEED SYSTEMS WITHIN THE BEAN VALUE CHAIN: EXPERIENCE OF AGRICULTURAL INNOVATION PLATFORMS IN THE DEMOCRATIC REPUBLIC OF CONGO

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ABSTRACT

Access to good quality seed is the beginning of successful crop production as an enterprise. Unfortunately, this remains a challenge to the smallholder farmers in the eastern and central Africa, whose seed systems are still under-developed. The situation is even worse in conflict burdened parts of some countries like the eastern region of the Democratic Republic of Congo (DRC), where socio-economic systems have been progressively disrupted. This paper presents the process and findings from a study which involved application of an Agricultural Innovation System (AIS) approach to the seed systems to improve the bean (*Phaseolus vulgaris* L.) value chain in South and North Kivu provinces of the DRC. Seventy four stakeholders were involved, including farmers and farmer associations, local grain/seed traders, private and public extension agents, researchers, finance and credit cooperatives and Non-Governmental Organisations (NGOs). The study was conducted in four sites, namely Mudaka and Katana (South Kivu), Rugari and Kinyandonyi (Nord-Kivu). The findings revealed increase in access to seeds of marketable varieties between 2009 and 2012 from less than 10% to about 42%. In 2012 more than 5 tonnes of bean seed was produced and distributed through non-Governmental Organisations (NGOs). About 56.3% of the farmers benefited through accessing one or more of the marketable improved bean varieties and skills to implement matching technologies. The price of bean per tonne at farm level increased by 120%, while seed purity increased from 70 to 95% over the same period. It is evident that innovation platforms provided a good forum for actors in the bean value chain to interact and improve seed system performance, thus resulting in increased smallholder farmers' access to lucrative bean seed markets.

Key Words: Marketable varieties, NGOs, *Phaseolus vulgaris*

RÉSUMÉ

L'accès aux semences de bonne qualité est le début d'une entreprise de production agricole réussie. Malheureusement, ceci reste une contrainte aux petits exploitants agricoles en Afrique de l'Est et Centrale où les systèmes semenciers sont encore peu développés. Cette situation est même aggravée par des conflits dans certaines régions telle l'Est de la République Démocratique du Congo (DR Congo), où les systèmes socioéconomiques ont été progressivement perturbés. Cet article présente le processus et les résultats d'une étude impliquant une approche de Système d'Innovation Agricole des systèmes semenciers pour améliorer la chaine de valeur du haricot (*Phaseolus vulgaris* L.) dans les provinces du sud et nord Kivu de la RDC. Soixante quatorze partenaires étaient impliqués, incluant les fermiers et les associations des fermiers, commerçants locaux des semences, agents de vulgarisation privés et publiques, chercheurs, coopératives de finances et de crédit et Organisation Non-Gouvernementales (ONG). L'étude était conduite dans quatre sites, à savoir, Mudaka et Katana (Sud Kivu), Rugari et Kinyandonyi (Nord-

Kivu). Les résultats ont révélé une augmentation en termes d'accès aux semences de variétés commerçables entre 2009 et 2012 de moins de 10 à environ 42%. En 2012 plus de 5 tonnes de semences de haricots étaient produites et distribuées à travers les ONG. Près de 56.3% des fermiers ont accédé à une ou plusieurs variétés commerçables améliorées et nouvelles connaissances pour exécuter les technologies acquises. Le prix des haricots par tonne au niveau de la ferme a augmenté de 120%, pendant que la pureté des semences a augmenté de 70 à 95% au cours d'une même période. Il est évident que les plates formes d'innovation fournissent un bon forum pour les acteurs dans la chaine de valeur du haricot pour l'interaction et la performance des systemes semenciers, ainsi résultant en une augmentation de l'accessibilité aux marchés lucratifs des semences par les petits exploitants agricoles.

Mots Clés: Variétés commerçables, ONG, *Phaseolus vulgaris*

INTRODUCTION

Access to good quality seed is the beginning of successful crop production initiatives globally. Unfortunately, this remains a formidable challenge to the smallholder farmers in the eastern and central Africa, where seed systems are still under-developed. The situation is even worse in conflict burdened parts of some countries like the eastern region of the Democratic Republic of Congo (DRC), where socio-economic systems have been progressively disrupted.

Eastern DRC, hereafter referred to as Kivu region, experienced a decade of conflict, which resulted in massive displacement of inhabitants, perpetuated poverty and food insecurity because many farms were abandoned and seeds of a wide range of crops were lost. The region's decline in agricultural productivity is basically linked to systemic weaknesses in the country's policies, markets and trade (USAID, 2010).

Although the situation has in some cases led to a growing seed business, most smallholder and resource poor farmers have not been able to benefit from this opportunity due to high costs of production. Farmers in the region mainly obtain seed from informal seed systems, which include farmers-own-saved seeds, seed exchanges among farmers and local seed business (Mastaki, 2006; Njingulula and Kalyabara, 2006). This situation is promoted by a complex and vast process of formal seed sector, whose requirements do not favour smallholder and resource poor farmers (Chirwa and Aggarwal, 2000). This system makes it difficult for the majority of farmers to access and produce quality seed needed for increasing agricultural productivity, and also to participate in the profitable markets (Wanjiku and Birachi, 2011). In DRC, very few seed companies are able to meet the requirements for formal seed production, such as standard seed quality. However, most of these companies have limited trade volumes and, thus are unable to meet the high seed demand in the two provinces of Kivu region (Njingulula, 2012). For example, in 2010 alone, the national bean seed requirement was estimated at over 30,000 against 3,000 metric tonnes which were available (MINAGRI, 2011). As Scott (1995) put it, in spite of a fairly large number of improved varieties released by the research institutes, seeds of these varieties are not easily available to the farmers due to the insufficient efforts made for their multiplication, promotion and distribution.

Although seeds from informal systems are believed to be cheaper, easier to obtain and available in divisible (small) quantities, there are challenges like limited dissemination of improved varieties, use of old and traditional varieties with low productivity. The situation is compounded by limited extension services and lack of access to input and output markets in Kivu region. These results in low, often declining bean yield due to use of poor quality seeds, application of poor agronomic practices and, thus low incomes among rural farmers.

It, therefore, became imperative to provide assistance to farmers, who were emerging out of war, to acquire seeds of improved varieties that would increase production and create surplus for marketing and related businesses to improve households' incomes, since majority of the communities relied on agricultural production for their livelihood. The Agricultural Innovation Approach therefore, was introduced by the National Agricultural Research Institute (INERA) together with other partners (CIAT, PABRA,

FARA and CIALCA) to bolster existing efforts for farmer access to good quality seed and to strengthen this component within the bean value chain of the country. Innovation platforms, which is one of the implementation tools of the Agricultural Innovation Approach, bring together various stakeholders and provide them with a stage to voice their needs. These platforms also provide site-specific solutions to align production with market demands, ensuring better prices for the smallholder producers.

The objective of this study was to strengthen local seed systems in the DRC using innovation platforms (IP) within the bean value chain. This study was conceived on the premise that past relevant initiatives for seed systems in the context of the bean value chain were fragmented, isolated and poorly coordinated and did not produce expected results (USAID, 2010).

Innovation Platform approach. Innovation Platform derives its roots from the innovation systems concept. IP facilitates dialogue between key parties and local players in a value chain; namely farmers and farmer organisations, input dealers, traders, transporters, processors, regulators, and the research and development actors. Innovation Platforms identify constraints and opportunities in production, marketing and the policy environment. The process is galvanised through discussions on important requirements in production, processing and marketing; followed by an analysis of existing strategies. The IP then identifies and implements technologies, innovations and management practices to improve production to fulfil market demand. In a parallel and similar process, the marketing system is analysed and improvements to benefit all role players are tabled and tested within the local context (Edelman, 2003).

The IP presents a dynamic entity with a growing membership that attracts appropriate expertise contingent to the problem being addressed. The central and key partners, often comprise of those with the highest stake. These include seed producers, buyers and users. The IP provides understanding on technology, innovations, management practices and information challenges in seed production and marketing in terms of articulating demands. By bringing together the various stakeholders and providing them with a platform to voice their needs/requirements, the IP generates site-specific solutions to align seed production with users requirements, which will ensure better environments for smallholder seed producers (Hawkins *et al*., 2009).

