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Makerere University Regional Centre for Crop Improvement: A model Training and Research Hub for Next Generation of Plant Breeders for Africa

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ABSTRACT
Africa has a significant shortage of first-class plant breeding professionals. To meet future food demand in Africa, there is need to train more expert plant breeders. The Makerere University Regional Centre for Crop Improvement (MaRCCI) has developed a unique approach to graduate plant-breeding training, to produce graduates that can independently run cultivar development programs meeting smallholder farmer needs in the African context. Since 2008, the center has trained 58 PhD and 117 MSc students from 20 sub-Saharan countries. The existing PhD curriculum has been revised to include recent advances in plant breeding. The Centre derives its strength from extensive cooperation with national, private sector, regional and international partners. The Centre runs two in-house breeding programs on sorghum and cowpea which are designed to deliver high yielding and stress resilient varieties, targeting food products and brewery industry. These breeding programs deploy modern breeding practices from which graduates gain hands-on skills.

Keywords: Makerere University, Plant breeding, Regional training hub, Uganda

RÉSUMÉ
L'Afrique souffre d'une pénurie significative de professionnels de la sélection végétale de première classe. Pour répondre à la demande alimentaire future en Afrique, il est nécessaire de former davantage d'experts en sélection végétale. Le Centre régional de l'Université Makerere pour l'amélioration des cultures (MaRCCI) a développé une approche unique de formation supérieure en sélection végétale, afin de former des diplômés capables de gérer de manière indépendante des programmes de développement de cultivars répondant aux besoins des petits exploitants agricoles dans le contexte africain. Depuis 2008, le centre a formé 58 doctorants et 117 étudiants en master issus de 20 pays d'Afrique subsaharienne. Le programme de doctorat existant a été révisé pour inclure les avancées récentes en sélection végétale. Le Centre tire sa force d'une coopération étendue avec des partenaires nationaux, du secteur privé, régionaux et internationaux. Le Centre gère deux programmes internes de sélection sur le sorgho et le niébé, conçus pour produire des variétés à haut rendement et résilientes au stress, destinées aux produits alimentaires et à l'industrie brassicole. Ces programmes de sélection utilisent des pratiques modernes de sélection, grâce auxquelles les diplômés acquièrent des compétences pratiques.

Mots clés: Université Makerere, Sélection végétale, Pôle de formation régional, Ouganda.

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Introduction

The high population growth in sub-Saharan Africa is one of the major causes of the chronic food and nutrition insecurity despite the continent's endowment with a rich and diverse agricultural potential that can be harnessed to overcome hunger and poverty (FAO, 2006; African Development Bank, 2010; AGRA, 2016). Unfortunately, the region has a severe shortage of plant breeders capable of developing high yielding cultivars and stimulating seed systems that meet communities' needs in the face of climate change. Africa's Higher agricultural education has been neglected for several decades and is inadequately prepared to address the need for qualified professionals (Flaherty and Lwezaura, 2010; Flaherty *et al.,* 2010; World Bank, 2015, 2016). Moreover, the current agricultural educational system is out of step with the job market (World Bank, 2015, 2016).

