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Table of Contents

About the Journal

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Editorial

Insights into efforts to build Africa's Science Capacity

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ABSTRACT
This Issue of African Journal of Rural Development (AFJRD) presents seven papers related to an Analysis of the Higher Education ecosystem in Malawi, ongoing efforts by RUFORUM (Regional Universities Forum for Capacity Building in Agriculture) to train PhD graduates for Africa in Africa, and an initiative to integrate Problem-based learning in teaching and learning in six African Universities. Six other papers, linked to crop improvement, present research findings from studies conducted to improve pest and disease resistance and enhance nutrition content of selected crop varieties. The studies provide insights into the next steps to develop improved crop varieties for the continent. The key message is that Africa must hasten efforts to strengthen its human and science capacity to drive development efforts in the continent and universities would need to be more integrated in such efforts. Special attention needs to be put into increasing the pool of women scientists in African Universities and Research Organisations, and indeed in broad development and livelihood processes.

Key words: Africa, crop improvement, gender, Higher Education, STI

RÉSUMÉ
Ce numéro du Journal africain du développement rural (AFJRD) présente sept articles portant sur une analyse de l'écosystème de l'enseignement supérieur au Malawi, les efforts en cours de RUFORUM (Forum régional des universités pour le renforcement des capacités en agriculture) pour former des doctorants africains en Afrique, ainsi qu'une initiative visant à intégrer l'apprentissage base sur la resolution de problème dans l'enseignement et l'apprentissage dans six universités africaines. Six autres articles, liés à l'amélioration des cultures, présentent les résultats de recherches menées pour améliorer la résistance aux ravageurs et aux maladies, ainsi que pour augmenter la teneur en éléments nutritifs de certaines variétés de cultures sélectionnées. Certaines études fournissent des aperçus sur les prochaines étapes pour développer des variétés améliorées de cultures pour le continent.
Le message clé est que l'Afrique doit accélérer ses efforts pour renforcer ses capacités humaines et scientifiques afin de stimuler les efforts de développement sur le continent, et les universités doivent être davantage intégrées à de tels efforts. Une attention particulière doit être accordée à l'augmentation du nombre de femmes scientifiques dans les universités et les organismes de recherche africains, ainsi que dans les processus de développement et de subsistance en général.

Mots-clés : Afrique, amélioration des cultures, genre, enseignement supérieur, STI

A strong science capacity has been the key driver for development across the world. It is even more so today as Artificial Intelligence takes a centre stage in spurring innovations for today and the future. Unfortunately, Africa's science base is still very low with the continent contributing barely 5% of the global knowledge science outputs. Fortunately the Continent has recognized these deficiencies and has put in place necessary frameworks to spur innovations and development. Central to this is the African Vision 2063 that lays out the dream and Vision for the continent: *Building the Africa We Want*. Necessary frameworks for achieving Agenda 2063 have been put in place even at country level including for example Malawi Vision 2063.

The African Journal of Rural Development (AFJRD) was founded in 2015 to support sharing of knowledge including research advances across the continent. In this publication of AFJRD Volume Seven Issue 1, we present four major highlights. First, we present a Malawi country case study to highlight ongoing efforts including policy frameworks for strengthening the country's science, technology and innovation capacity which aligns to the Science, Technology and Innovation Strategy for Africa (STISA 2024) and other related frameworks. The country case study conducted by Chibowa *et al*. (2022) describe the current status of Science, Technology and Innovation ecosystem in Malawi with a focus on the Higher Education Sector and examining gender issues. The review shows a strong Government commitment to build a strong STI ecosystem. Several frameworks are in place that have opened increased access to higher education with a focus on STEAM (Science, Technology, Engineering, Arts and Mathematics). Overall, there is increase in students' intake but female participation is still low requiring additional measures to address the gender gap including at leadership level of the education sector. Enrolment in Public Universities increased from 4,772 in 2017/18 to 7,410 in 2021/22 representing a 38 % increase in enrolment but overall enrolment in Higher education remains low, only about 38%. Initiatives are needed to address issues that limit participation of women in the broader education and development landscape. Similar issues have been raised such as in the case of DR Congo (see Majaliwa *et al*., 2020), South Sudan (Akec *et al*., 2020) and Uganda and in other African countries (Nakayiwa *et al*., 2020).