METHODOLOGY

Study location. The Kivu region is located only two degrees south of the equator. It has three distinctive ecological zones; the central basin, western highlands and the eastern plateau, ranging from 500 to 3, 000 metres above sea level. It has good quality soil for agriculture, supporting a wide variety of food production and industrial activities. The region has two rainy seasons (February–May and September–December) with an annual average rainfall of 1,400 mm, ranging from 1,200 mm in the south-eastern to 2,200 mm in the wet equatorial area. It experiences either mild or tropical climate.

Kivu region has a total surface are of 124,553 km^2 (with North Kivu having 59,483 km^2 and South Kivu 65,070 km^2). Based on DSRP (2000), the region is estimated to have a population of 10,382,713 (with North Kivu having 5,767,945 and density of 71 persons km^{-2} and South Kivu 4,614,768 and density of 97 persons km^{-2}).

The study applied the integrated agriculture research for development (IAR4D) approach, adopted from the Forum for Agricultural Research in Africa (FARA). This approach brings together stakeholders as actors in innovation platforms (FARA, 2011). The study was conducted from 2009 to 2012. A total of 74 participants were randomly selected from Mudaka and Katana in South-Kivu and Rugari and Kinyandonyi in North Kivu. Selection of the locations and participants was based on; the significance of bean production in the area; and being located within INERA Mulungu Research Centre's jurisdiction.

Setting up Innovation Platforms. Setting up of IPs was facilitated by INERA researchers based on FARA IAR4D model (Hawkins *et al.,* 2009). Prior to setting up the IPs, a series of surveys

(Baseline survey and specific survey) and meetings were conducted using focus group discussions and key informant interviews with farmers (both men and women) in the study areas. The surveys were conducted strategically to analyse opportunities and challenges in agricultural productivity in the location, identify commodities, policies, product development and their market chains and to profile the key actors along the value chain in each site. A number of influential farmer groups and traders (men and women), officials, extension agents and NGOs were identified to participate in the inception meeting. During the meeting, 15 participants representing famers, farmers' cooperatives, extension service providers, savings and credit cooperatives, researchers and input dealers and traders) were selected to establish the IP. The actors were selected because they had a stake in the IP based on the identified and quantified output market in relation to the input, advisory services, processing, transportation, agricultural finance and insurance.

The IP process started by selecting a product to be developed as an enterprise, and bean seed was preferred because of its capacity to develop commercially. Training was conducted to develop capacity and understanding of the members of IP process. A market opportunity identification exercise was performed to assess various products viability in terms of agronomic practices, economic and market potential. IP members then developed a work plan with roles of each member on what to do, when and where to meet.

The IPs' meeting intervals depended on issues at hand, usually IP members met at the beginning of the season to plan; then two months later for process monitoring and at the end of the season for evaluation. However, some meetings were held occasionally whenever need arose.

In the IPs, a number of activities were conducted to improve bean productivity and seed production, including training on integrated crop management (ICM), integrated soil fertility management (ISFM) and integrated pest management (IPM) options, use of improved varieties, training on seed and grain differentiation, monoculture and growing of pure and preferred varieties. Improving seed marketing activities such as certification of seed to ensure its quality was done by national seed service. Produced seed was gathered and sold in a group not on individual basis; a marketing committee was formed to promote the product marketing. Members of the IPs from NGOs were responsible to connect farmers to potential buyers, some of which were NGOs themselves and training on business plan, and others marketing strategies among the IP members.

Policy issues were very important, thus the IP process was responsible for improving the policy environment. This was done through involving public officials such as IP members who eventually became advisors. At the same time, other officials' requirements such as acknowledgements were given to IPs.

During implementation of activities in the IPs, a series of meetings and survey were conducted with the objective of enhancing the understanding of key stakeholders' views and experiences with the IP process. Figure 1 represents the IP schematic process.

INERA supplied the initial high quality seed of four released bean varieties, namely CODMLB001, CODMLB059, NUV 178 and NUA 99 for the initial seed multiplication of the bean varieties. These varieties were selected because of their desirable characteristics and tolerance or resistance to important biotic and abiotic constraints.

Bean nurseries were established in each site. Additional training on IAR4D was conducted in each of the established IPs to strengthen capacity of members in IAR4D. Small seed packs of varying sizes (100, 250 and 500 g) were introduced as a follow up on the work done by CIAT in Malawi (Chirwa and Aggarwal, 2000). Simple polythene bags were used and simple labels printed with the name of the variety, were inserted inside each pack.

The technical extension staff also supervised the day-to-day activities; while seed inspectors from National Seed Control Service (SENASEM), periodically inspected seed production activities in the fields. The seed from research systems was multiplied as quality declared seed (QDS) in the farmers' fields. QDS is an intermediary seed category between formal and informal seed.

RESULTS AND DISCUSSION

The trend of IP attendance. There was a rapid increase in the IP participation because of the positive change within the communities where implementation was taking place. Between 2009 and 2012, the membership had increased from 74 (52 male and 22 female) to 1585 farmers (552 men and 1033 women) (Fig. 2), 20 to 45 private sector marketers, 5 to 7 Researchers, 6 to 8 Extension agents and 3 to 4 NGOs. In Kanyandonyi, women's participation in IP meetings and activities was less than 50% in 2009 and improved to 87% in 2012. This increase in women farmers' participation was attributed to increased efforts to mobilise, train and sensitise women for involvement in business and trade as a result of establishing the IPs in this post conflict area.

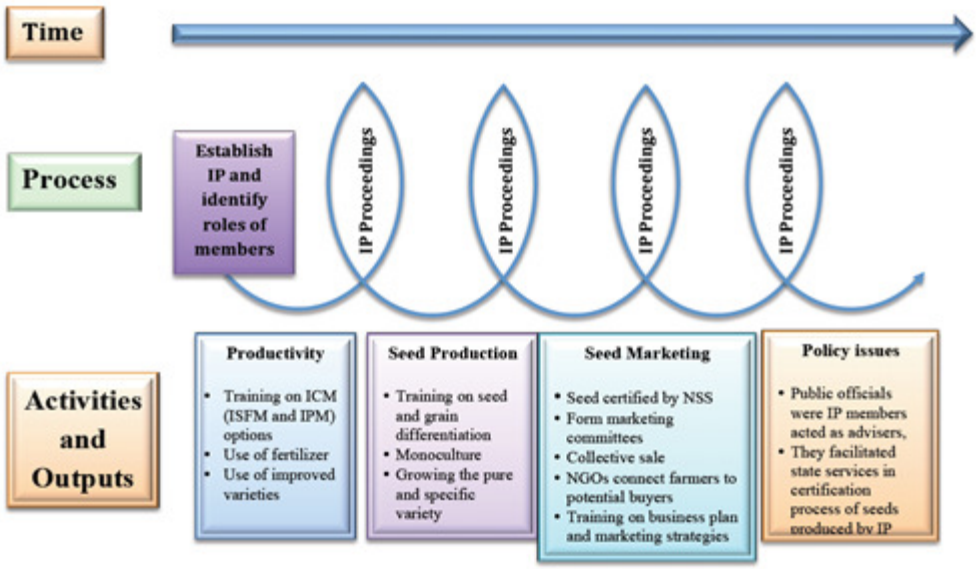

Figure 1. Schematic presentation of the interaction, process and activities in the bean seed value chain Innovation Platform of the Democratic Republic of Congo.

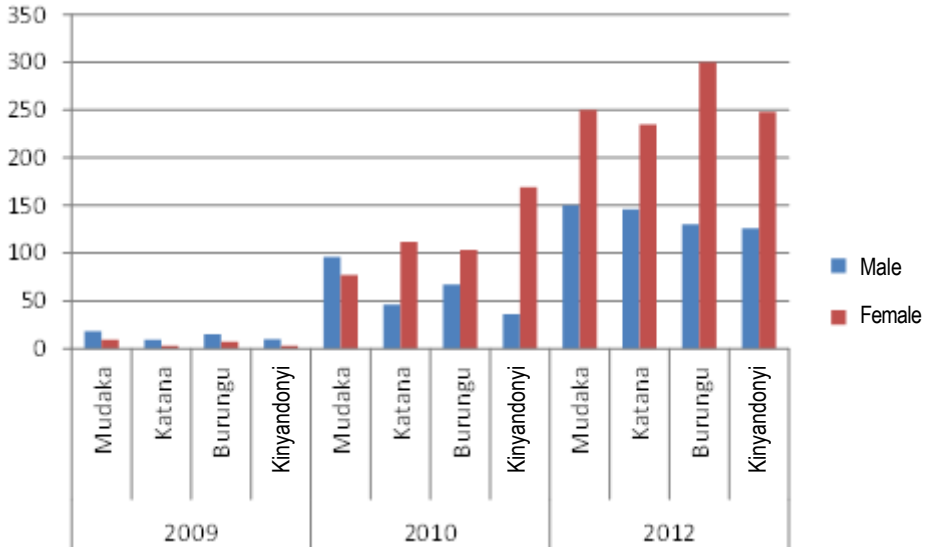

Figure 2. Male and female participation trend in bean seed value chain IP in the Kivu region of the DRC.

