

Research Application Summary

Sorghum breeding for improved productivity, nutrition and industrial use

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Abstract

Sorghum and cereals in general are staple cereals consumed predominantly with little value addition. Consequently, these crops yield low remunerability in the economy of Uganda and many similar countries. The value of cereals such as sorghum can be increased if key technical and socio-economic debilitating factors are addressed. Cereals in general could have multiplier effects to the economy, improving food security, incomes, livelihoods as well as food sovereignty. For eastern and southern Africa, investing in specific staples especially sorghum can help increase required agricultural gross domestic growth (Ag GDP) needed to move millions out of poverty and meet food security targets. Sorghum production in eastern Africa is never the less low, with an annual productivity decline of about -7%. The purpose of our research team is to develop specialized sorghum and maize-based technologies, in order to reduce food and nutrition insecurity, widen the market opportunities and sustainably use natural resources for production. The programme engages both graduate students and university-based researchers from the south as well as in north to generate innovations need to improve functionality of the sorghum value chain in Uganda and eastern Africa in general. Equally important, is the engagement of communities in partnership via the Community Action Research Project (CARP) of RUFORUM. Our research for development (R4D) activities are harnessing advances in cereal research and a combined use of participatory and socioeconomic research approaches to innovate. Through these engagements, new lines for breeding purposes, as well as pipeline varieties are underway. Pioneering research is also generating novel lines that are being evaluated for use in the development of value added products. Details of these outputs and their implications for university based research for development programmes are discussed.

Key words: Breeding, eastern and southern Africa, improvement, University-based research

Résumé

Le sorgho en particulier et les céréales en général sont des cultures de base consommées principalement avec une faible addition de valeur. Par conséquent, ces cultures donnent une rémunérabilité faible dans l'économie de l'Ouganda et de nombreux pays similaires. La valeur des céréales telles que le sorgho peut être augmentée si les principaux facteurs techniques et socio-économiques débilissants sont adressés. Les céréales en général pourraient avoir des effets multiplicateurs sur l'économie, l'amélioration de la sécurité alimentaire, les revenus, les moyens de subsistance ainsi que la souveraineté alimentaire. Pour l'Afrique de l'Est et du Sud, investir dans les cultures de base spécifiques, en particulier le sorgho, peut aider à l'accroissement requis du produit intérieur brut agricole (PIB Ag) nécessaire pour faire sortir de la pauvreté des millions de personnes et atteindre les objectifs de sécurité alimentaire. La production du sorgho en Afrique de l'Est est pourtant faible, avec une baisse de productivité annuelle d'environ 7%. Le but de notre équipe de recherche est de développer des techniques spécialisées basées sur le sorgho et le maïs, afin de réduire l'insécurité alimentaire et nutritionnelle, élargir les opportunités du marché et l'utilisation durable des ressources naturelles pour la production. Le programme incite les étudiants diplômés et les chercheurs universitaires du Sud, ainsi que du Nord de générer le besoin d'innovations pour améliorer la fonctionnalité de la chaîne de valeur du sorgho en Ouganda en particulier et en Afrique orientale en général. Tout aussi important est l'engagement des communautés en partenariat par le biais du Projet de Recherche - Action Communautaire (CARP) du RUFORUM. Notre recherche pour les activités de développement (R4D) constitue des progrès en matière de recherche sur les céréales et une utilisation combinée des approches de recherche participative et socio-économiques pour innover. Grâce à ces engagements, de nouvelles lignes pour des buts de reproduction, ainsi que d'autres variétés de lignes sont en cours. La recherche de pointe est en train également de générer de nouvelles lignes qui sont évaluées pour être utilisées dans le développement de produits à valeur ajoutée. Les détails de ces résultats et leurs implications pour la recherche universitaire pour les programmes de développement sont discutés.