Second, the issue includes a paper by Adidja (2022) profiling the effort by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) to build human and research capacity for the continent. This is being done using various mechanisms including joint efforts by African Universities to train academic staff through a Program where two universities co-fund the training of a staff member from one University in a partner University. The Program initiated by African Vice Chancellors in 2014 (Graduate Teaching Assistantship) primarily aims to increase the pool of PhD trained Staff in African Universities. RUFORUM has received funding support from a number of agencies to support training at both Masters and PhD levels and the training invariably includes research. To date RUFORUM has trained about 700 PhD and 2,500 MSc students. The paper by Adidja (2022) describes the partnership support from Carnegie Corporation of New York which has supported RUFORUM to beef up its graduate training program, and especially to increase the pool of women trained at MSc and PhD levels.

The third paper by Määttänen *et al*. (2022) describes an initiative funded by the EU-Erasmus Program to mainstream Problem based learning in African Universities. The initiative is led by HAME University in Finland and involves universities in Eastern Africa (Bishop Stuart University in Uganda and Egerton University in Kenya), University of Zambia in Zambia (Southern Africa) and University of Abomey Calavi in the Republic of Benin, West

Africa. Faculty academic staff are engaging in the implementation of the training and learning approaches in their respective Universities. The overall aim is to improve the teaching and learning approaches for enhancing quality of training in African Universities.

The remaining six papers present study results of efforts to develop improved crop varieties in the continent. The paper by Ayesiga *et al*. (2022) describes a study to improve maize genotypes for resistance to Fusarium Ear Rot, a widespread and devastating maize disease globally. But in the case of Sub-Saharan Africa the disease apart from reducing cob yield has the hidden impact of Aflatoxins infection that affects humans and livestock health and results in market rejection of maize grain. The study is part of a wider ongoing research efforts by national and International Research Centre (CIMMYT) to develop Fusarium Ear Rot resistant maize varieties. The paper by Ndusha *et al*. (2021) describes a study on identification of indigenous rhizobia species for enhancing yield of soybean in South Kivu, DRC. Indeed a number of nodulating indigenous rhizobia were identifies. Other studies done in Zimbabwe by Mpepereki *et al*. (1996 a&b); Musiywa *et al*. (2005) also identified nodulating strains of local rhizobia that have been adopted resulting in enhanced yield and production of cow peas and soybean in Zimbabwe. Similar findings have been reported on common beans in Kenya by Kawaka *et al*. (2018).

The paper by Badji *et al*. (2022) aimed to identify common genomic regions for short cooking time (CT) and iron and zinc content, which are key desirable Grain Quality Traits (GQT) in common beans (*Phaseolus vulgaris* L.). The study characterised 106 genomic regions of which 27 were associated with multiple traits, 17 with single trait for CT while nine were associated with both Fe and ZN contents. Both Fe and Zn contents are important for human health reasons and breeding for their increased content and short bean cooking time are desired. Hence, the study recommends that research, taking advantage of genomics-assisted breeding, should combine these trains into new varieties, as previously also suggested by the work of Saradadevi *et al*. (2021).

The last paper by Namakula *et al*. (2022) assessed variability and heritability of starch content in white fleshed and provitamin A cassava genotypes. A total of 112 cassava clones were studied in two locations in Uganda, East Africa. The study found significant variation in starch content and the trait appeared heritable. High starch content is a desired trait for human and livestock consumption but also in industrial uses such as production of bioethanol. Thus breeding programs for high cassava starch content should be supported

This Issue of AFJRD thus presents the need to beef up STI ecosystems in the continent, need to strengthen Higher Education in the Continent to build both Human capital and Science Capacity and the need for increased investment in Research for Development to address key gaps such as improving yield and nutritional quality of crop varieties.