Local seed system. The study revealed that most smallholder farmers in the Kivu region were resource poor and had not been able to benefit from formal seed systems, likely due to high cost of production. The farmers got seed from informal seed systems, whereby they selected from their previous crop harvest good grains as seed and preserved them for the next season. This system is known as farmers-own-saved seed system (CIAT, 2000). Seed in this system is often of very poor quality and sometimes contaminated with diseases. Furthermore, several bean varieties are mixed up in the seed lot. On the other hand, where some farmers did not have enough harvest, they obtained the seed from neighbours through farmer-to-farmer seed exchanges and in some cases from local seed businesses. The local seed systems involve grain production, followed by seed selection where the farmers selected good grains for next season and stored them. The diffusion stage (Fig. 3) is where seeds were distributed for sowing. This stage include seed exchange among the farmers and in some cases local seed business.

With establishment of the IPs in the study sites, the seed systems were improved through supply of improved bean seed and varieties from INERA (Fig. 4). This was further enhanced by tailor-made training on integrated crop management technologies and innovations.

Farmers capacity to produce and trade more bean seeds. Farmers' participation in the bean seed IPs enhanced their potential to multiply and market their seeds. The IPs facilitated a close collaboration between smallholder informal seed

Figure 3. Schematic presentation of typical local bean seed system before establishment of Innovation Platforms in the Democratic Republic of Congo.

Figure 4. Schematic presentation of local bean seed system after establishment of the innovation Platforms in the Democratic Republic of Congo.

multipliers, researchers, NGOs, extension agencies, traders and other institutions involved in bean value chain. The IPs received initial seed of four improved bean varieties released by the INERA namely; CODMLB00,CODMLB059, NUV 178 and NUA 99 for multiplication in the study sites. This was intended to increase productivity and provide a surplus for trade. The IPs also enhanced farmers' capacity to adopt and implement the innovations, which were promoted in the platforms. The IPs helped the farmers to improve the quality of the crop produced by ensuring constant supervision of their seed production processes, by both the technical advisory team and SENASEM staff. A number of trainings were conducted to ensure that the seed produced met the desired market standards.

The IPs ensured that the quality-declared-seed (QDS) was disseminated, with priority given to the IPs members; while the rest was supplied to the NGOs who in turn distributed them to farmers in their areas for further multiplication. The seed produced under this arrangement was of better purity than the one from farmer-own-saved seeds As a result of using the value chain approach; the QDS was sold at a price set at15% higher than normal grain market.

In 2012, NGOs involved in the IPs used this arrangement, to purchase and distribute more than 5 metric tonnes of seeds. Through the IPs, the use of small seed packs of 1.0, 0.25 and 1 kg was introduced. This helped small scale and resource poor farmers to access quality seeds of the improved varieties. Through this, more than 3,000 households accessed quality seeds of the new improved bean varieties. However, bulk seed packages were sold to the NGOs and others partners. Basing on bean seed multiplication ratio of 1:10 by Chirwa and Aggarwal (2000), at least 50 metric tonnes of seed were produced by the farmers' associations, who were part of the IPs.

Most small scale farmers in the region commonly engage in informal markets as consumers, often lacking access to improved markets (Barrett, 2008). Engagement in markets by producers is limited because of poor infrastructure, poor inputs and services, high transaction costs and increased risks along the value chain. For example, the fraction of smallholder farmers selling staple grains in the Kivu region is typically between 25-30% (CIALCA, 2010). With regards to seed requirements, smallholders farmers were not permitted to produce and sell certified seed. However, through the IP process, smallholder farmers were transformed from subsistence to small-scale commercial bean farmers. Table 1 presents the evidence of this, where the IP members were able to sell more than 5 tonnes of improved bean seed.

Achievements of the IP approach. A study conducted by INERA (2012) revealed that the IPs played an important intermediary role in stimulating and influencing innovation processes such as shifting from subsistence to commercial bean production. Smallholder farmers benefited in various ways of synergising with others value chain actors. Their involvement in IPs resulted in increased bean yield from 350 to 820 kg ha^{-1}, seed quality improved and increased price for bean producers.

About 46.0% of the farmers reportedly benefited from the association with various actors in bean value chain. A major component of the benefits included improved knowledge in bean production, especially through provision of training. About17.1% of farmers reportedly

TABLE 1. Bean seed production and distribution by IP in 2012 in the Democratic Republic of Congo

Innovation Platform	Quantity distributed to members (kg)	Quantity produced (kg)	Quantity sold (kg)
Mudaka	120	820	500
Katana	360	1340	850
Burungu	830	2350	1300
Kinyandonyi	760	3620	2500
Total	2070	8130	5150

benefited from accessing improved bean varieties; while 11.1% were able to access social support. Other benefits included; access to seed markets, increased incomes and access to credits from financial institutions participating in the IPs, where the NGOs provided the required guarantee or security and many other benefits (Table 2).

About 56.3% of farmers indicated that they easily accessed marketable improved bean varieties and appropriate production techniques. According to INERA (2012), between 2009 and 2012, the bean seed price per metric tonne increased by 120% and seed purity increased from between 70-75 to 95%. It was also observed that farmers responded positively to this process across major bean growing areas of Kivu region.

The study by HarvestPlus (2012) revealed a continuous increase in access to quality seeds (certified, quality declared seed) of both improved and adapted varieties. This resulted in higher adoption of various improved agronomic practices by farmers namely; seed rate, ploughing, timely weeding and judicious use of fertilisers. About 37% of the farmers in the IPs reportedly increased their areas under bean production. Altogether, across the four sites, the area under bean production increased by 34.3%. This was attributed to increased profitability of beans due to increased incentives along the supply chain, increased access to improved bean production packages, and increased awareness of farmers and other supply chain actors. Also, there was increased production and reliable marketing, because several development organisations like NGOs and private sector increasingly mobilised farmers and invested their resources to facilitate farmers to acquire loans, thus improving farmers' livelihoods and helping them in poverty alleviation.

TABLE 2. Opportunities arising from the bean IP membership in the Kivu region of DRC

Opportunities	Percent (n=120)
Improved knowledge on bean production	46.0
Acquired improved bean varieties	17.1
Social support/sharing labour	11.1
Eased marketing of seed	8.0
Income for other necessities	7.3
Source of food/improved nutrition	3.5
Able to access agricultural inputs/support	3.2
Source of credit (capital, seed, equipment)	2.4
Popularity as bean farmers	1.4

Challenges of the IP approach. The IP as a concept requires time for the value chain actors to understand and implement. At the beginning, different actors had different understanding of how the IP operated and had different interests. In order to understand the IP concept, several awareness meetings with stakeholders are required. This is important to ensure that sustainability of the value chain is achieved. The initial meetings have financial implications and require an outsider to be in charge. However, with time the numbers are expected to grow and the costs become too large to be manageable. There has been limited support and mentoring in agro-business, yet it is crucial if the farmers are to transform their farming into commercial and sustainable seed production system. Also, there has been limited flexible mechanisms of building links and local competences so as not to impose models on IPs, but help them to build trust between smallholders and actors in the value chain by developing their competences as the IP process develops.

LESSONS LEARNED

During the study, a number of lessons learnt on the operationalisation of IP were gathered and documented as follows:

(a) The IP plays an intermediary role in facilitating smallholder farmers' involvement in the poverty reduction and food security programme. Farmers who participated in the programme earned more income than those who did not participate. The beneficiaries increased the chances of paying bills such as school fees and feeding of their children

(b) The process of IP revealed that when small-scale farmers are grouped during marketing, they are in a better bargaining position to deal with processors, traders and exporters, due to increased product volumes and reduced transaction costs compared to when

each farmer works independently. The IPs approach also showed that the costs of coordination can be reduced through collective efforts, which are usually limited for individual producers;

(c) Linking smallholder seed producers to value chain has multiplier effects and spreads the benefits of growth across smallholdings system; their linkages with other value chain actors and facilitating institutions can be enhanced. The establishment of IPs and the provision of loan collateral enables resource poor members to access and secure credit from commercial credit providers, who previously were hesitant to lend to farmers.

