Research Application Summary

Harnessing University-NARS partnership to breed climate change resilient and nutrient-rich maize varieties for Africa

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Abstract

Maize is the most important cereal crop in Sub-Saharan Africa (SSA) and more than 300 million people depend on it for their food security and livelihood. Its production is constrained by the effects of climate change, most importantly drought, under investment in agricultural research and development (R&D), low capacity for R&D, and low use of inputs such as improved seed and fertilizers. National Agricultural Research Systems (NARS) in collaboration with Universities have made remarkable progress in increasing maize crop yields during the past century. Re-orienting maize research to produce 'Smart' varieties that yield more in a changing climate has been pivotal to achieving success. New maize improvement themes need to be set between NARS and Universities, in a concerted effort with other implementing partners and intensive effort to improve maize varieties for Africa. This will contribute to the well-being of small-scale maize farmers and economic development of countries throughout the SSA region through increased food and income security. Joint efforts will need to be directed towards the identification of new genetic sources of tolerance to stress (drought, diseases, high temperature and low soil nitrogen) and high nutrient content (High lysine and Vitamin A), with broad adaptation and suitable for use as parental material for breeding novel varieties. In this paper, we summarize the advances, constraints, and opportunities for genetic improvement of maize for drought and low N tolerance, disease resistance and enhanced nutritional quality through NARS-University collaboration.

Key words: Maize breeding, National Agricultural Research Systems, Sub-Saharan Africa, Universities

Résumé

Le maïs est la culture céréalière la plus importante en Afrique sub-saharienne (ASS) et plus de 300 millions de personnes en dépendent pour leur sécurité alimentaire et les moyens de subsistance. Sa production est limitée par les effets du changement climatique, surtout la sécheresse, dans le cadre des investissements dans la recherche agricole et le

développement (R & D), la faible capacité de R & D, et la faible utilisation des intrants tels que les semences améliorées et les engrais. Les systèmes nationaux de recherche agronomique (NARS), en collaboration avec les universités ont réalisé des progrès remarquables dans l'augmentation des rendements des cultures de maïs au cours du siècle passé. Réorienter la recherche sur le maïs pour produire des variétés «Smart» qui produisent plus dans un climat changeant a joué un rôle essentiel pour atteindre la réussite. Les nouveaux thèmes d'amélioration du maïs doivent être mis entre les NARS et les universités, dans un effort concerté avec d'autres partenaires d'exécution et un effort intensif pour améliorer les variétés de maïs pour l'Afrique. Cela contribuera au bien-être des producteurs de maïs à petite échelle et au développement économique des pays à travers la région d'Afrique sub-saharienne par l'accroissement de la sécurité alimentaire et du revenu. Les efforts conjugués devront être orientés vers l'identification de nouvelles sources génétiques de la tolérance au stress (sécheresse, maladies, haute température et faible azote du sol) et la haute teneur en éléments nutritifs (Haute lysine et vitamine A), avec une adaptation large et indiquée pour être utilisées comme matériel parental pour la reproduction des variétés nouvelles. Dans cet article, nous résumons les progrès, les contraintes et les opportunités d'amélioration génétique du maïs à la sécheresse et à la faible tolérance de N, la résistance aux maladies et la qualité nutritionnelle améliorée grâce à la collaboration entre les NARS et les Universités.

Mots clés: Reproduction du maïs, Systèmes Nationaux de Recherche Agricole, Afrique sub-saharienne, Universités

Background

Maize is a widely grown crop in approximately 30 million ha of the region's 200 million ha arable land. Current yields are very low (about 1.8 t/ha) relative to the existing potential. Per capita consumption ranges from 25-85kg depending on the region. Additionally, about 77% of maize grain is used as food in SSA in countries outside South Africa (DTMA, 2012). As such the anticipated impacts of climate change on maize yields will have far reaching consequences on the rural poor who depend on maize for food security in the region, for example, drought alone causes 25-50% yield loss each year. The development of climate change resilient germplasm to offset these impacts is of the utter most importance. A strong foundation for a graduate student training in sub-Sahara Africa lies is cooperative effort between the Universities and National Agricultural Research

Institutions (NARS) that offer complementary roles in strengthening indigenous educational and research systems. On one side, the NARS work closely and have been encouraged to strengthen the partnership with the private sector for uptake and utilization of technologies generated from research institutes by the end users- farmers. The strength of breeding programs in the NARS also depends on the other side, on *inter alia*, quality, number, resources and availability of graduates from universities. Inevitably, strengthening University-NARS partnership is a 'win-win' situation for both institutions. Makerere University and the National Crops Resources Research Institute have recently developed a regional model for training graduate students in the fields of Plant Breeding, Biotechnology and Seed Systems. This program is a parternship betweeen the institutions above, and is supported by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), and the Alliance for a Green Revolution in Africa (AGRA). Experience so far from this partnership has brought to lime light the efficiency of a team-based approach in human capacity development. In this case, both theoretical and pratical training of breeding students was conducted with the availble infrasturcture, who immediately applied the knowledge in development and improvement of various food crops in Africa. Over the few years of implementation, this program has quickly developed into a model program, having provided improved quality of training over that which most individual African universities can provide.