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A gender-based assessment of Science, Technology and Innovations in Higher Education Ecosystem in Malawi

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ABSTRACT
Malawi has a number of policies to promote gender equality and social inclusion and advocate for women participation in science, technology and innovations. Yet, participation of women and girls in science, technology and innovations is still low. The study examined the current status of science, technology and innovations in higher education in Malawi with a gender perspective. The review was conducted to assess the national commitment and strategies in promoting gender equality. The study also used 2021/2022 public universities' selection data and five-year (2017-2022) enrolment data from the National Council for Higher Education. The findings revealed commitment of Malawi in promoting science, technology and innovations and ensuring gender equality and inclusiveness in higher education through its policies and plans. However, despite an overall increase of 36% in enrolment of students in public universities from 2017 to 2022, enrolment of female students was still low with a highest enrolment rate of 42% in 2021/2022 academic year. The enrolment of female students in science, technology and innovation programmes was even lower with less than 20% female participation. In 2021/2022 academic year, only 35% of the STEM related programmes were among the 20 top popular programmes while 90% were among the 21 least popular programmes. The study recommends a holistic approach in addressing barriers to women and girls' participation in ST&I and higher education by targeting upper primary and secondary school students, parents/ guardians, and rural community leaders among other interventions.

Key words: Gender equality, Higher Education, Malawi, Social inclusion, STEM

RÉSUMÉ
Le Malawi a un certain nombre de politiques visant à promouvoir l'égalité des sexes et l'inclusion sociale et à plaider pour la participation des femmes à la science, à la technologie et aux innovations. Pourtant, la participation des femmes et des filles à la science, à la technologie et aux innovations est encore faible. L'étude a examiné l'état actuel de la science, de la technologie et des innovations dans l'enseignement supérieur au Malawi dans une perspective de genre. Une étude etait menée pour évaluer l'engagement et les stratégies nationales en matière de promotion de l'égalité des sexes. L'étude a également utilisé les données des universités publiques sélectionnées de 2021/2022 et les données d'inscription sur cinq ans (2017-2022) du Conseil national de l'enseignement supérieur. Les conclusions ont révélé l'engagement du Malawi à promouvoir la science, la technologie et les innovations et à garantir l'égalité des sexes et l'inclusion dans l'enseignement supérieur par le biais de ses politiques et plans. Cependant, malgré une augmentation globale de 36% des inscriptions d'étudiants dans les universités publiques de 2017 à 2022, les inscriptions d'étudiantes étaient encore faibles avec un taux d'inscription le plus élevé de 42% au cours de l'année académique 2021/2022. L'inscription des étudiantes dans les programmes de science, de technologie et d'innovation

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était encore plus faible avec moins de 20 % de participation féminine. Au cours de l'année académique 2021/2022, seuls 35 % des programmes liés aux STEM figuraient parmi les 20 programmes les plus populaires, tandis que 90 % figuraient parmi les 21 programmes les moins populaires. L'étude recommande une approche holistique pour éliminer les obstacles à la participation des femmes et des filles à la ST&I et à l'enseignement supérieur en ciblant, entre autres interventions, les élèves du deuxième cycle du primaire et du secondaire, les parents/tuteurs et les dirigeants des communautés rurales.

Mots clés: Égalité des genres, Enseignement supérieur, Malawi, Inclusion sociale, STEM

INTRODUCTION

The role of Science, Technology and Innovations (ST&I) in the social and economic development of any country cannot be overemphasized. The Malawi 2063 development agenda recognizes that science, technology and innovation is a catalyst for achieving its three pillars namely: Agriculture Productivity and Commercialization, Industrialization, and Urbanization (NPC, 2020). Hence, the emphasis on human capital development including strengthening infrastructure in ST&I such as construction of world-class laboratories and expanding programmes in Science Technology, Engineering, Arts and Mathematics (STEAM) as an enabler to achieve the vision. The higher education institutions and technical and vocational education training institutions in Malawi are challenged to expand opportunities to STEAM programmes for both male and female students. However, gender inequalities still exist in the enrolment and participation in Science, Technology, Engineering, and Mathematics (STEM) programmes, careers and higher education ecosystem. The barriers to access and success for female students in STEM are well documented world-wide, including in Malawi, and from numerous perspectives, leading to findings which suggest that: STEM environments can be unfriendly for women.