(d) Whereas the multi-stakeholders' nature of IP is useful, it can be limiting in the sense that the different intermediary actors tend to focus on what seems to be their areas of interest and in some cases this can undermine the broader vision of the programme. For instance, some NGOs worked on the basis of rescue and emergency programmes which distributes free money and input to farmers; while private and governmental services worked on the basis of research and development (R&D) programmes intended to push farmers to invest money so as to acquire agricultural inputs. Therefore, there is need for well-defined and coordinated methods taking into account various areas of interest of different partners; and

(e) Good coordination of actors along the value chain ensured that producers obtain a fair share of the final value. They received a price slightly higher than common grain bean price. Research and NGO involvement in production, processing, and marketing improves the product quality at reasonable prices although the whole sector is owned and managed by farmers.

Sustainability of the IP process. Supply chains that have champions taking the initiative in brokering new arrangements, overseeing changes and resolving problems tend to be more effective and efficient. However, in this particular intervention, the champion was lacking and to fill the gap, the researchers took the lead in bringing together all participants for consultation and further collaboration. The champion could be a dominant processor, wholesaler or exporter with some degree of market power; but it can also be an NGO, government body or donor project. For sustainability of the IP process, it is necessary to identify a champion who will take risks and invest in new arrangements; private sector firms will usually only do this if there is some commensurate reward for the effort, so this will only occur when there is a business opportunity. The challenge is to create conditions that will encourage such initiative, but without allowing the champion to extract undue charges. However, for markets which are contestable, there may be little competition in a market, but there is a credible threat of competitors entering the market that provides a discipline for current participants. The inclusion of the private sector in seed delivery systems is necessary for sustainability, market development, and competitive pricing and product provision.

ACKNOWLEDGEMENT

The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) facilitated the publication of this paper.

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African Crop Science Journal, Vol. 22, Issue Supplement s4, pp. 1013 - 1025 ISSN 1021-9730/2014 $4.00

LAND USE AND COVER CHANGE IN PASTORAL SYSTEMS OF UGANDA: IMPLICATIONS ON LIVESTOCK MANAGEMENT UNDER DROUGHT INDUCED PASTURE

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ABSTRACT

The rangelands of Uganda used to be historically managed under traditional systems where grazers had open access with mobility as a main coping strategy to drought. Changes in land ownership, increased population and demand for food and fuel have led to changes in land use and cover types, affecting livestock management practices. This study assessed the extent of land use and cover change in Buliisa and Nakasongola Districts in the cattle corridor of Uganda over 27 years (1986 –2013), and their impacts on livestock management under drought induced pasture. Landsat TM (1986) and Landsat ETM+ (2000 and 2013) images were processed using a hybrid of supervised and unsupervised classification algorithm, using ENV1 software 4.7. Area under open water and grassland declined by 3.5 and 48.3%, while woodland, wetland, small scale farming and forest increased by 0.2, 62.2, 320.7 and 64.1%, respectively, in Buliisa. In Nakasongola, grassland, bushland and forest decreased by 96.1, 25.6 and 17.2%, respectively; while open water, bare ground, wetland, and small scale farming increased by 5.3, 210.9, 2.7 and 26.8%, respectively, between 1986 and 2013. Individualisation of land in Nakasongola led to settlement of cultivators and fencing of land leading to blockage of livestock migration routes. Reduced mobility of livestock during drought, increased stock densities resulting in land degradation exemplified by bare land in Nakasongola compared to Buliisa, where communal land ownership and limited cultivation enabled mobility. The current land use and cover changes have delineated mobility as a coping strategy to drought, contributed to degradation of rangelands, reduced the resilience of pastoral systems to drought and increased their vulnerability to climate change. Farm based water and forage conservation should be enhanced to sustain livestock production.

Key Words: Cattle corridor, coping strategy, forage, migration

RÉSUMÉ

Les pâturages de l' Ouganda étaient historiquement gérés sous système traditionnel où les éleveurs avaient un accès facile avec libre mouvement comme stratégie d'adaptation aux conditions de sécheresse. Les changements dans les systèmes de propriéte foncière , l'augmentation de la population et la demande accrue de la nourriture et produits de chauffe ont induit des changements dans l'utilisation des terres et types de couvert, affectant ainsi les pratiques de gestion de l'élevage. Cette étude a évalué l'ampleur du changement dans l'utilisation des terres et couvert végétal dans les districts de Buliisa et Nakasongola dans le corridor du bétail en Ouganda depuis 27 ans (1986 –2013), et leurs impacts sur la gestion de l'élevage en conditions de sécheresse. Les images Landsat TM (1986) et ETM+ (2000 et 2013) étaient exploitées par utilisation d'un mélange d'algorithme de classification supervisée ou non supervisée utilisant le logiciel 4.7 ENV1. Les surfaces d'eau et les pâturages ont diminué de 3.5 et 48.3%, pendant que les zonesz boisées , les marrais, les surfaces cultivées et les forets ont augmenté de 0.2, 62.2, 320.7 et 64.1%, respectivement, dans Buliisa. Dans la région de Nakasongola, les pâturages, les terres surbrulis et les forets ont diminué de 96.1, 25.6 et 17.2% respectivement; pendant que les surfaces d'eau, les

surfaces dénudées , les marrais et les surfaces cultivées ont augmenté de 5.3, 210.9, 2.7 et 26.8%, respectivement, entre 1986 et 2013. La privatisation des terres à Nakasongola a conduit à l'occupation des terres par les cultivateurs, restreignant ainsi les mouvement migratoire du bétail. Cette réduction de la mobilité du bétail durant la saison sèche a entrainé une augmentation de leur densité entrainant une dégradation avec dénudation des terres en comparaison avec Buliisa, où l'utilisation des terres communales et l'activité agricole limitée ont facilité la mobilité. L'utilisation actuelle des terres et les changements du couvert végétal ont renforcé la mobilité du bétail comme stratégie d'adaptation à la sécheresse, contribué à la dégradation des pâturages, réduit la résilience des systèmes pastoraux à la sécheresse et augmenté leur vulnérabilité au changement climatique. La conservation du fourrage et de l'eau au niveau des exploitations devrait être renforcée pour permettre un élevage durable.

Mots Clés: Corridor du bétail, stratégie d'adaptation, fourrage, migration

INTRODUCTION

Pastoral and agro-pastoral production systems are home to majority of ruminant livestock and supply more than 85% of milk and 95% of beef consumed in Uganda (King and Allan, 2002). Climatic variability is an intrinsic feature in pastoral areas with both seasonal and inter-annual variations in water and pasture availability. Historically, the rangelands of Uganda were managed under traditional systems, where grazers had open access to resources (Kisamba-Mugerwa, 1995) and largely depended on mobility to search for pasture and water. However, changes in land ownership, land uses and increased human population have compromised pastoral mobility as a coping strategy to drought induced water and pasture scarcity (Kisamba-Mugerwa, 1995). These changes have increased conflicts over resource use among different livelihood groups. Pasture scarcity, reduced water and resource degradation are on the increase due to deforestation, inappropriate land use practices and exceeding livestock carrying capacities. The rangelands are degraded with visibly compacted soils, open gullies, bare patches of soil, termite damage and woody encroachment affecting livestock production and threatening food security and livelihoods of rangeland communities (Mugerwa *et al*., 2008; Zziwa *et al*., 2008).

Protection of pastoral and agro-pastoral grazing resources from degradation is a priority for sustainable livestock production and improved livelihood of pastoral communities. The objective of this study was to critically identify and map existing rangeland resources to guide the development of appropriate strategies and innovations for managing livestock especially during drought in the typical rangelands of Uganda.

MATERIALS AND METHODS

The study areas. This study was conducted in the rangelands of two districts, namely Buliisa and Nakasongola in Uganda. The two districts were identified and selected as study sites in a bigger regional project "Up-scaling feed packaging and feed conservation innovations to increase feeds availability and mitigate effects of drought crises in pastoral systems of ECA (ASARECA_RC12_LFP-01)".