Data from AGRA country baseline studies in 2006 indicates that the continent of Africa has about 500 active breeders, which is about a tenth of the recommended number. The need to train the next generation of plant breeders is more urgent in Africa than elsewhere (Soybean Innovation Lab, 2014). Moreover, a high portion of the individuals with the requisite qualifications who train outside Africa do not return to their home countries to practice their profession. In addition, with the pace of scientific advancement, there is a need to improve regional education to include training in modern technologies and associated approaches that can substantially increase the rate of genetic gain and decrease the overall development time involved to bring improved varieties to market (Suza *et al.,* 2016). A concerted effort has been directed towards provision of a solution to this problem and evidence for this shows in the form of vibrant crop improvement centres that have been established across the content. Examples of this are West African Centre for Crop Improvement (WACCI) in Ghana, the African Centre for Crop Improvement in South Africa and the Makerere University Regional Centre for Crop Improvement (MaRCCI) in Uganda. The three were established with support from AGRA and RUFORUM (www.ruforum.org) to train a new cadre of plant breeders who are equipped to address the food security agenda on the continent. The outcome of this effort is beginning to show in the emergence of strong breeding programs across the continent coupled with the increased release of new crop varieties. In order to sustain this process, there is need for continued investment in high quality graduate training in modern crop improvement practices to generate the required critical mass to address the food security challenge across the continent. In this respect MaRCCI, with current support from the World Bank, is well positioned to champion this agenda. The MaRCCI builds on existing multi institute cooperation, including private sector industry, regional educational partners, national agricultural research organizations, international agricultural research centres, major United States universities and beyond. Through further development of the effective, progressive, and comprehensive training model, MaRCCI is poised to make a major impact on the transformation of plant breeding and seed systems training across the African continent. Major outputs of the establishment of this centre include a stronger regional PhD program, improved curriculum and delivery, 30 highly trained PhD plant scientists, targeted research that is relevant to the region's agriculture, and a strengthened training and research capacity that serves the whole region.

The Genesis of MARCCI

MARCCI was formed as a Regional Training Centre at Makerere University in 2017 with funding from the World Bank. The Centre started from a very successful postgraduate student training in plant breeding at Makerere University with initial curricula done by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) and funding of initial cohorts by RUFORUM. The MSc and PhD training programs continued to improve with further funding from AGRA on the "Improved MSc in Cultivar Development" a program that worked with Iowa State

University's Plant Breeding E-learning for Africa (PBEA) that developed together two state of the art e-modules in plant breeding. This improvement enabled Makerere University to start paid internships with public and private sector that are now being sought after by industry.

Approach to training next generation plant breeders

The MaRCCI was established with a deliberate purpose to attract students from across Africa. This is aimed at producing professional plant breeders who are able to return to their home countries and contribute to local and regional agricultural productivity.

Operational strategies. In order to achieve the stated goals, the Centre engages visiting lecturers from other countries in the region to achieve the regional context. The Centre deliberately adopted the following strategies:
(a) identify and recruit appropriate regional academic staff as visiting lecturers,
(b) attract regional students (30% of sponsorships allocated to non-Ugandans),
(c) publicize the program, advertise sponsorships, and screen applicants,
(d) selected students with stipend, insurance, travel, research funds, and payment for supervision support,
(e) enroll an additional students who have partial or total funding from sources other than the ACE, and
(f) Implement a rigorous monitoring program for student progress and provide the requisite academic support as needed.

Quality of graduate training. Makerere University offers an internationally acclaimed regional MSc program in Plant Breeding and Seed Systems and PhD program in Plant Breeding and Biotechnology. To enhance the quality of these programs, MaRCCI and its partners have (1) increased the number of staff and provided them with training, (2) set up field, laboratory, greenhouse and screenhouse research and state of the art teaching facilities, and (3) developed distance-learning and video conference capabilities. The Centre provides for a minimum of six months staff skill enhancement programming to train the teaching staff in areas such as bio- informatics, seed quality control, and formal and semi-formal seed systems. An enhanced Bioinformatics Training Facility is in place for use to incorporate locally developed learning exercises into the PhD Bioinformatics course. This facility also provides an intensive short courses geared to meet the growing needs for practicing researchers in the region. Consultants from Cornell University and elsewhere often assist with planning and procurement of the required equipment, identification of staff required for the training, assessment and improvement of equipment needs, staff capacity needs procedures, and training methods for the courses. Expert advice from consultants, on state of the art seed handling and storage facilities have been engaged for the improvement of existing facilities in order to set solid infrastructure to support the research and teaching programs including greenhouses, seed store, molecular lab, and field equipment (e.g., irrigation systems). In order to tap experts further afield, and to enhance the distance learning component of course delivery, MaRCCI's video conferencing capability is currently under development in partnership with RUFORUM, Cornell University and others. This process will define the appropriate operational capacity, infrastructure, hardware and software, bandwidth and appropriate service providers to deliver an efficient distance learning outfit for the program. The videoconferencing will also facilitate meetings of the students guidance committees and other meetings involving participants from other locations.