A study on gender and inclusivity in Malawi's technical institutions, classified programmes were as male-dominated and female-dominated depending on the nature of the programme ((UNESCO, 2018). Less than 40% of the female applicants were enrolled in technical programmes. The ratio of female to male students in Malawi's technical training colleges remains unbalanced with 30:70 for STEM related programmes and 70:30 for programmes such as secretarial studies, tailoring and design. Not surprisingly, female students identified the shortage of female lecturers as one of the barriers to their success in male-dominated STEM programmes. Other identified barriers related to lack of inclusive policies and strategies along with an absence of concrete and measurable actions and outcomes from policies and interventions. Some barriers are more fundamental and originate from culture and deficits in early education. The educational deficits greatly affect female students' ability to enroll in STEM programmes in higher education.

Nevertheless, globally, there have been interventions designed to increase women's participation and success such as: active, or inquiry-based, learning in STEM (Craig, 2014; Savage, 2018); engineering design (Chukwurah and Klein-Gardner, 2014); after-school gender equity mentorship programs (Froschl and Sprung, 2014); alternative pedagogies (Taube and Polnick, 2014); assessments in STEM courses (Wallace and Hattingh, 2014) and mentorship programmes/workshops for sustaining female STEM faculty in higher education institutions (Mavriplis *et al*., 2014). The reality is that well-intentioned interventions can unintentionally perpetuate equally (or more) harmful barriers to women's participation in STEM such as feelings of being tokenized (Garces and Jayakumar, 2014), stereotype threat (STT) (Steele and Aronson, 1995; Fink, 2015; Gregory, 2017), and misguided ('deficit') focus on fixing and fitting women into STEM instead of challenging underlying social

and cultural beliefs about the nature of STEM.

Despite the initiatives to increase women participation in STEM, women still lag behind in enrolment in STEM fields. However, there is inadequate information on gender assessment in ST&I and higher education ecosystem to ascertain the effectiveness of the initiatives in reducing the gender gap in ST&I and higher education. This paper presents findings from the gender assessment in ST&I and higher education ecosystem in Malawi.

METHODOLOGY

Data were collected through document analysis of policies, legislatures and other reports that promote the advancement of science, technology and innovations as well as supporting gender equality in ST&I. A number of documents were analysed and these included: The Malawi 2063; the National Science and Technology Policy and the Science and Technology Act (2003), The National Commission for Science and Technology (NCST); the National Education Sector and Investment Plan (NESIP 2020-2030); The National Inclusive Education Strategy (NIES-2017-2021); and The model gender and anti-sexual harassment policy for higher education institutions in Malawi. The analysis was conducted to assess Malawi's commitment in promoting Science, Technology and Innovations and ensuring gender equality and inclusiveness in higher education especially in STEM programmes.

The study used five-year (2017-2022) enrolment data from the National Council for Higher Education (NCHE) to assess participation of female and male students in STEM related programmes. The study mainly focused on the six public universities namely: University of Malawi (UNIMA), Mzuzu University (MZUNI), Lilongwe University of Agriculture and Natural Resources (LUANAR), Malawi University of Science and Technology (MUST), Kamuzu University of Health Sciences (KUHeS) and Malawi University of Business Sciences(MUBAS). Most of the STEM related programmes in Malawi are offered by public universities. The STEM programmes were selected based on the significant differences in enrolment rates between male and female students. Programmes with large gender disparities were selected. The time series data provided trends on the enrolment of female students in ST&I programmes over the five years. The study also used the 2022 public universities' selection data from the National Council for Higher Education (NCHE). The selection data were used to assess students' choices in relation to science, technology and innovations' programmes.