Buliisa District. Buliisa District covers an area of 3,200 Km^2 and is located between latitude 1º 232 and 2º 212 N and longitude 31º 242 and 33º 242 E. Crop farming, livestock production and fishing are the main economic activities. Rainfall is bi-modal, occurring in March to May and August to November and ranging between 700 and 1,000 mm annually, with seasonal variations and prolonged droughts. The soils are ferralitic, ferrisol and hydromorphic (Harrop, 1960) and are yellowish-red clay loams. The vegetation is classified into forest, savannah, grassland and swamp. Forest vegetation includes Budongo high tropical forest; while savannah vegetation consists of perennial grasses, scattered trees and shrubs. The dry savannah lies contiguous to Lake Albert, turning into wet savannah grassland up to the escarpment. Swamp vegetation fills most of the water logged valleys (Langdale-Brown *et al.*, 1964).

Nakasongola District. Nakasongola District covers an area of 4,909 Km^2 located between latitudes 0º 57' 44.89" and 1º 40' 42.76" North and

between longitudes 31° 58' 03.77" and 32° 48' 00.29" E. The rainfall is about 1000 mm annually and bi-modal, falling between March and May and between August and November. Seasonal variations and prolonged droughts are common. The dominant vegetation is dry savanna dominated by *Hyparrhenia filipendula* and *Loudentia arundinacea* grasses and scattered fire-tolerant *Combretum terminalis* and *Acacia brevispica* trees (Radwanski, 1960; Langdale-Brown *et al*., 1964). Extensive bare ground and termite activity cause low organic matter in the topsoil. The soils classified under the Buruli catena (Radwanski, 1960) have inferior nutrient status with clay content of 12% in the upper layer, low organic carbon (1%), pH of below 5 and are deficient in phosphorus and exchangeable bases.

Developing a catalogue of resources. Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were conducted to identify the existing natural resources, migratory patterns, livestock markets, perceptions and ideas on land use changes and causes. KIIs were conducted with officers in charge of key departments in local governments at District level. Key issues discussed were livestock production practices, challenges and opportunities, availability and accessibility to production resources such as pastures, water, health and markets, seasons of scarcity and the available coping and adaptation mechanisms. A list of geo-referenced resources was generated. FGD's were conducted in two sub-counties with high cattle populations and severe water and forage scarcity to elicit the coping strategies practiced by farmers, indigenous knowledge in livestock management and health, pasture and water management. FGDs of 8-12 persons were conducted in Nabiswera and Nakitoma Sub-counties of Nakasongola and Buliisa Town Council and Butiaba Sub-counties in Buliisa.

Resource mapping. Three sets of Ortho-rectified, cloud free multi-temporal Landsat TM/ETM+ images (30 m) for 1986, 2000 and 2013 were downloaded. The path and row were 172r58 and 172r59 for Nakasongola and 172r59 for Buliisa. The downloaded images were for the dry season months of the year. The multi-date images were subjected to atmospheric correction (Lu and Weng, 2007). The images were processed using a hybrid of supervised and unsupervised classification algorithm. An ISODATA clustering algorithm was adopted to merge spectral classes into meaningful classes; while the per pixel classification method was used to combine the spectra of all training set of pixels from a given feature of the images and classified using a maximum likelihood procedure using ENV1 Software Version 4.7. The Uganda Bureau of Statistics generated land use/cover map for 1986 and the land cover stratification maps from the National Biomass Study of 2003 were used as reference in the classification of the acquired images. The National Biomass Study (2003) classification scheme was adopted in the description of classified classes. Ground truthing and post-classification was carried out for the production of final land use/cover maps.

RESULTS

Land use and land cover types and changes. The extent of land use, land cover and their relative changes over a period of 27 years (1986 - 2013) for Buliisa and Nakasongola are presented in Tables 1 and 2, and Figures 1a-c and 2a-c. The land use types identified included grasslands, water bodies, forests, woodlands, bushes, wetlands, bare ground, livestock and livestock markets. Land use/cover changes for specific districts are presented in the following sections.

Land use/cover changes in Buliisa District. Land use/cover types in Buliisa for 1986, 2000 and 2013 are presented in Table 1 and Figure 1(a, b and c). In 1986, open water represented the highest land cover in the district, followed by grasslands; while small scale farming was the least covering only 2.2% of the area. Other land cover types were woodland, tropical forest and wetland. Buliisa District comprises of part of Lake Albert, which is associated with several small rivers and swamps, hence, the high water cover. The rivers include Sambiye, Waisoke, Bubwe and Sonso; and Kisiabi wetland (Fig. 3). Murchison Falls National Park and Bugungu game reserve contribute to grassland and woodland cover. In 2000, open water was still the most prevalent land

TABLE 1. Land use and land cover for Buliisa District in 1986, 2000 and 2013 in the rangelands of Uganda

Land use/ cover types	1986		2000		2013		Percent change in land use/cover		
	Area (km^2)	Percent Cover	Area (km^2)	Percent Cover	Area (km^2)	Percent Cover	1986 – 2000	2000 - 2013	1986- 2013
Open water	905.4	45.2	898.4	44.33	874.1	43.1	-0.77	-2.71	-3.5
Woodland	357.5	17.9	21.2	1.05	358.3	17.7	-94.1	1590.1	0.2
Grassland	475.1	23.7	698.3	34.46	245.7	12.1	47.0	-64.8	-48.3
Wetland	68.2	3.4	79.7	3.93	110.6	5.5	16.9	38.8	62.2
Small scale farming	44.9	2.2	213	10.51	188.9	9.3	374.4	-11.3	320.7
Tropical forest	151.9	7.6	116	5.72	249.2	12.3	-23.6	114.8	64.1

TABLE 2. Land use and land cover for Nakasongola District in 1986, 2000 and 2013 in the rangelands of Uganda

Land use/ cover types	1986		2000		2013		Percent change in land use/cover		
	Area (km^2)	Percent Cover	Area (km^2)	Percent Cover	Area (km^2)	Percent Cover	1986 – 2000	2000 - 2013	1986- 2013
Open water	247.6	7.1	263.1	7.5	260.8	7.4	6.3	-0.87	5.3
Bare ground	409.7	11.7	407.2	11.6	1273.7	36.2	-0.61	212.8	210.9
Grasslands	790.5	22.5	915.6	26.1	31.3	0.9	15.8	-96.6	-96.1
Bushland	1128.4	32.2	1123.1	32	839.7	23.9	-0.47	-25.2	-25.6
Wetland	285.6	8.1	248.2	7.1	293.4	8.3	-13.1	18.2	2.7
Small scale farming	635.1	18.1	542.5	15.5	805.3	22.9	-14.6	48.4	26.8
Forest	12.2	0.3	9	0.3	10.1	0.3	-26.2	12.2	-17.2

covers type; followed by grassland. However, small scale farming increased almost 5 times that of 1986 from 2.2% to 10.51%. Tropical forests and woodland as covers substantially reduced over the same period. In 2013, there was increase in woodland and tropical forest cover; while grassland cover reduced from 34.46 to only 12.1%. There were no major changes in open water, small scale farming and wetland.

The period 1986 to 2000 led to reduced open water, woodland and tropical forest by 0.77, 94.1 and 23.6% , respectively; while grasslands, wetland and small scale farming increased by 47, 16.9 and 374.4%, respectively. Between 2000 and 2013, the area under open water, grassland and small scale farming declined by 2.71, 64.8 and 11.3%, respectively; while woodland, wetland and tropical forest increased by 1590.1, 38.8 and 114.8%, respectively. Overall, between 1986 and 2013, there was a decline in open water and grassland of 3.5 and 48.3%, respectively; and increases in woodland, wetland, small scale farming and tropical forest of 0.2, 62.2, 320.7 and 64.1%, respectively.

Livestock types, numbers, and productivity in Buliisa District are given in Table 3. The number of households owning livestock (cattle and goats) and the total number of livestock were higher in Nakasongola than in Buliisa, although mean herd sizes per household were higher in Buliisa. Both districts kept mostly indigenous livestock. Although the number of cows milked was higher in Nakasongola, milk yield per cow did not differ significantly between the two districts.