Curriculum enhancement. Building on the successful MSc program in Plant Breeding and Seed Systems, an expanded and improved PhD curriculum has been developed and strengthened by the inclusion of content on modern technologies, and engagement of processes to achieve effective teaching and learning. The first two semesters are devoted to foundation knowledge, while the third semester presents advanced courses. Several new or revised courses that present the frontiers of the various subject matter areas are delivered residentially, and in Years 2 and 3, and a blended course format is used both for distance learning and residential instruction. The blended

delivery format allows continuation of coursework while the student is conducting research remotely which allows flexibility for students to engage with their instructors and peers onsite and at a distance through various e-learning technologies.

E-learning approach. Plant Breeding E-Learning in Africa (PBEA), an Iowa State University (ISU) program that develops and delivers e-learning modules customized to local (African) needs, has partnered with Makerere, Kwame Nkrumah University of Science and Technology (KNUST, Ghana) and University of KwaZulu Natal (UKZN, South Africa) to develop MSc-level plant breeding modules that present the most current techniques in cultivar development. Through World Bank funding, ISU has contributed two PhD-level e-learning courses: Breeding for Abiotic and Biotic Stresses Tolerance, and Seed Science and Seed Systems. These will add to the minimum of five e-courses developed under PBEA. These innovative courses are designed to elevate MaRCCI to a centre of excellence for delivering high quality plant breeding e-learning and blended learning content. E-learning materials will be hosted locally within the Makerere University Agricultural Research institute at Kabanyolo . A mobile web application will also be developed to allow consistently convenient and reliable access through mobile devices.

Research excellence. The MaRCCI research activities target critical needs in the region. Faculty supervisors ensure that dissertation topics are targeted to provide solutions to critical economic developmental challenges. Topics and objectives are formulated in consultation with the student's guidance committee, consisting of an academic supervisor from Makerere, a product-oriented research supervisor in Uganda NARS, CGIAR centres, a seed company representative when appropriate, and where possible a supervisor from the student's home country institution. Dissertation topic formulation involves all stakeholders in a meeting early in the topic selection process (the student's home institute representative participates by videoconference) To ensure the effectiveness of this committee, its formation is overseen by MaRCCI leadership and departmental leaders. Students are connected with expert volunteer mentors (typically international). In addition, in their dissertation, students are required to adequately define farmers' needs through a synthesis of available information, or, if inadequate information exists, to employ an appropriately targeted needs assessment on site in the relevant geographical area (s).

The research effort is coordinated between the home institution supervisor and the Makerere University supervisors through scheduled conference calls and occasional visits by MaRCCI leadership. Furthermore, continuity and coordination of the research projects among the students is maintained using a database of previous graduate student research. This database categorizes the projects by crop, germplasm studied, traits, and recommendations for application of results and for further research. Students are trained on the Breeding Management Systems (BMS) platform to acquire skills for trial organization and how to maintain data on the BM, a software suite developed as part of the Integrated Breeding Platform to ensure accessibility to all previous results related to a genotype.

The Centre operates cowpea and sorghum breeding programs that have the objectives of developing and releasing improved varieties and contributing to meeting national needs for improved varieties. They provide a platform for demonstration of the principles and practices of plant breeding and provide research material for student research projects in plant breeding and biotechnology. The breeding program methodologies focus on the use of modern precision breeding methods such as molecular methods in marker assisted selection, statistical tools that enhance selection and breeding pipeline optimization. This provides an efficient system for enhanced delivery of improved, farmer-preferred varieties. These breeding programs avail a base for frequent field experience for different activities and modeling of best practices in field breeding activities. The whole mark of MaRCCI is a systemic focus on the discharge of high quality training. To this end, the students research projects are subjected to a rigorous ongoing evaluation process to review data collection and data

quality and progress toward achievement of the stated objectives. In addition, a seasonal supervisory assessment for field-based research or by evaluation cycle for lab or greenhouse-based research is conducted at least once every six months. Graduating students are encouraged and supported in pursuing further grant funding to continue their research. After returning to their home institution, students are provided a small grant to support preliminary research, as well as either onsite or remote videoconferencing consultation with MaRCCI personnel and others on the development of research proposals for submission to funding agencies. Approximately one to two years after completion, students receive a mentoring visit from a MaRCCI staff or designate. Students are also linked to one or more networks and online communities of practice (COP).