FINDINGS AND DISCUSSION

Gender Equality and Social Inclusion in ST&I: Overview of policies and legislature. There are a number of policy documents that support the Malawi's STI systems and gender equality in STI and higher education. These include: The Malawi 2063; the National Education Sector and Investment Plan (NESIP 2020-2030); The National Inclusive Education Strategy (NIES-2017-2021); The model gender and anti-sexual harassment policy for higher education institutions in Malawi; and the National Science and Technology Policy and the Science and Technology Act (2003).

The Malawi 2063 expresses the vision of the country to be an inclusively wealthy and self-reliant nation through its three pillars namely: 1. agriculture productivity and commercialization; 2. Industrialization, and 3. Urbanisation. It recognizes the role of science, technology and innovations in achieving this vision and calls upon institutions of higher education to strengthen infrastructure in STIs and expand programmes in STEM in order to increase human capacity required to implement the pillars. The Malawi 2063 also calls for inclusiveness in wealth creation by ensuring gender equality in all activities including participation in ST&I and higher education. The vision, therefore, provides opportunities for higher education ecosystem to be creative and innovative in strengthening ST&I and increasing participation of women in ST&I and higher education (NAP, 2020).

The National Science and Technology Policy. The policy recognises the role of science and technology in enhancing socio-economic development of the country and improving the standard and quality of life of Malawians. This will be achieved through: (i) Establishing and strengthening national capacity for research; (ii) Developing and raising the national productive capacity and improve competitiveness through the efficient application of technologies; (iii) Promoting and developing traditional, endogenous, new and innovative technologies; and (iv) Creating knowledge and S&T awareness to improve and develop the scientific and technological culture of Malawians. The policy also provides for an elaborate organisational structure (Figure 1) to institutionalise ST&I in Malawi. The structure includes the cabinet committee on science and technology whose role is to scrutinise draft policies and bills before they are presented to the full cabinet. The structure also includes the Parliamentary Committee on Education, Science and Human Resources that performs an advisory role to the National Assembly on science and technology matters (Figure 1). The draft policies and bills related to science and technology are referred to this Committee prior to being debated in the National Assembly. The existence of these committees shows the national commitment and political will towards ST&Is and presents a challenge for higher education to respond to the increasing demand for ST&Is.