Land use and land cover changes in Nakasongola District. Land use/cover types for Nakasongola

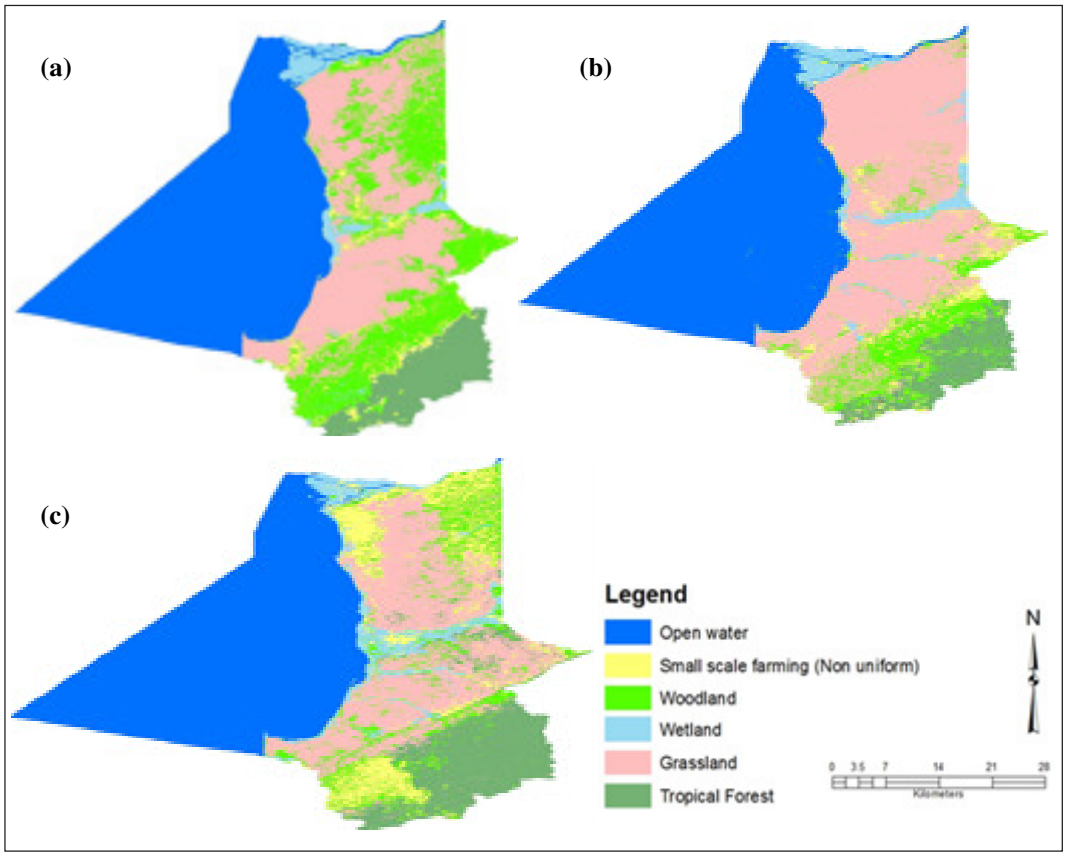

Figure 1 (a). Land use/cover map for Buliisa (1986), (b) Land use/cover map for Buliisa (2000, (c) Land use cover map for Buliisa (2013) in Uganda.

are presented in Table 2 and Figure 2 (a, b and c). In 1986, bushland was the highest land cover type, followed by grassland and small scale farming. The high prevalence of bare ground was also evident in Nakasongola. There was relatively less open water coverage compared with Buliisa District. In 2000, little difference was observed in land use in the district from that of 1986. In 2013, however, the bare ground (36.2%) dominated all the other land cover types, followed by bushland and small scale farming; but a significant decline in grassland was observed.

Between 1986 and 2000, bareground, bushland, wetland, small scale farming and forest declined by 0.61, 0.47, 13.1, 14.6 and 26.2%, respectively; while open water and grasslands increased by 6.3 and 15.8%, respectively. Between 2000 and 2013, open water, grassland, bushland decreased by 0.87, 96.6 and 25.2%; while bare ground, wetland, small scale farming and forests increased by 212.8, 18.2, 48.4 and 12.2%, respectively. Generally, there was a decline in grassland, bushland and forest by 96.1, 25.6 and 17.2%, respectively between 1986 and 2013; while open water, bare ground, wetland, and small scale farming increased by 5.3, 210.9, 2.7 and 26.8%, respectively. The water bodies in Nakasongola (Fig. 4) include Lake Kyoga; and Rivers Nile, Kafu, Lugogo, Mukote, Namwanga and Ndala. Livestock types, numbers, and productivity in Nakasongola District are represented in Table 3.

Water resources, livestock migration and cattle markets. Tables 4 and 5 show additional water sources in Buliisa and Nakasongola Districts. Nakasongola had more valley tanks and dams than Buliisa District. Also, Nakasongola had six

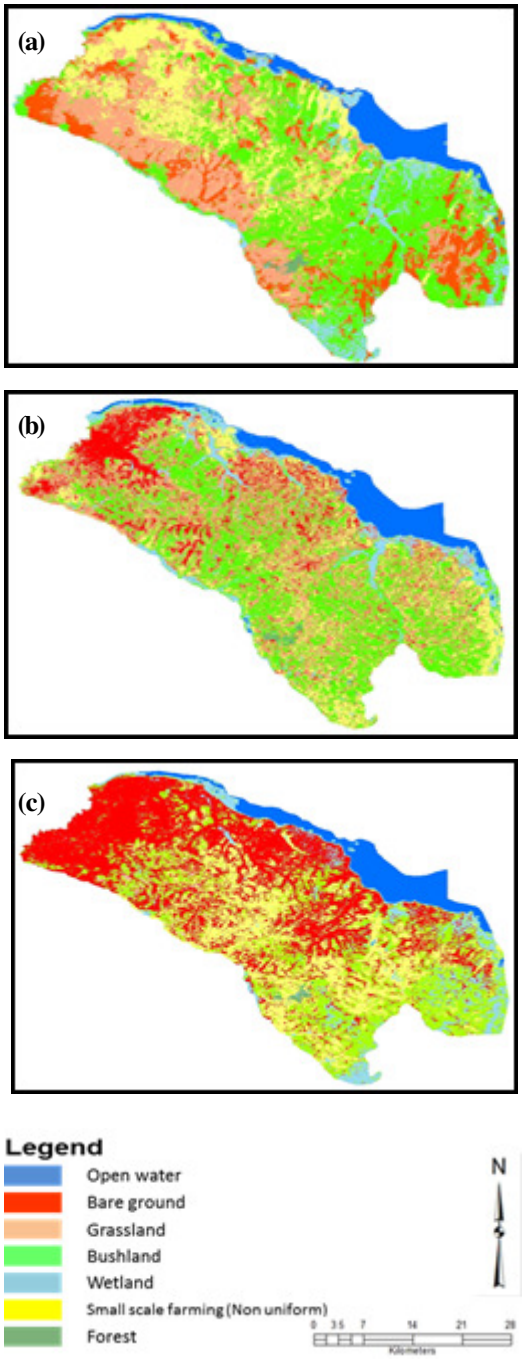

Figure 2 (a). Land use/cover map for Nakasongola (1986), (b) Land use/cover map for Nakasongola (2000), (c) Land use/cover map for Nakasongola (2013) in Uganda.

livestock markets while Buliisa had two. Buliisa had many operational livestock migration routes (Figs. 3 and 4), yet Nakasongola's were blocked and migration had virtually ceased. Contagious livestock diseases (Foot and Mouth Disease (FMD), Contagious Bovine Pleura Pneumonia (CBPP) and Brucellosis) were more prevalent in Buliisa than in Nakasongola, especially in areas where livestock converged during migration.

In Buliisa, migration targeted rivers and Lake Albert, and sometimes towards the Park. In December to February and June to August dry seasons, herders followed normal migration in search of water and pasture. During drought, migrations followed water points (streams, rivers up to Lake Albert). Buliisa experienced more frequent prolonged droughts estimated at 3-4 years interval. Encroachment on restricted wild life conservation areas sometimes occurred resulting in conflicts. Movement during droughts sometimes caused conflicts between herders and cultivators.

In Nakasongola, migration only took place during prolonged droughts. Prolonged droughts had reduced to every 3-4 years as in Buliisa, from the original 8-12 years before 2000. Due to increased on-farm water resources, individual land ownership characterised by fencing and cultivation, there was limited migration in Nakasongola, occurring only in degraded areas with pasture scarcity.