Progress todate

The Centre aims to provide effective post-graduate level training that produces plant breeders with sound theoretical and practical knowledge, with capability to employ the most current breeding approaches to effectively develop and release improved crop varieties that meet stakeholders needs and preferences across the region. This focus is accompanied by research and outreach efforts that address these same issues.

Training. Since 2008, the Makerere University Plant breeding programs have trained 117 MSc and 57 PhD students who have completed their studies, with more than 20 African countries represented (Figure 1). The centre has developed a reputation for producing graduates of a high quality at both MSc and PhD that are able to head breeding programs in the region. This is driven by MaRCCI's concretely set target profiles of their graduates as described below.

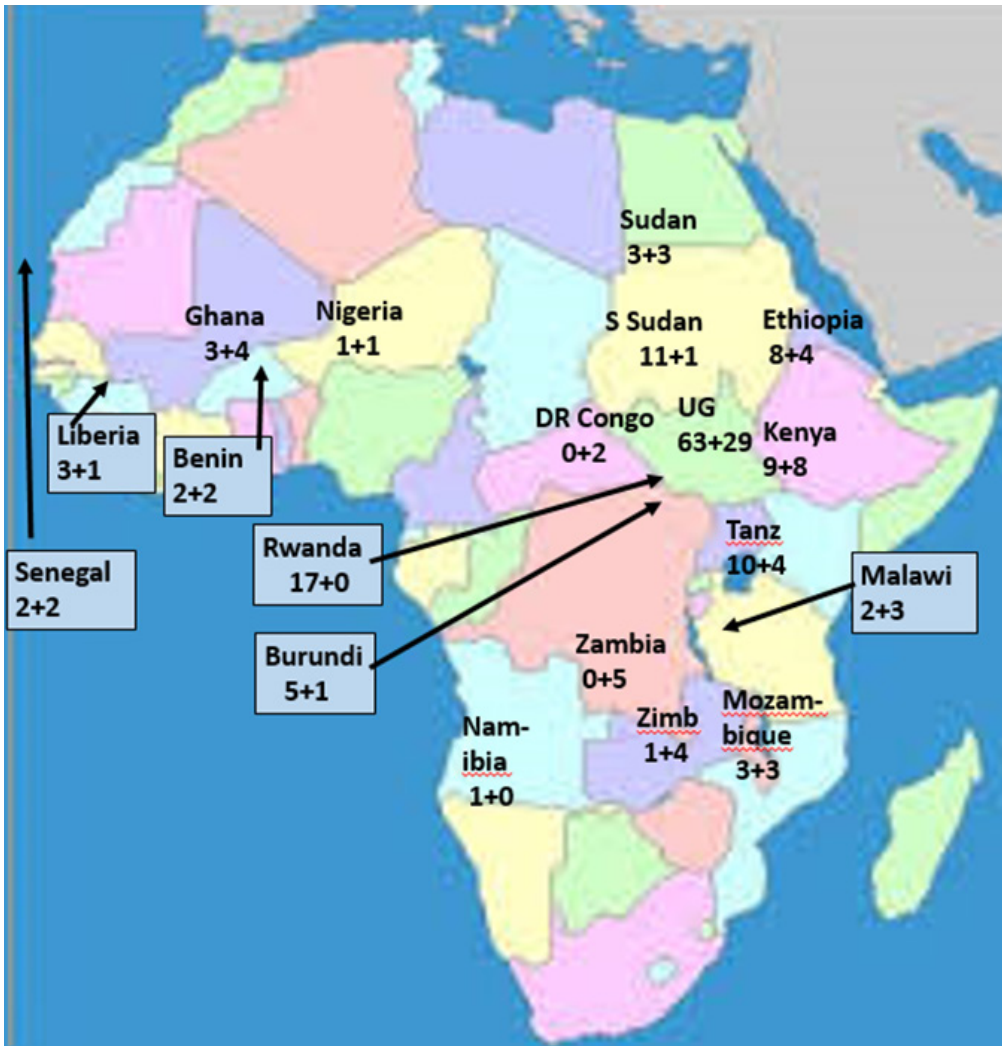
Target profile of PhD graduates from the Makerere University Regional Centre for Crop Improvement