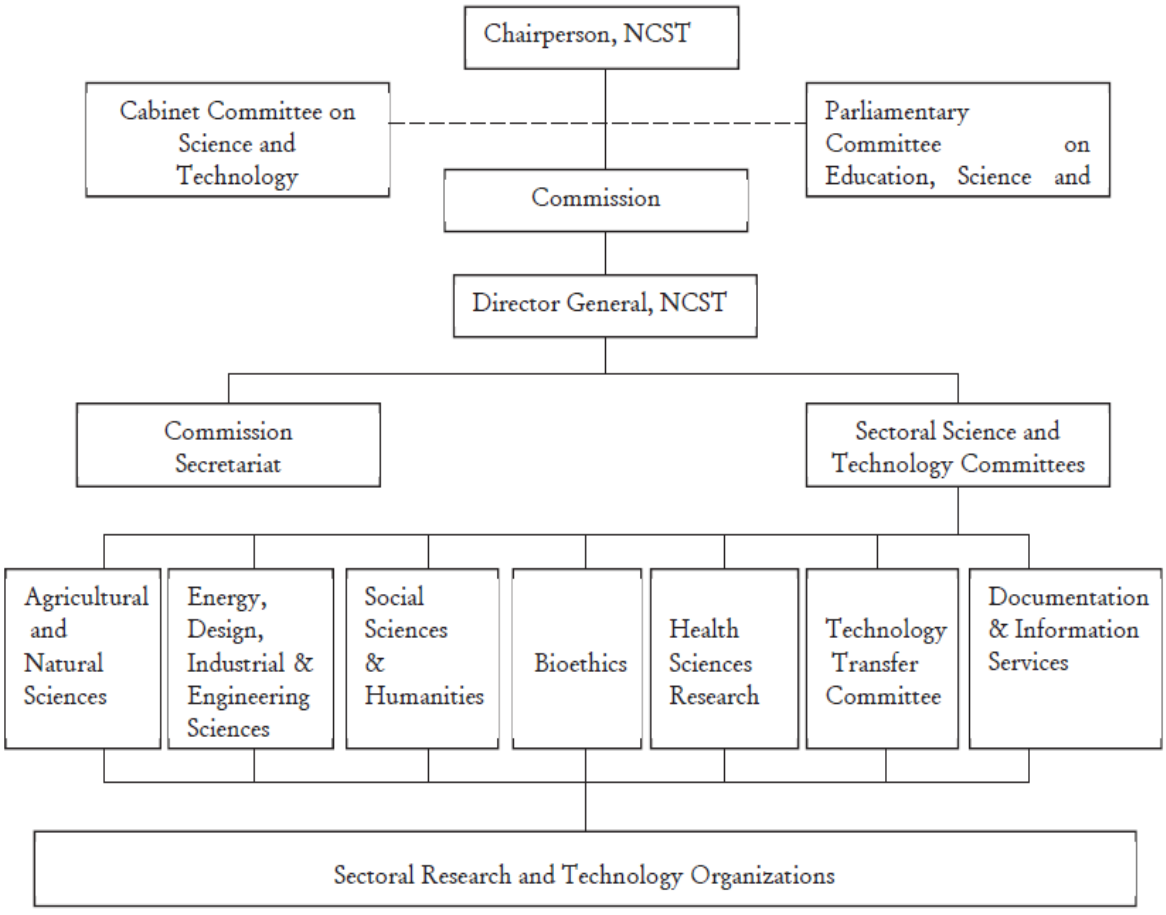

Figure 1. Institutional and Organization Framework for STI in Malawi

The policy also proposes adopting strategies that foster the participation of women in the development and utilization of S&T that include: (i) encourage research into all forms of gender differentiation in S&T education and employment; (ii) promote women's access to S&T education at all levels; (iii) foster gender equity in S&T in education and the workplace; (iv) facilitate the entry of women into employment in S&T fields and their career advancement, and; (v) foster socially responsible, gender-inclusive S&T. However, despite these strategies that have been there over the years, women are still underrepresented in higher education especially in ST&I programmes. This calls for further assessment whether the strategies were implemented or there were challenges that affected their implementation.

The Science and Technology Act (2003). This is the legislature that provides a legal backing for the advancement of science and technology in Malawi. The main objectives of the Act were to: (i) Provide for the advancement of science and technology; and (ii) Establish the National Commission for Science and Technology. The Act became operational in 2008 and the National Commission of Science and Technology in Malawi was established in 2009 through this Act.

The National Commission for Science and Technology. The Commission was established as a principal advisory body to Government and other stakeholders on all science and technology matters for advancement of science, technology and innovation for sustainable growth and development in Malawi that will also lead to wealth creation as well as improving quality of life for all Malawians. The commission reports to the Ministry of Education, Science and Technology on policy and technical issues and the Department of Statutory Corporations in the Office of the President and Cabinet on governance and other administrative matters. The Commission has seven functional sectoral committees namely: (i) Agriculture and Natural Sciences, (ii) Energy, Design, Industrial and Engineering Sciences, (iii) Social Sciences and Humanities, (iv) Bioethics; (v) Health Sciences Research, (vi) Technology Transfer; and (vii) Documentation and Information Services. These committees are the entry points for the research institutions and higher education institutions to advance their agenda in science, technology and innovations. Recently, the commission in collaboration with the Directorate of Science and Technology in the Ministry of Education, Science and Technology is hosting the Women in Science Engineering and Technology Organisation (WSETO) in Malawi. This is a platform where women interact, share experience and network on ST&I issues. Currently the platform has 210 participants. The commission also provides a forum for disseminating research in science and technology through the annual dissemination conferences. The forum can be used to drive the agenda for promoting gender equality and social inclusion in science, technology and innovations.