Advances in NARS-University Collaboration

Curriculum and human capacity development. Regional training (involving 30 Universities) of Masters and PhD students in plant breeding, biotechnology and seed systems has been running at Makerere University for the last 4 years. Universities have been continously revising curricula and developing plant breeding programs or department to enhance quality graduate and post graduate training of breeders to adress a diverse set of Africa's crops in a collaborative team-based environment, which is essential for breeding today. The new Plant Breeding, Biotechnology and Seed System Program at Makerere University attaches students (PhD and MSc.) in on-going activities in national breeding programs and also CGIAR Centres and Seed Companies. Here students are exposed to a wide range of mentors in both theoritical and practical fields. This unique exposure enables the students to participate in a broader range of breeding activities while undertaking their research. Secondly, students are also able to gain networks with wider

collaborators such as Scientists at the International Research Centres like International Maize and Wheat Improvement Center (CIMMYT), Center for Tropical Agriculture (CIAT), International institute for Tropical Agriculture (IITA),International Potato Centre (CIP), West Africa Rice Development Association (WARDA), and Asian Vegetable Research and Development Center (AVRDC) that work closely with the National Programs. The process also allows students to learn directly from experienced technicians, as well as to link to commercial seed companies. This dual experience from both public and private plant breeding operations exposes the students to and prepares them for jobs in both public and private institutions. The partnership has also developed a field attachement program to enable students further their experience and open them up to employment opportunities that suit their future carriers.

Breeding for climate-resilient maize

Maize is one of the most important and predominant food crops in sub Sahara Africa (SSA) grown in more than 30 million hectares (FAOSTAT, 2010). It is projected that by 2050, demand for maize will double in the developing world, and maize is predicted to become the crop with the greatest production globally, and in the developing world by 2025 (Rosegrant *et al*., 2008). In most African countries, maize is the principle staple crop, accounting for an average of 32% of consumed calories in Eastern and Southern Africa, rising to 51% in some areas (FAOSTAT, 2010). However, climate change projections suggest that large yield losses will be occurring in many regions, particularly within sub-Saharan Africa. Already, drought continues to ravage the continent, making agriculture an increasingly daunting task, and especially for the resource-poor smallholder farmers. While, the farm production levels fluctuate due to insufficient and erratic rains, and low soil fertility further reduce crop yield as few farmers afford fertilizer. This has stagnated maize production in SSA, relegating farmers' livelihoods to bare survival.

Overall, drought is second only to poor soil fertility in reducing yield in the developing world, leading to a 15% overall reduction in grain yield in these countries. Maize in the region is almost exclusively grown under rainfed conditions with minimal input and management by the small scale farmers that grow it. The anticipated impacts of climate change on maize yields will have far reaching consequences on the rural poor who depend on maize for food security. The development of climate change

resilient germplasm to offset these impacts is of utmost importance and immediate challenge. Various regional projects have devoted efforts to developing drought tolerant inbred lines and populations for pedigree breeding. In Uganda, the National Maize Breeding Program has been able to capitalize on these efforts (germplasm and capacity for screening germplasm) by embedding students under the plant breeding and seed systems program to evaluate germplasm for tolerance to drought and low soil nitrogen, and resistance to foliar diseases. To achieve these, considerable work has been done jointly by students, NARS scientists, technicians and university mentors to develop effective screening techniques and selection methods, and to undertaking genetic studies of resistance to these stresses. Combining ability and heritability estimates of several elite inbred lines have been determines. Several hybrids have been developed and delivered into the variety release pipeline and breeding populations have been developed from stress tolerant sources. In the past 3 years, over 200 inbred lines from different sources have been screened for multiple tress tolerance through collaboration. Over 100 pedigree breeding populations have been developed and half the number has been selected and advanced to later generations. This approach has been able provide research areas for students but also provide a hand to the breeding program working with several breeding lines and populations.