1. Have the scientific and practical skills to initiate and manage an efficient and effective crop improvement program,
2. Have developed critical thinking skills and creative problem solving skills sufficient to develop new methodologies, creative solutions and innovative research addressing crop breeding challenges,
3. Be capable of teaching graduate level plant breeding and related courses at a high standard university,
4. Capable of providing leadership to national, regional and international networks of crop improvement specialists, and
5. Demonstrate a strong motivation and contribute to agricultural policies and development of their own countries and Africa.

Target profile of MSc graduates from the Makerere University Regional Centre for Crop Improvement

1. Have scientific and practical skill to manage an effective crop improvement program,
2. Have developed critical thinking skills and creative problem solving skills sufficient to understand and apply continuing developments in crop breeding class in crop breeding approaches,
3. Have sufficient academic background to successfully undertake PhD training at a world class institution,
4. Have developed a broad and strong linkages with other plant breeders in Sub Saharan Africa and beyond, and
5. Be strongly motivated to contribute to the agricultural development of their own country and Africa.

Graduate students from the Makerere University Plant Breeding and Seed Systems programs have excelled internationally and virtually and all of them are employed in national crop improvement programs in their home countries. Some of the MSc students completed or are completing PhD degrees at world class universities around the globe, and some are heading various research programs upon return to their home countries. Results of a tracer study by MaRCCI depicting the success of MSc students trained in the regional program are presented in Table 1. This demonstrate the quality of graduates trained at the Centre, capable of translating theories into practice and have wide ranging impact in agricultural development, food and nutrition security and on other sustainable development goals around the globe through plant breeding research.



Number displayed in red are for PhD's while those in green are for the MSc students trained.

Figure 1. Coutries represented and the number of graduate students so far trained at the Centre.

Internship program: To compliment the hands-on training of graduate students in practical breeding, MaRCCI has organized placements for students. This has been achieved through the broad and effective national, regional and international networks that MaRCCI has created and facilitated by the high quality of the program and the confidence that the Centre has generated. Students are sent to active breeding centres in National breeding programs, CGIAR centres and seed companies where they are able to comprehend plant breeding theories by participating in actual plant breeding and seed systems programs in these institutions. Survey feedback from internships revealed promising results. For instance, when students were asked to relate concepts learned in class to what they discovered during internship, 92% found the concepts, principles and theories taught in class to be relevant to the internship (Fig. 2).

In-house Research. The research wing of MaRCCI is driven by two in-house breeding programs in cowpea and sorghum. These programs are designed to offer hands on training opportunities to graduate students and acti as breeding models where best practices and modern breeding tools are deployed leading to development of improved varieties for the region. The cowpea and the sorghum breeding programs have assembled unique and diverse germplasm through the Centre's active networks with various partners. Most of these genetic materials have molecular marker data that are utilized for trait discovery and development of a genomic-aided selection platform.

Table 1.Tracer study for first cohort of MSc students trained in Makerere's regional program