The National Education Sector Investment Plan (NESIP- 2020-2030). The NESIP (2020-2030) is a long-term strategic document for the education sector that guides the implementation of key activities to achieve national and international commitments from 2020 to 2030. The plan emphasizes the need to increase access to education at all levels. For example, in the higher education sector, the Government committed resources to expand physical infrastructure at Malawi University of Science and Technology (MUST) and Lilongwe University of Agriculture and Natural Resources (LUANAR). In addition, the University of Malawi was delinked on 4th May, 2021 into three universities namely: Malawi University of Business and Applied Sciences (MUBAS), Kamuzu University of Health Sciences (KUHES) and University of Malawi (UNIMA) to further increase access to higher education and improve governance and management of the public universities. Besides establishment of new public universities, other innovative Open and Distance Learning (ODL) approaches in higher education are expected to

further increase access to higher education in Malawi. The plan also emphasizes on inclusive and equitable access to education. The strategies have been put in place to ensure that female and disadvantaged students including persons with disability have access to higher education. One of the strategies is ensure that all physical infrastructures such as classrooms, laboratories and hostels in higher education institutions are accessible by persons with disabilities.

The National Inclusive Education Strategy (NIES-2017-2021). Over the years, the Education Sector in Malawi has been facing challenges of equity, access, quality, relevance, governance and management. The strategy was developed to show commitment of the Government of Malawi in promoting equitable access to relevant and quality education at all levels, namely Early Childhood Development, Primary Education, Secondary Education, and Tertiary Education. It also responds to the UN conventions and agreements to which Malawi is party to. The NIES was a medium-term intervention aimed at promoting quality inclusive education at all education levels. This was also the basis for increasing access to higher education for female students and Persons With Disabilities (PWD). During the implementation period of this strategy, female enrolment in public universities increased from 33% in 2008 to 41% in 2018 as a result of Government's affirmative action though female enrolment in STEM programmes remains lower than that of their male counterparts.

Model Gender and Anti Sexual Harassment Policy for Higher Education Institutions (HEIs) in Malawi (2021). There are discrepancies in enrolment, performance as well as participation in decision making in HEIs in Malawi. To address this, NCHE with funding from United Nations Development Programme (UNDP) developed a model gender policy to create a gender-transformative environment in HEIs for all staff and students, particularly women and persons with disabilities. Among others, the policy promotes equality in the enrolment, retention and performance of male and female students as well as equal representation of male and female staff in recruitment and decision-making positions. The policy also provides for inclusive education where infrastructure and materials are supposed to be accessible by Persons with Disabilities. The HEIs are supposed to use this opportunity to close the gap between male and female students in science and technology programmes by ensuring that strategies are in place to increase enrolment, enhance performance and increase retention of students.

Current Status of Higher Education Institutions in Malawi. The universities in Malawi fall into two primary sub-sectors: public universities, which are established by Government through Acts of Parliament; and private universities, which are established through university charters but are accredited by Government. The Ministry of Education, Science and Technology is responsible for drafting bills to establish public universities but does not exercise direct control over public universities, as these are statutory organizations which are governed by the board of governance. However, the directorate of Higher Education within MoEST works closely with public universities and serves as a link between universities and the Government on matters of policy. Public universities in Malawi are subsidized by the Government and they obtain funding directly from the Ministry of Finance.

Currently, there are six public universities in Malawi namely: University of Malawi (UNIMA), Mzuzu University (MZUNI), Lilongwe University of Agriculture and Natural Resources (LUANAR), Malawi University of Science and Technology (MUST), Kamuzu University of Health Sciences (KUHeS) and Malawi University of Business Sciences (MUBAS). The LUANAR was delinked from UNIMA in 2012 while MUBAS and KUHeS were delinked in 2021. All the six public universities were established by Acts of Parliament which clearly delineate institutional governance and management structures. The delinking of UNIMA is an opportunity for increasing access to higher education. The 2021/22 enrolment

registered an increase of 6% from the 2020/2021 enrolment. This was unexpected very low increase rate considering that two new universities were established. The Government of Malawi is further investing in physical infrastructure such as laboratories, lecture theatres and hostels to allow more students to enrol in public universities.