Mots clés : Reproduction, Afrique orientale et Australe, amélioration, recherche basée à l'Université

Background

Development relevance of sorghum. In the marginal and medium potential agricultural zones, sorghum (*Sorghum bicolor* (L.) is a high priority staple ranked as 1st, 2nd and 3rd in Ethiopia, Sudan and Uganda, respectively (Ketema, 2008). The crop is of particular significance in dryland agro-ecologies where agriculture contributes between 10 to 55% of Gross Domestic Product (Ag GDP) (Sidahmed and Kessaba, 1998). In these dry lands, which comprise 54% of agricultural lands in sub-Saharan Africa (SSA), only one third is suitable for arable production and is dominated by drought hardy cereals such as sorghum (Henaio and Baanante, 2006). Yet the dry lands account for up to 100 million people and with population growth rates of up to 2.8%, cereal production may be outstripped by population growth thereby exacerbating poverty and food insecurity (de Graaff *et al.*, 2011). In deed, Africa's per capita grain production declined from the mid-1970s, only rising to the 1961 levels recently (IAASTAD, 2009). Africa's productivity is also most impacted by the lack of diffusion of improved technology for agricultural production (Juma, 2011). As such, appropriately designed sorghum based innovations provide an excellent opportunity to address food insecurity especially in the drylands. The crop is prioritized to deliver development solutions in Eastern and Central Africa. Sorghum can also be bred for increased productivity, end-use diversification and resilience for rain-fed agriculture, the major production system in Africa, now threatened by climate change.

The major challenge therefore that confronts Africa, especially the semi arid zones, is the promotion of steady agricultural sector growth. The African Union through the Comprehensive Africa Agriculture Development Programme (CAADP) has prioritized investments in Agriculture. The CAADP seeks to assure a 6% annual agricultural GDP growth. Stimulating agricultural growth requires exploiting growth poles that increase social opportunity, as well as decrease climatic and socio-geo-economic vulnerability (Omamo *et al.*, 2006; UNCTAD/TIR, 2009). Our research team proposes to generate technologies that hasten breeding of resilient sorghum to abiotic and biotic stresses that can cause up to 60% yield loss, or 9, 000 metric tons of grain approximately amounting to 2.5 million USD per year (Ndulu *et al.*, 2007). The focus on sorghum and other cereals is underpinned by the recognition that sustaining a 1% increase in annual cereal production has potential to move millions out of poverty and hunger in SSA (Ndulu *et al.*, 2007).

Scientific significance. Sorghum production in Eastern Africa is low with an annual productivity decline of about -7% (FAST, 2008). Biotic stresses such as diseases -foliar and grain anthracnose (*Colletorichum sublineolum*), leaf blight (*Exserohilum turcicum*,) the gall midge (*Stenodiplosis sorghicola*), the witch weed striga and grain borers account for up to 80% of losses (DeVries and Toenniessen, 2001). Quantitative Trait Loci (QTL) for resistance to important traits including resistance to pests and diseases have been mapped. Our own efforts have led to the mapping and characterization of disease resistance loci to folia diseases (Beshir *et al.*, 2012; Tom *et al.*, 2011; Biruma *et al.*, 2012). This and other knowledge, has however not been exploited in sorghum breeding. Yet deployment of resilient varieties could improve yields by up to 40%, the yield increase needed to stabilize food security and meet development targets (de Graaff *et al.*, 2011; Juma 2011). Harnessing biotechnologies can enable exploitation of scientific advances such as; (i) the completely sequenced sorghum genome, (ii) genome wide assays, and (iii) cheaper and faster sequencing platforms. The sorghum research team at Makerere University uses these advances in biotechnology to generate pipeline materials for new varieties and genetic resources among others.

Programme Conceptual Framework

The purpose of the Makerere Cereals Programme is to develop specialized sorghum and maize-based technologies, in order to widen the market opportunities, reduce food and nutrition insecurity and sustainably use natural resources for production. To achieve this, our research programme uses a pluralistic value-chain based research for development to generate novel cereals based products and innovations. These innovations will improve incomes, health, and nutrition of farming communities and protect the environment. Specifically, the vision of success for our programme is to transform the use of sorghum and other cereals from staple cereals roles into diversified novel foods and beverages, animal, fish and poultry feed and industrial crops. It is built on the national and continental aspiration of transforming SSA's agrarian based economies into regional and globally linked bio-resource economies. The aim is to improve remunerability of cereals by developing specialized high value products while ensuring sustainable production systems. The team is mobilizing state of the art science and technology, to generate novel products and technologies, based on sustainable and renewable natural resources. We are also building the country's and regions' scientific capacity to innovate, as well as competitively expand

and engage other market actors in Africa and globally. This approach is based on our vision to strengthen the Uganda Agricultural Science and Technology Innovation systems (ASTI), which is hitherto, focused on food security and is weakly linked to markets (NARS Act-GOU, 2005). We therefore propose to strengthen both the supply and demand sides of the ASTI. In the supply side, our interventions aim at enhancing research and technology capacity by developing highly skilled human resources and research infrastructure, diversify product portfolio and support for policy development and implementation. On the demand side, we propose to strengthen policy development, advocacy and access to services by various actors including women, youth and disadvantaged groups. The programme will contribute to the strengthening of the Ugandan ASTI in five result areas (Fig. 1). This is guided by four major thrusts;