Graduate	Country	Position and Employer (Public/Private/NGO/ others)
Patrick O. Ongom	Uganda	Associate scientist: cowpea molecular breeder, IITA, Kano,
Nigeria	Uganda	Maize breeder, Victoria Seeds, Uganda Ltd
Kwemoi Daniel Bomet	Uganda	Maize Breeder, National Agricultural Research Organisation, NaCRRI, Uganda
Namazzi Birabwa Sylvia	Uganda	Head of Business and Cooperation, Ecolife Foods, Uganda
Namugga Prossy	Uganda	Plant Breeder, National Agricultural Research Organisation, Uganda
Nsabiyera Vallence	Uganda	Research scientist, National Agriculture Research Organisation–NaBUN, Uganda
Gafishi Kanyamasoro .M	Rwanda	Research Scientist, Rwanda Agricultural Board, Maize program, Rwanda
Habarurema Innocent	Rwanda	Research Scientist, Rwanda Agricultural Board, Wheat program, Rwanda
Ndacyayisenga Theophile	Rwanda	Research Scientist, Rwanda Agricultural Board, Potato program, Rwanda
Nyombayire Alphonse	Rwanda	Research Scientist, Rwanda Agricultural Board, Rwanda
Shumbusha Damien	Rwanda	TAP-AIS, Rwanda/Country Project, FAO, Rwanda
Inimahoro Micheline	Burundi	Research Scientist, ISABU, Burundi
Niyongabo Fulgence	Burundi	Research Scientist, ISABU, Rice Team Leader, Burundi
Atwok Luka	South Sudan	Research Scientist, Maize program, Ministry of Agriculture, South Sudan
Maurice Mogga Laddo	South Sudan	Senior Research Scientist, Ministry of Agriculture, South Sudan
Mayada Mamoun Beshir	Sudan	Research Associate, Agricultural Research Cooperation, (ARC), Sudan

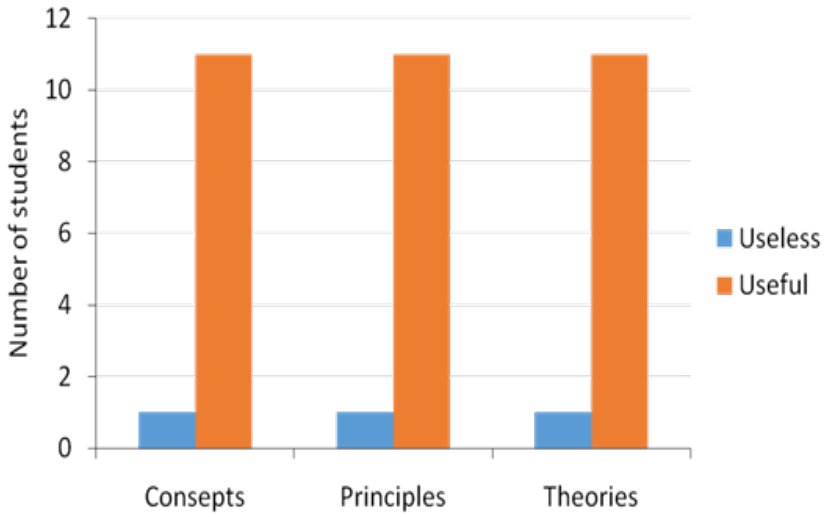


Figure 2. Response of students interns to whether class concepts, principles and theories were relevant to the internship

When student interns were asked as to whether the internship placement met their needs and expectations, more than 50% indicated that they were satisfied with MaRCCI internship program (Fig. 3).