Research and Breeding of maize for nutritional quality in a changing climate

A large population depends on maize as staple in SSA as indicated by the high per capita consumption of 85kg, 25kg, 25kg and 25kg for Southern, Eastern, and Western and Central Africa, respectively (FAOSTAT, 2010). Africa's maize breeding programs are therefore developing maize with improved nutritional qualities suitable for maize consuming communities. The National Maize Breeding Program in Uganda has prioritised development of high lysine maize (commonly dubbed, Quality Protein Maize-OPM). Through NARS-University collaboration, several QPM inbred lines have been screened for foliar diseases (Okello *et al*., 2005). Molecular marker systems for QPM maize breeding was also developed through the same collaboration (Manna *et al*., 2005; Maphosa, 2007). A widely adopted open pollinated variety that was modified to increase lysine content is also under advanced cycles of recurrent selection for resistance to foliar diseases, ear rots and storage weevils. New QPM lines have been accessed from CIMMYT and they are currently under evaluation for combining ability for adaptive traits and disease resistance. Work is also on-going to combine

high lysine and waxy properties and this research will greatly contribute to strategies for improvement of grain quality. To further improve on nutritional quality of maize, breeding for resistance to mycotoxin causing fungi has been strengthened through NARS-University collaboration. Several lines have been screened for resistance to cob rots and genetic studies have been carried out to aid development of a comprehensive breeding strategy (Kwemoi *et al*., 2010; Langa *et al*., 2012).

Although maize is a major staple in Africa especially in East and Southern Africa, it is generally poor in pro-vitamin A. Beta-carotene is a key dietary source of vitamin A, a nutrient whose deficiencies cause night blindness and other health problems for more than 5 million children and nearly 10 million pregnant women, according to the World Health Organization (WHO). Fortunately, for this trait, a group of scientists at CIMMYT have perfected the breeding methodologies for introgression of alleles that control B-carotene in maize. Through regional and institutional collaborations NARIs and the Universities can take on this research initiative and develop pro-vitamin A rich maize that will feed the future and reduce risks of health conditions associated with deficiency of the pro-vitamin A. Already, donor parent have been accesed and are being multiplied by the Uganda National Maize Breeding Program.

Constraints

A number of constaints have led to limited synergies between NARI and Universities in development of climate change-resilent and nutritionally enhance maize in SSA. National and university policies to initiate and guide collaborative agricultural research are generally not formally established in policy frameworks. Additonally the mutual benefits obtained from NARS-Iniversity collaborations have not been fully recognised in the SSA's agricultultural sectors. Other factors contributing to the problem include gaps in the policies and practices that influence the professional and career environment. Inadequate research funding, weak research infrastructure and inadequate physical infrastructure also limits the capacity to undertake research and hinders dessemination of new research research products.

Existing Opportunities

Breeding resource. Resource is always a limiting factor and influences breeding objective and capacity. In many African countries, breeding is a public service and until recently, the benefits from public plant breeding were realized by the private sector through 1) public release of improved varieties, and 2)

Table 1. Allocation of resources to the maize sector in Uganda.

Activity	% allocation
Variety development (breeding)	15.9
Variety release	6.0
Seed production (breeder/foundation/certified)	9.8
Technology targeting to inform scale up efforts	6.8
Extension and variety dissemination (demonstrations/promotion/awareness)	21.3
Improving markets for producers and net buyers	11.0
Post harvest management and value addition	14.9
Capacity building/ infrastructure development	8.9
Impact assessment and policy research	5.6

training of plant breeders, many of whom eventually joined the institutions and private sector. This arrangement has facilitated close collaboration and mentorship by experienced breeders. The relationship between the NARS and private sector are becoming stronger and have fundamentally changed the way business is done and limited germplasm exchanged between NARS due to legal protocols. In countries where the Plant Variety Protection laws are operating, the public research is also demanding interim paybacks from research investments in the name of efficiency. As a result, most of breeding focus is now on development of hybrids demanded by the private sector to be released using intellectual property protection such as royalties and licensed on exclusive or semi-exclusive arrangement. To date, this arrangement together with limited government funding is not sufficient to plough back for research, rather, most programs continue to and for sometime will be funded by grants. Resources both within universities and NARS can also be shared in a complementary way to both train students and develop new crop varieties.

SSA's developing seed system. There is generally, low number of plant breeders in Africa for improvement of all the crops grown. This situation is exacerbated by the fact that there is a paradigm shift to strengthen crop value chains with emphasis on commercialization for end users- farmers to benefit from new crop technologies that require more breeders. Liberalization policies in support of these initiatives have led to establishment of several Seed Companies on the continent, who can adopt and disseminate new varieties. These Seed Companies, mostly small to medium scale, do not have their own breeding programs but rely on the public sector for improved varieties to produce foundation and certified seeds. This situation is likely to remain for a long time because of the expensive nature of research for

private investment and lack of experienced breeders. However, in the short-term, for these Companies to produce good quality and adequate quantities, production research and maintenance of germplasm is important, a role that needs more breeders in the private sector.