DISCUSSION

Both temporal and spatial changes in land use/cover in the two districts were observed with spatial changes including expansion of cultivated lands into natural vegetation types (grasslands, bushland, wetland and forests), expansion of grasslands into bushland and woodlands, bush and woodlands encroachment in grasslands and increased bare ground (Figs. 1 and 2). Temporal changes included the regeneration of woodlands after clearance for wood and charcoal production and, thereafter, cultivation of the land. Bare ground prominently occurred in Nakasongola and

TABLE 3. Cattle and goat production status in Buliisa (B) and Nakasongola (N) Districts in the rangelands of Uganda

Livestock production parameter	Cattle		Goat	
	B	N	B	N
Number of household owning livestock	1,120	13,400	5,760	13,880
Percentage of livestock owning households in District	7.8	46.7	40	48.4
Total number of animals in district	34,800	222,190	43,326	87,823
Mean herd size per HH	31	16.6	7.5	6.3
Percentage of indigenous cattle in district	99.5	99.8	100	99.5
Percentage of Ankole breed in indigenous herd	28	45.6	-	-
Percentage of zebu and Nganda breed in herd	72	54.4	-	-
Percent of Mubende goat in herd	-	-	42.3	27.5
Percent of small East African goat in herd	-	-	56.6	72.4
Percent of Kigezi breed in herd	-	-	1.1	0.1
Number of cows milked	3,720	35,170	-	-
Average daily milk/cow (litres)	0.39	0.54	-	-
Percentage of milk sold	46	20.4	-	-

TABLE 4. Water reservoirs and livestock markets in Nakasongola District (2013) in the rangelands of Uganda

Sub-county	Communal valley tanks	Private valley tanks and ponds	Communal valley dams	Livestock markets
Nabiswera	10	94	3	2
Nakitoma	6	67	0	1
Kakooge	16	33	0	0
Wabinyonyi	13	43	0	1
Town council	2	4	1	1
Kalungi	5	20	0	0
Kalongo	9	47	0	1
Lwampanga	3	6	0	0
Lwabyat	5	27	0	0
Total	69	337	4	6

TABLE 5. Water reservoirs and livestock markets in Buliisa District (2013) in the rangelands of Uganda

Sub-county	Communal valley tanks	Private valley tanks and ponds	Communal valley dams	Livestock markets
Town council	0	3	0	1
Buliisa	2	7	0	0
Biiso	1	3	0	0
Ngwedo	1	4	0	0
Kigwera	2	4	1	1
Butiaba	1	2	0	0
Kihungya	1	4	0	0
Total	8	27	0	2

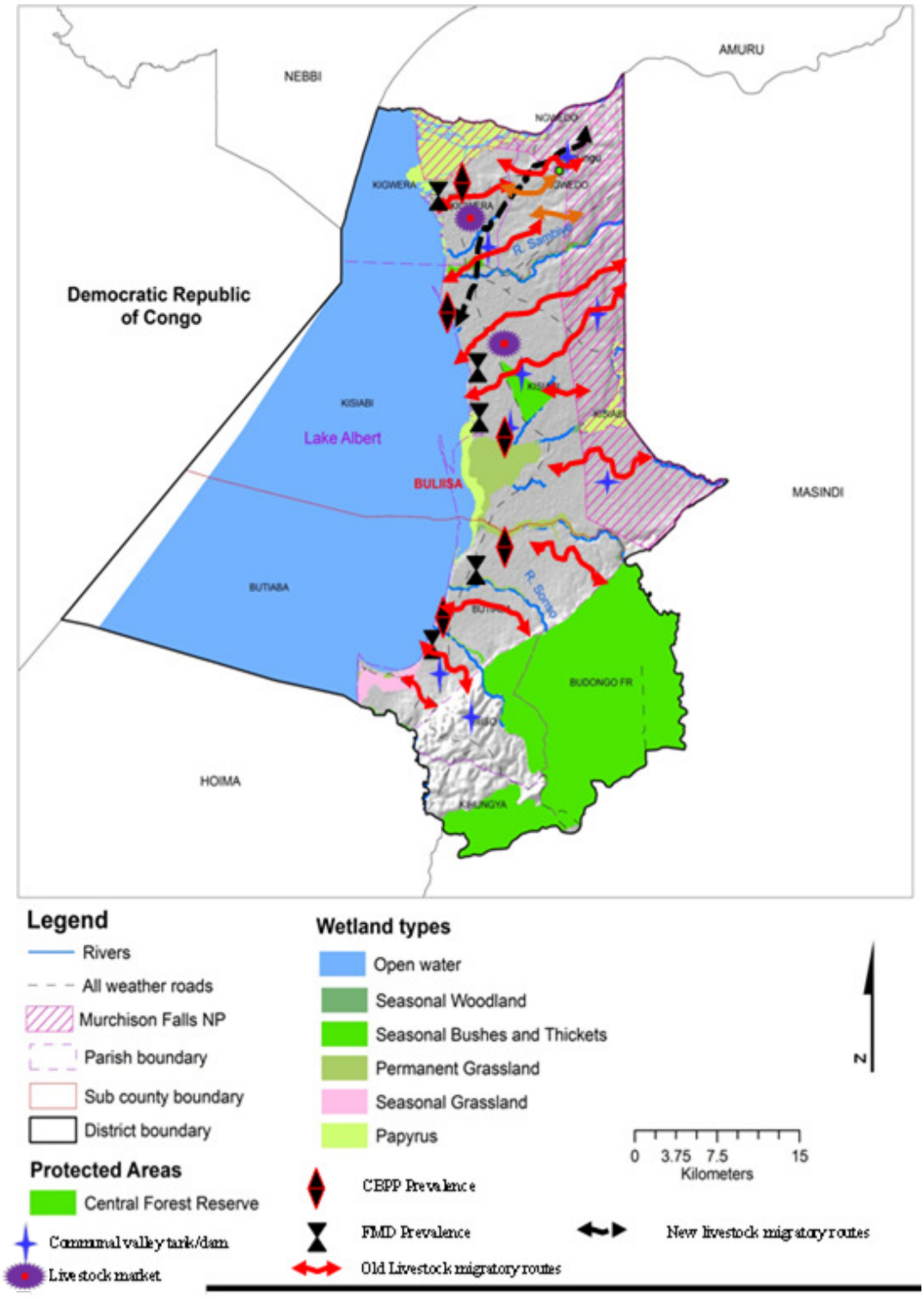

Figure 3. Livestock migration routes, markets and water resources in Buliisa District in Uganda.