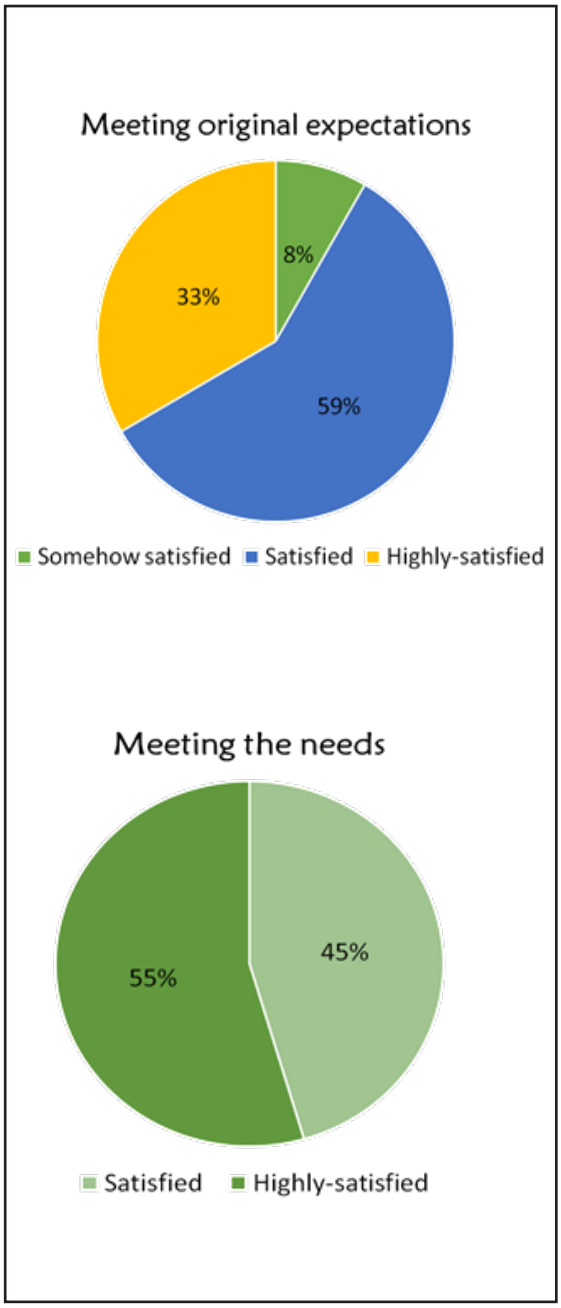


Figure 3. Response of intern students as to whether their needs and expectations were met

The diversity of these genetic materials is presented in Figure 4.

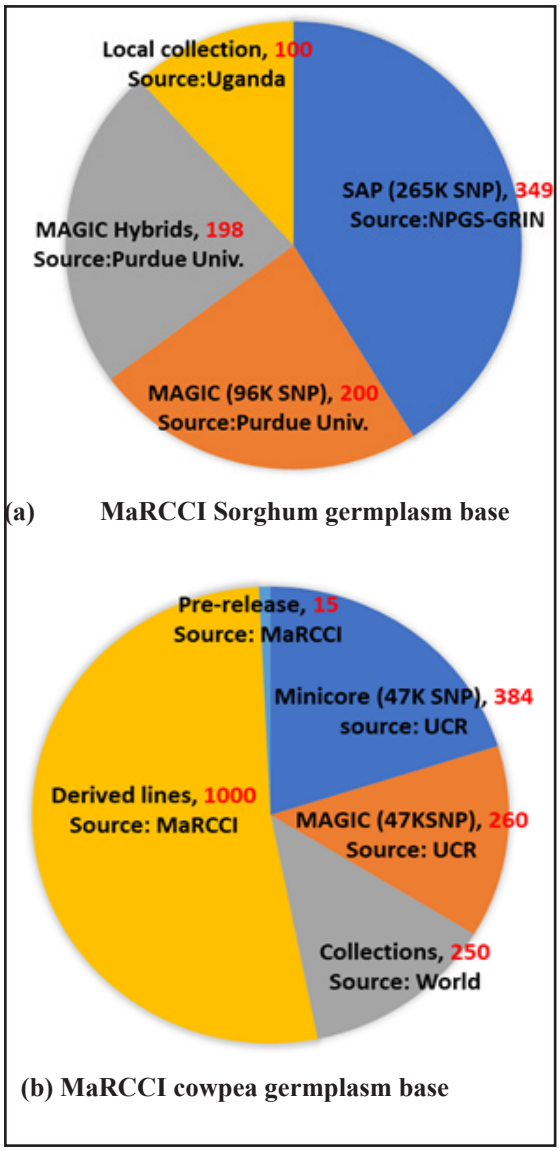


Figure 4. Germplasm base for sorghum (a) and cowpea (b) depicting the number of lines, source of genetic materials and single nucleotide (SNP) marker data available

Conclusion. A number of factors have contributed to MaRCCI's success in delivering quality training and research in plant breeding making it a regional training hub in East Africa that can be emulated elsewhere in Africa. The training is focused on market-led variety development; curriculum has been realigned to produce "market-ready"labor force; Practical hands-on training uses established breeding programs; Experienced and highly skilled staff teach and mentor students; Internships with private or public institutions improve appeal to prospective employers, and improved facilities

Table 2. Tracer study for second cohort of MSc students trained at the Makerere's University Regional Training Centre