Capacity building and germplasm development. The NARS usually have several sources of germplasm and exchange these germplasm with other institutes and international centers. The students' research embedded within the on-going breeding activities provides dual advantage. It enables the students to easily develop research hypothesis from the current activities and reduces the time to source for new germplasm and making initial crosses. The students fit in and continue with either crosses from known inbred lines or advancing existing population, thus saving time. This approach also provides practical hand-on enrichment for students' research experience and exposes them to become familiar with a number germplasm that they can later capitalize on when starting careers or new projects. Experience obtained from running the NARI-Makerere University collaborative breeding and training shows that the students have been able to graduate on time while contributing to developing new sources of germplasm. In this way, the choice of research area (crop and problems identified), arguably, keeps university programs relevant to national poverty eradication campaigns and aligns training to research agenda. Most of the students who graduated from this arrangement have been absorbed in the breeding programs with ease, and in some cases in countries such as Rwanda and South Sudan, they have started new breeding programs without much technical challenge. We have also been able to share screening facilities for different stresses including diseases and drought. This effort has increased capacity and amount of new germplasm in the pipeline being developed.

Infrastructure development and sharing. In universities and research institutions, the capacity of individual researchers, including their skills, competencies and values, is developed primarily through appropriate training programs and courses and involvement in research activity. However, adequate research infrastructure is limited in both the universities and research institutes. Breeding facilities most often are present in the research institutes and most universities have laboratory facilities. There is thus, present an opportunity to capitalize on these research assets of both institutions for training and germplasm

development. To contribute to achieve these goals, NARS and Universities need to review the research needs together and develop a set of new research themes related to improvement of maize varieties.

Institutional arrangements and environments. Increased recourse to research funding currently, by and large, favours multi-disciplinary and more applied projects with a positive bearing on strong relationships between implementing institutions. To a large extent, joint project planning and implementation between NARS and universities is growing stronger. In Uganda for instance, reforms in the National National Agricultural Research Systems (NARS Act, 2005) emphasise enhancing extension and research efforts with institutional arrangements that ensure increased responsiveness to clients' needs. The Act provides for a mechanism of facilitation for the involvement of the private sector, universities, the civil society and others in the governance, financing, management and conduct of agricultural research. Thus, the research policy provides for a pluralistic research system that gives opportunity for stakeholders to participate in research and to enhance public-private partnerships. Within this framework, it is important to build relationships among institutions to increase the university's capacity to provide training, and strengthen the linkages between NARS and University. In addition, there is also the benefit of cooperation between colleagues in institutions that is becoming part of institutional culture, even, though there is very little formal arrangements.

Conclusion

NARI-University partnership presents great opportunities which have not been fully utilized. These can be in sharing infrastructure, germplasm, human resource and expertise. Also in the face of changing climate a combination of theoretical and applied research expertise can be drowned from the partnership at country level to address the ever changing climate to provide for the unchanging need of the small scale farmer, ie. Food security through suitable varieties. Moreover, it can lead to stremelined and focused allocation of resources for national interest without spreading out across partners.

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References

Drought Tolerant Maize for Africa, DTMA, 2012. Summary Reports of proceedings at annual Meeting September 2012, Nairobi, Kenya.

FAOSTAT. 2010. Food and Agricultural Organization of the United Nations (FAO), FAO Statistical Database, from http://faostat.fao.org.

Kwemoi, D.B., Okori, P. and Asea, G. 2010. Characterization of a diverse set of maize germplasm for resistance to infection by *Aspergillus flavus* and accumulation of aflatoxin. *Proceedings at the Second Regional Universities Forum for Capacity Building in Africa (RUFORUM) Biennial Conference, September 2010, Entebbe, Uganda.* pp. 299-302.

Langa, T., Asea, G., Gibson, P.T. and Okori, P. 2012. Resistance breeding strategy for *Stenocarpella maydis* and *Fusarium graminearum* cob rots in tropical maize. *Plant Breeding* doi:10.1111/pbr.12013

Maphosa, M. 2007. Developing molecular markers for background selection and modifier genes for quality protein maize breeding. In: Proceedings of the Rockefeller Foundation Biotechnology, Breeding and Seed Systems for African Crops, 26-29 March 2007, Maputo, Mozambique.

Manna, R., Okello, D.K., Imanywoha, J., Pixley, K. and Edema, R. 2005. Enhancing introgression of the opaque-2 trait into elite maize lines using Simple Sequence Repeats (SSR). 2nd General Meeting on Biotechnology, Breeding and Seed Systems, Nairobi, Kenya, January 24-27th, 2005.

Okello, D.K., Manna, R., Imanywoha, J., Pixley, K. and Edema, R. 2005. Evaluation of potential Quality Protein Maize (QPM) inbred lines for improvement of the protein quality of adaptable maize lines in Uganda (Poster). Second General Meeting on Biotechnology, Breeding and Seed Systems, Nairobi, Kenya, January 24-27th, 2005.

Rosegrant, M.W., Msangi, S., Ringler, C., Sulser, T. B., Zhu, T. and Cline, S. A. 2008. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description. International Food Policy Research Institute, Washington, D.C.