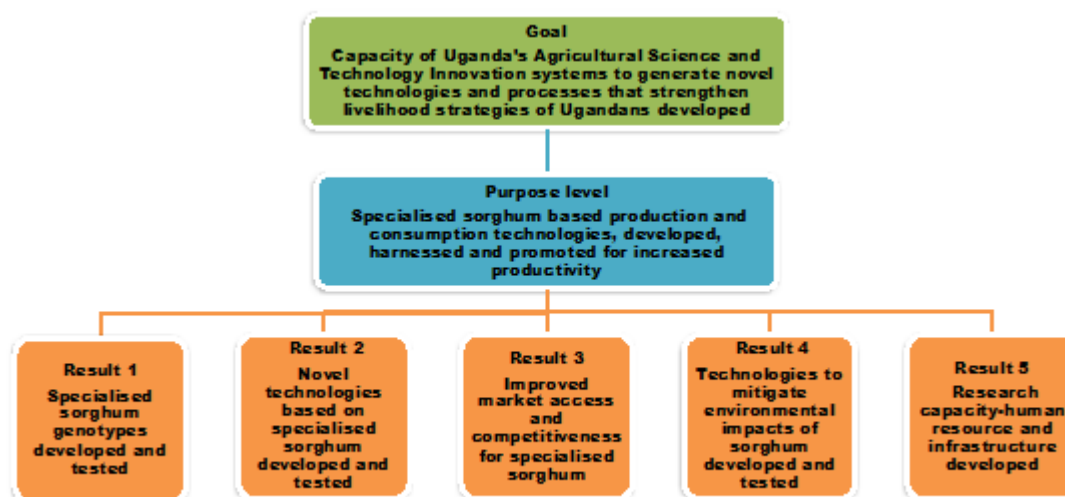


Figure 1. Makerere University Cereals Programme Results Framework.

1. Improved production systems for specialized sorghum developed and tested for adaptation and up-scaling;
2. Novel technologies based on specialized sorghum developed and tested for adaptation and up-scaling;
3. Improved market access and competitiveness for specialized sorghum;
4. Research capacity-human resource and infrastructure developed.

In an effort to strengthen the Ugandan ASTI, the entry points for this project are the Universities, represented by Makerere University, the National Agricultural Research Institutes,

represented by the National Agricultural Research Organisation; linkage to private sector represented by the Makerere Private Sector Forum and the Uganda Manufacturers Association. Production and advisory services will be made using our existing partnerships with the National Agricultural and Advisory Services (NAADS). This approach builds on our past efforts to provide services and products that assure efficiency and effectiveness from production to the market place in Uganda. In the next section we describe progress we have made as a research team.

Unlocking the potential of sorghum through breeding

1. Novel genotypes developed. Our research team has developed a number of novel varieties of sorghum and maize that include quality protein maize (QPM), waxy- high amylose maize and sorghum genotypes and sorghum genotypes with high diastatic power (fermentation potential). The waxy maize inbred line *wx/Hi27* was used to improve local material, whilst QPM breeding has been based on the donor line CML182. The progenies currently at $F_{3:4}$ are being advanced for ultimate release as varieties. All breeding work is being done at Makerere Agricultural Research Institute Kabanyolo (MUARIK) with support of the Cereals Programme- of the National Agricultural Crops Resources Research Institute (NACRRI). In the case of maize, there are at least 4 lines being evaluated with several inbred materials (over 10 lines) being developed for hybrid development. And in the case of sorghum, the materials include-improved Epuripur, a leaf blight susceptible but suitable variety for brewery, for tolerance to leaf blight and waxy sorghum-high amylose. These materials are present as ($F_{3:4}$) populations being advanced to $F_{4:5}$ derived populations for subsequent evaluations on farm in 2012. In the case of sorghum there are at least 10 candidate lines being advanced.

2. Hybrid technology. We have initiated the development of sorghum hybrids, being the first attempt to do so in the country. Twenty three local sorghum germplasm were crossed to a male sterile parent (A line (P5907) to test potential non- emasculated sorghum hybrid development. Through this process, we have identified parent material also called restorers (12), as well as five maintainer (B lines) that could be used to convert local materials to male sterile line (A lines). The sorghum accession MUC 007/144 was identified as suitable for producing high yielding hybrids with high tolerance to diseases and drought whilst the sorghum accession MUC007/167 could be used for hybrid with early maturity properties.