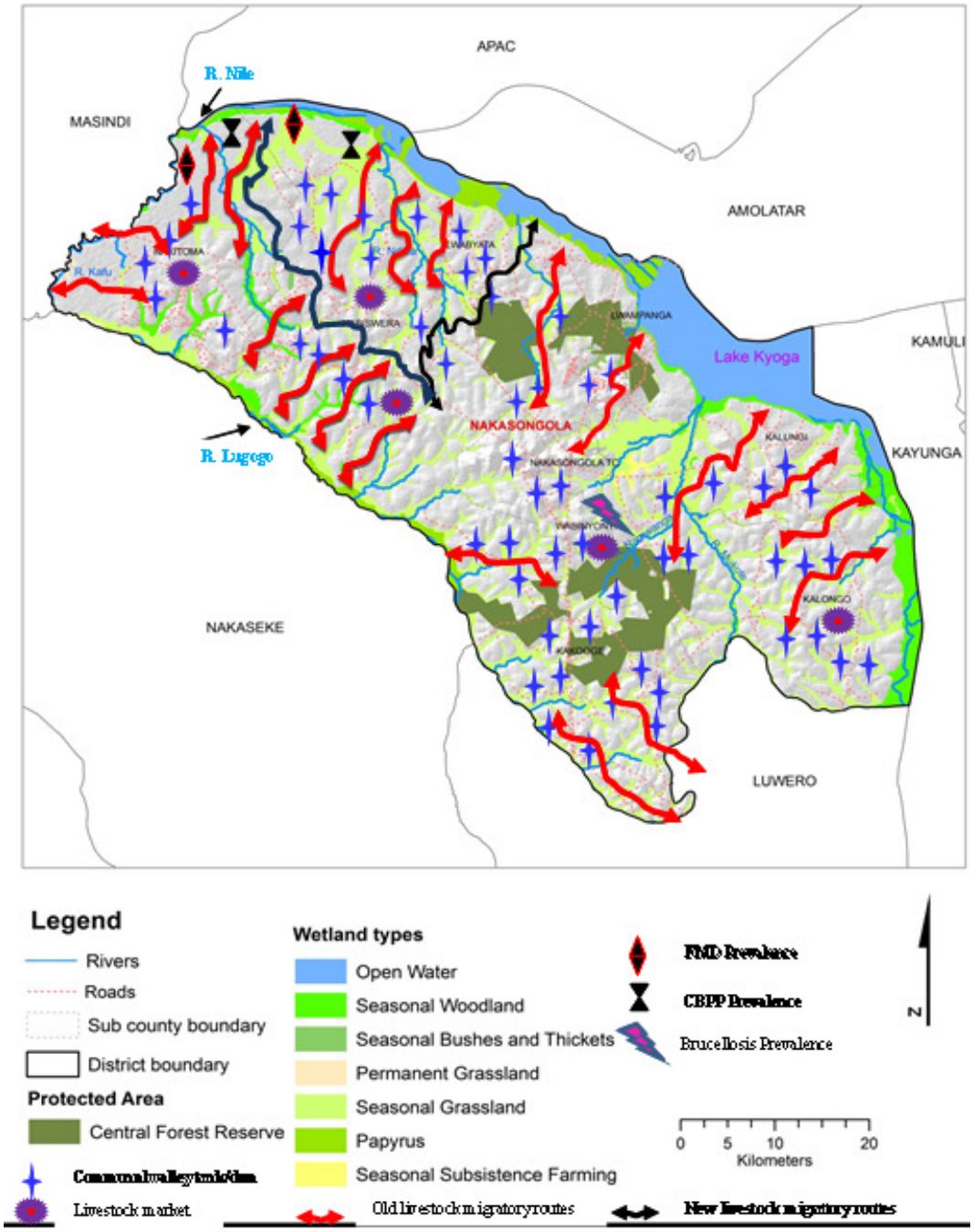

Figure 4. Migration routes, markets and water resources in Nakasongola District in Uganda.

was observed to increase at high rates. The role of human activities in the quest for food production, economic and social gains has been responsible for the observed spatial changes. Some of the changes observed are derived from non-supportive policies that encouraged investments and land use transformations that interfered with ecological and social dynamics of pastoralism. Multiple-uses of rangelands, droughts and climate change have interfered with the coping mechanisms of pastoral communities to changes (Galvin *et al*., 2004; Sidahmed, 2008).

Changes in bare ground and bushland. Human settlements contributed to changes in bare ground between 1986 and 2000 in Nakasongola District (Fig. 2). Information gathered indicates that the stable political environment after 1986 led to movement of people into Nakasongola. These were returnees who had left the area due to civil war as well as new persons seeking new opportunities in the district. The sub-division and re-distribution of ranches in 1994 led to overstocking in several places, hence, limiting regeneration of pastures. Degradation will occur when natural forage productivity is reduced severely by soil erosion due to overgrazing (Jarvis, 1984). Termite activity and charcoal burning exacerbated land degradation; creating bare patches between 2000 and 2013. There was evidence of intensified termite damage and charcoal burning around 1996 and 1998 leading to creation of large patches of bare land, with undesirable consequences to the livestock industry (Mugerwa *et al*., 2008).

Increased human population, demand for food and increased cultivation in Nakasongola were partly responsible for the decline in the area covered by bushland. Generally, bush is a transitional succession stage to woodlands. Reduced livestock populations during and after instability, before and after 1986, resulted in reduced grazing pressure on the land leading to increased infestation by bushes. With the ensurance of political stability, there was increased settlement, bush clearing for cultivation, settlement and grazing, leading to the decline in area covered by bush between 2000 and 2013.

The decrease in forest cover between 1986 and 2000 in Buliisa District may be attributed to clearing land for sugar cane for the nearby factory, tobacco growing, subsistence farming due to population growth and settlements (Mwavu and Witkowski, 2008). Improved management of Budongo Forest through afforestation, gazetting and monitoring eventually contributed to increases in forest cover.

Changes in grassland and woodland. The decline in area covered by grasslands in Buliisa and Nakasongola deprived livestock of a basic grazing resource. The decline was attributed to increasing cultivation, bush and woody encroachment. In Nakasongola, the increase in bare areas contributed to declining grasslands. Increased conversion of grasslands into crop farming was driven by the increasing human population and demand for food, especially by immigrants from high potential areas who carried with them their former land use practices. Expansion of cropping systems and increase in domestic grazing put unnatural stress on native grassland species, pushing grazing pressure up on remaining rangelands (Brown and Archer, 1999). Overgrazing, climate change and increased carbon dioxide emission are partly responsible for increases in woody species in grass dominated savannas (Archer *et al*., 1995; van Auken, 2000; Asner *et al*., 2004; Zziwa *et al*., 2012), a possible cause of increased woodland between 2000 and 2013.

Anthropogenic activities that included tree cutting, establishment of plantation forestry, grassland and charcoal production were major drivers of changes in woodland and forest (Mwavu and Witkowski, 2008). Increased woodlands affected cattle grazing through reduction of grazable pasture and in extreme cases limiting cattle movement during grazing. The encroachment on woody species in grassland ecosystem is a complex process attributed to ecological events, including changes in management practices, climate and atmospheric composition (Archer *et al*., 1995; van Auken, 2000; Asner *et al*., 2004), acting singly or in combination with other factors such as overgrazing, suppression of fires, increased

termite activity, episodic rainfall and drought events, grazing and browsing pressures.

Increase in small scale farming. There is a strong relationship between human activity and the intensity of livestock production. The increase in small scale farming in both districts resulted in reduced area available to livestock grazing. Increased human population, especially with immigrants from a cultivation background, individualisation of land attracting fencing and cultivation, sedentarisation of pastoralists and their need to diversify the income base all contributed to increased small scale farming. In Nakasongola, the sub-division of ranches into small farms/patches unviable for livestock grazing, contributed to the adoption of crop production as the most appropriate land use for the small land holdings. However, because of the limited potential of soils in this area to support crop growth and the practice of low input agriculture, farmers often opened up new areas in search of fertility, in the process encroaching on woodland, bushland, grassland and wetland.

Livestock migration and changes in water resources. Both Buliisa and Nakasongola districts are water deficient just as in other rangelands of Uganda. Generally, water is a major constraint in livestock production in pastoral systems in Uganda's cattle corridor. Livestock movement is driven by pasture and water scarcity, with the latter having a strong bearing in migration than pasture scarcity (Zziwa *et al.*, 2008). Increased water harvesting capacity in Nakasongola reduced the need for seasonal migration, compared to Buliisa where few livestock water resources existed. Communal land ownership and free movement in Buliisa was a disincentive to private ownership of water sources, hence, the dependence on the few communal water resources, rivers and lakes.

Episodic changes in the area covered by water and wetlands were attributed to low rainfall received, droughts and encroachment of wetlands by cultivators. Increased rainfall amounts result in increased wetlands due to inundation of nearby areas. Conversely, long dry spells result in a reduction of area under water and wetland coverage.

Disappearance of livestock migration routes in Nakasongola was due to the individualisation of land, subdivision of ranches and fencing of land, increased cultivation and blockage of livestock migration routes that encouraged construction of private water sources (Tables 4 and 5). New but long routes were being created in areas prone to degradation and droughts (Nabiswera and Nakitoma sub-counties), where migration was still practiced. Mobility has been the cornerstone of dryland livestock cattle keeping (Peters, 1994).

In Buliisa, most livestock migration routes still existed with new but longer routes observed in Ngwedo and Kigwera sub-counties where crop cultivation was practiced. Land was communally owned with free movement of animals in search of water and pastures. In cultivated areas, conflicts were common between crop and livestock farmers during migration.

Changes in livestock markets and prevalence of livestock diseases. The high number of livestock markets in Nakasongola may be attributed to relatively larger number of animals (Table 3) and settled herders. Presence of many animals in an area attracts creation of markets to easily satisfy the animal requirements of traders. Being sedentary also meant a predictable supply of animals for the market. On the other hand, in Buliisa, there were few markets because cattle were concentrated in a small area easily accessed by traders. The availability of more livestock and markets in Nakasongola had potential to attract more cattle traders with likelihood of offering better prices.

CONCLUSION

Land use and cover changes in the pastoral systems of Buliisa and Nakasongola Districts have negatively impacted livestock management under drought induced pasture. Blockage of migratory routes and decline in grazing lands have resulted into concentration of animals in specific areas leading to overgrazing and bare areas, long migration routes and increased prevalence of contagious diseases during migration. Construction of individual water resources (ponds and valley tanks), reduction in

livestock numbers and taking long migration routes are the adaptive and coping strategies used by pastoralists in response to drought amidst changes in land use. The resilience of pastoral systems to drought has reduced and their vulnerability to impacts of climate change increased. Given the current trends in land use and cover change, pastoral communities are advised to harness feed conservation technologies and use of crop residues as dry season feeding resources to avoid long migration routes, conflicts with cultivators and contagious diseases in migratory sites.

ACKNOWLEDGEMENT

This publication is a product of a project funded by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). The views expressed are not necessarily those of ASARECA.

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