Graduate	Country	Position and Employer(Public/Private/NGO/ others)
Amongi Winnyfred	Uganda	Associate Scientist: CIAT Uganda; PhD Student MaRCCI, Uganda
Aru John Charles	Uganda	Millet Breeder, National Agricultural Research Organisation, NaSARRI, Uganda
Dramadri Isaac Onziga	Uganda	Lecturer Makerere University; Research Team Leader MaRCCI
Iragaba Paula	Uganda	Research Scientist, National Agricultural Research Organisation, NaRCCI, Uganda
Kayondo Ismail Siraj	Uganda	Research Scientist, PostDoc Fellow, IITA, Ibadan
Kesiime Eunice Vaster	Uganda	Research Associate, National Agricultural Research Organisation, NaRCCI, Uganda
Liri Charles	Uganda	Managing Director at Tropical Seeds and Foods Ltd, Uganda
Okot Francis	Uganda	Plant Breeder/ Seed specialist-Sorghum for Beer Brewing and Sugar at Genesis Farms.
Opio Robert Oluge	Uganda	Agricultural Officer, Lira District Local Government, Uganda
Ozimati Alfred Adebo	Uganda	Lecturer, Makerere University, Team Leader Horticulture program, MaRCCI
Waniale Allan	Uganda	Research Associate, National Agricultural Research Organisation, Uganda
Mukamuhirwe Floride	Rwanda	Research Scientist, Rwanda Agricultural Board, Rwanda
Munganyiknka Esperance	Rwanda	Research Scientist, Rwanda Agricultural Board, Rwanda
Nizeyimana Fidele	Rwanda	Research Scientist, Rwanda Agricultural Board, Rwanda
Rashid Killoh Lussewa	Tanzania	Principal Agricultural Research Officer, Ministry of Agriculture, Food Security &Cooperation, Tanzania
Castiano Binaissa U. Levene	Mozambique	Breeder, Lecturer, Polytechnique Maniqua,, ISPM, Mozambique
Emabye Lijalem Gebrewahid	Ethiopia	Assistant Lecturer, Mekelle University, Ethiopia
Nolipher Khaki	Malawi	Agric. Research Scientist, in Malawi
Nyambok Anne Achieng	Kenya	Program Coordinator, Somo Ber Foundation, Kisumu County, Kenya

Table 3. Tracer study for Third cohort of MSc students trained at Makerere Regional Training Centre

Graduate	Country	Position and Employer (Public/Private/NGO/ others)
Bombom Aleexander	Uganda	Associate Scientist: Fortaleza, Ceara, Brazil
Maphosa Mcebisi	Zimbabwe	Assoc. Prof, Lupane State University, Zimbabwe
Mwololo James Kyalo	Kenya	Lead Scientist, Groundnut Breeder and Seed Systems, ESA
Sadik Kassim	Uganda	Director of Research, National Agricultural Research Organisation, AbiZARDI, Uganda
Sefasi Abel Yoas	Malawi	Senior Molecular Biologist, Lilongwe Univ. of Agriculture
Tembo Langa	Zambia	Senior Lecturer, University of Zambia
Mayada Mamoun Beshir	Sudan	Research Associate, Agriculture and Research Cooperation, Sudan
Runyararo Rukarwa J	Zimbabwe	Program Officer, RUFORUM, Uganda
Nzuve Felister Mbute	Kenya	Lecturer, University of Nairobi, Kenya
Munyir Shelmith	Kenya	Lecturer, Chuka University, Kenya
Edmore Gasturaa	Zimbabwe	Associate Prof, University of Zimbabwe

and equipment has increased quality of training of the graduates. The Centres' success is clearly evidenced by high satisfaction feedback, provided by students, employers, and sponsors. In addition, there is high retention rate of graduates in the region as a result of better training environment that keep African students within the continent. MaRCCI is now a highly appealing as a destination for training by local and regional governments and funders. It has now been designated by World Bank as a Center of Excellence for training plant breeders in Africa.

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Statement of no conflict of interest.

The authors declare that there is no conflict of interest in this paper

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