3. Transformation of sorghum. The main objective of this part of our work is to develop an efficient *in vitro* culture system for selected Ugandan elite sorghum genotypes as well as demonstrate the possibility of agrobacterium mediated transformation of sorghum genotypes amenable to tissue culture. We have developed an efficient *in vitro* culture system, the first of its kind for Ugandan adapted sorghum genotypes. The protocol requires a combination of 2.5 mg/l of 2, 4 D and 0.5 mg/l Kinetin for sorghum regeneration. The appropriate age for regeneration material was also established. Model Ugandan sorghum genotypes on each medium type tested were identified with genotype MUC007/193 and MUC007/194 highly amenable to tissue culture on MS basal medium. This study further demonstrated that agrobacterium strain by sorghum genotype interactions did not appreciably affect the transformation efficiency and level of GUS gene expression in explants. The Agrobacterium strain EHA105 was better than AGL1, whereas genotypes MUC007/193 and MUC007/124 showed highest transformation frequencies and can thus be used as model genotypes for further sorghum transformation studies (Fig. 2).

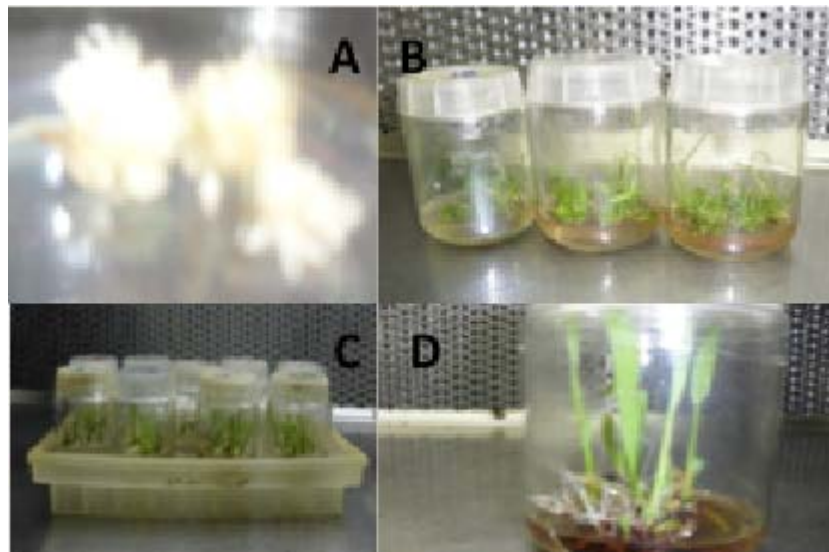


Figure 2. *In vitro* cultures of sorghum accessions developed by the Makerere University Cereals Programme. (A) Somatic embryos formed on callus, (b) Somatic embryos germinated to form shoots, (C) Shoots cultured on half strength MS rooting medium, (D) Roots formed on plantlets.

4. Breeding tools developed. Using a transcript profiling approach we have developed tools to support marker assisted breed of sorghum for resistance to anthracnose (Fig. 3). The markers designated in this study, will simplify and streamline

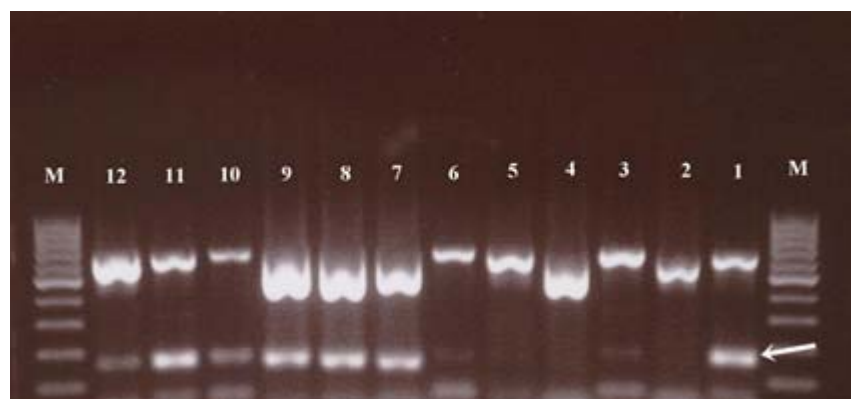


Figure 3. Polymorphism detected in resistant and susceptible genotypes when screened using the PCR primers Primers BCS43 and BCS35 developed by the project team. Lane 1, Resistant parent, 2 susceptible parent, 3,4,5 susceptible genotypes, 6,7, 8 F2 plants from a cross between 1 and 2, 9-12, resistant genotypes and M is 100bp DNA ladder.

New value – added products developed from sorghum

marker assisted selection for resistance breeding to anthracnose, as they are completely predictive of the functional nucleotide polymorphism that differentiates resistant and susceptible alleles. These markers are relatively inexpensive and can be used without any special equipment and are thus well suited to breeding programs in developing countries where anthracnose is most often a problem.

This key result area of our work focuses on developing value-added products for food, feed and processing. Examples of technologies we have developed include;

1. Break fast cereals development. This project aimed at developing a convenient and acceptable breakfast cereal product from sorghum. Work involved characterization of food quality of sorghum, optimization of protocols for breakfast cereals and evaluation of sensory and physicochemical properties. To-date we have developed sorghum based breakfast cereals. Overall sorghum flakes developed from 9% slurry concentration were preferred to those from 19% slurry. Analysis also shows that the quality of starch present of the resistant type suitable for diabetic and cancer patients with reduced glycemic indexes. And in general, the flaking technology resulted in increased calcium bioavailability. No microbe contamination under storage were identified.

2. Ice-cream cone development. The focus of this part of our work is to develop value added products based on sorghum such as ice cream cones, breakfast cereals and fermented

beverages. For ice cream cones, wheat was substituted completely with whole sorghum flour of the *Epuripur* variety in a cone recipe and other ingredients varied to form different sorghum cones. Through this process, a technique for making ice cream cones based on sorghum has been developed. The best cones held ice cream for 22 minutes and remained crisp for another 20 minutes. Consumer acceptability tests based on hedonic 1-9 scale and the Food Action Rating Scale (FACT) rated sorghum cones better than commercial wheat based cone.

3. Development of sorghum based fish feeds. In this study we investigated the effects of substituting maize with low-tannin sorghum as the energy supply source on growth performance, body composition and carcass characteristics of Nile Tilapia. Sorghum replaced maize at levels of 0, 50, 75 and 100%. There were no significant differences in feed conversion ratio (FCR) among treatments ($P = 0.24$) except a slight difference between the 50% sorghum diet and the commercial feed ($P = 0.045$). The Relative Growth Rate (RGR) of fish fed the commercial diet was significantly lower ($P < 0.05$) than that of the test diets, while no significant difference in RGR ($P > 0.05$) was observed between fish fed the test diets. It can be concluded that low-tannin sorghum can completely replace maize in tilapia diets without compromising growth, body composition or carcass characteristics.

Competitiveness and market access enhanced

In this key result area our team aims at generating information to guide policy formulation and implementation with regard to development of specialized maize and sorghum-based industry. This information would in turn enhance commercialisation of smallholder agriculture and market competitiveness.

1. Producer preferences for attributes of maize and sorghum in Uganda. Maize and sorghum are important staple cereal crops in Uganda and Africa as a whole. This study was conducted to examine producer preferences for maize and sorghum attributes in Uganda, with the aim of informing their breeding programs. The empirical work employed the hedonic price model. A number of productive attributes (plant height, plant cycle length, pest and disease resistance and drought tolerance) and two consumptive attributes, grain size and grain colour, were considered in the analysis. In addition, an array of household socioeconomic characteristics was also included in the analysis. The data for the study were collected from the four Ugandan districts of Masindi, Iganga, Soroti and Pallisa. A

total of 325 observations from Masindi and Iganga for maize and a total of 326 observations from Soroti and Pallisa for sorghum were collected, in a survey of farmers. The results of the study indicated that; maize producers were willing to pay a premium price for varieties that with short stature and increased yield, while they discounted plant cycle length, grain size and white grain colour. Drought tolerance and pest and disease resistance had little influence on the price farmers were willing to pay for maize seed. On the other hand, sorghum producers were willing to pay a price premium for short to medium plant cycle length and small grain size, while they discounted red-kernelled grain. High drought tolerance, plant height and medium grain size had little influence on the price farmers were willing to pay for sorghum seed.

2. A policy analysis matrix study of the impact of policies on maize and sorghum sub-sectors. The objectives of this work was to analyse the impact of policies on maize and sorghum sub-sectors of the Ugandan agricultural sub-sectors. A policy analysis matrix was used to gain better understanding of the policy environment influencing sorghum trade in Uganda. Three main activities have been undertaken so far: (i) An assessment of the impact of policy changes on various stakeholders in the maize and sorghum sub-sectors, (ii) an assessment of the contribution of maize and sorghum to the national income and to private incomes of farmers, (iii) an assessment of whether Uganda has comparative advantage in maize production in the region. Some of the key findings are that: (1) Uganda has comparative advantage in production of maize and sorghum. This is clearly shown by positive social profits (maize 1, 000, 750 Ug. shs /ha (equivalent to 477\$/ha) and sorghum 1, 263, 452 Ug. shs. /ha) (equivalent to 602\$/ha). Thus given a good policy environment, maize and sorghum can be profitably produced by Ugandan farmers; (2) The Domestic Resource Cost Ratio (DCR) which determines whether production processes efficiently use domestic resources per unit of value added for sorghum and maize was 0.28 and 0.34 respectively implying that Uganda has a comparative advantage in sorghum and maize production; (3) The *Private Cost Ratio (PCR)* for sorghum and maize was found to be 0.65 and 3.4 respectively. A higher PCR index represents a reduction of competitive advantage again confirming that Uganda has relatively lower comparative advantage in production of maize compared to other countries in the region. Therefore, maize production is less competitive compared to sorghum production; (4) Sorghum and

maize sub-sectors are not protected. The Nominal Protection Coefficients for Output (NPCO) a measure of protection were 0.43 and 0.38 for sorghum and maize respectively. These findings are being used to guide research and development processes and will be used to draft policy briefs and publications.

Conclusion

1. A paradigm shift in linking University to development practice. The sorghum group at Makerere University is just under five years old. A number of breeding lines are being developed for release as new crop varieties. These materials will contribute to expansion of the production and utilization niche of cereals which incidentally have been earmarked as investment opportunities to move millions out of poverty and the hunger and food insecurity trap. In the past, Makerere University has released soybean varieties in partnership with the National Agricultural Research Organisation. These varieties are now widely distributed in the region. A key lesson learnt from the soybean experience is the need to partner with national agricultural research agencies and other stakeholders to generate both Distinctiveness, Uniformity and Stability (DUS) Value for Cultivation and Use (VCU) data needed for national to regional variety release. We have therefore entered into strategic partnership with north research and farmer agencies to support both DUS and VCU analyses. We are also strengthening our participatory variety selection both for VCU analysis and to support speeding up variety dissemination. For sorghum production, we have developed hybrids that will require strategic partnerships with private sector but producing speciality varieties for food processing industry. We are also targeting production of specially varieties for niche markets and opportunities. This approach is a shift away from the old paradigm of targeting yield increase per se. Our cereals breeding paradigm is thus focusing on products and value added directed breeding conducted in partnership with diverse partners. These new ways of working will improve the impact thrust of the Makerere University Breeding Programme.

2. Strategic expansion of breeding programme scope. Increasing urbanisation of towns in Uganda and Africa in general implies that feeding habits of such populations will change gradually with most people consuming rice, wheat and value added products. As such, the Cereals Programme at Makerere University is diversifying its actions to address these strategically important crops. We have begun a rice-breeding programme focusing on increasing productivity of both paddy and upland

rice. The current target is to develop breeding tools for biotic stresses especially blast (*Magnapothe grisea*). The programme is also addressing the issue of resilience by targeting finger millet a crop of increasing importance because of its low glycemic index and long storability. These new thrusts will enable the university to contribute to addressing strategic food security and sovereignty concerns of the country.

3. Influencing policy business incubation. A key weakness of most research efforts is the weak contribution to policy information. In the case of the Makerere University Cereals Programme, information that could inform strategic investments by the county into maize and sorghum research has been generated. Development of appropriate media channels will help disseminate such vital information to policy-making institutions.

Overall, as a university based breeding programme, the basics needed to generate resilient and highly productive crop varieties have been put in place. The programme is also now underpinning the regional Programs in Plant Breeding and Biotechnology. A critical gap is the development of strong seed systems and linkage to value addition processes that incidentally could be brokered with the Department of Food Science and other partners. In partnership with RUFORUM, the programme will also benefit from the wider network allowing the programme to tap into the scale and scope-opportunities provided by large regional networks such as RUFORUM.

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