There are 21 Private Universities in Malawi, mostly owned by churches. Most of the private universities offer programmes in arts and humanities, business administration, financial accounting and management, procurement and education. Very few private universities offer programmes in science, technology and innovations because they are presumed expensive to run due to demand for laboratory equipment and materials and other infrastructure. There is also higher demand for enrolment in art and humanities programmes than science and technology programmes because of the deficiencies in the entry requirements which is mostly a credit in STEM courses. Most of the students, especially females and students from Community Day Secondary Schools (CDSS), fall short of entry requirements for STEM programmes.

Women participation in Top University Management Positions. Two out of six Vice Chancellors (VC) in public universities in Malawi are women representing 33% while two out of the six Deputy Vice Chancellors(DVC) are women also representing 33% (Table 1). This is an improvement from the past two years, in 2020, where out of the four vice chancellors, only one was a woman representing 25% and all the DVCs in four institutions were men. The presence of women in top university management positions is a positive direction towards embracing gender transformation and is an opportunity for reducing gender inequalities in higher education. Women in top management positions are able to make decisions that can influence change in gender equality and social inclusion.

Students' Choices for STEM Programmes in Public Universities. The 2021/2022 Public Universities selection in Malawi revealed that STEM programmes are unpopular among prospective university students. Out of the 20 top popular programmes according to students' choices, only 7 were STEM related programmes representing 35% (Figure 2). Out of the 7 STEM programmes, 3 were education sciences, 2 were nursing and midwifery related programmes, 1 was Bachelor of Science in Environmental Health and 1 was Bachelor of Pharmacy (Hons} programme. None of the 20 top popular programmes was Engineering, Technology and Mathematics related programme. Full list of the top and least popular programmes is presented in Tables 2 and 3.

Table 1. Gender Representation in University top management positions

University	Vice Chancellor		Deputy Vice Chancellor	
	M	F	M	F
MUBAS		1	1	
KUHES	1			1
UNIMA	1		1	
LUANAR	1			1
MUST		1	1	
MZUNI	1		1	
Total	4	2	4	2

Table 2. The 2021/22 top popular programmes among students' choices

NO	Programme CODE	PROGRAMME NAME
1	UMA-HU	Bachelor of Arts
2	MZU- BED SC	Bachelor of Education (Science)
3	MUB-JOU	Bachelor of Arts in Journalism
4	MUB-BAC	Bachelor of Accountancy
5	KUH-NM	Bachelor of Science in Nursing and Midwifery
6	MUB-BBC	Bachelor of Arts in Business Communication
7	UMA-SSSW	Bachelor of Social Science (Social Work)
8	MUB-BBAG	Bachelor of Business Administration (Generic)
9	MZU-BEDA	Bachelor of Education (Arts)
10	UMA -BEDSED	Bachelor Education (Social Studies)
11	MUB-BAF	Bachelor of Commerce (Banking and Finance)
12	MZU-BED L	Bachelor of Education (languages)
13	MZU-BSNM	Bachelor of Science (Nursing and Midwifery)
14	MZU-BACOS	Bachelor of Arts in Communication Studies
15	UMA-BEDLED	Bachelor of Education (Language)
16	MUB-EH	Bachelor of Science Environmental Health
17	UMA-ECD	Bachelor of Early Child Development
18	UMA-BEDCHE	Bachelor of Education (Chemistry)
19	UMA-BEDMAT	Bachelor of Education (Mathematics)
20	KUH-PHARM	Bachelor of Pharmacy (Hons)

Table 3. The 2021/22 least popular programmes among students'choices

NO	Programme CODE	PROGRAMME NAME
1	MST-MEC	Bachelor of Science in Meteorology and Climate Sciences
2	UMA-SOC	Bachelor of Arts in Sociology
3	LNR-BAQF	Bachelor of Science in Aquaculture and Fisheries Science
4	UMA-SCIFC	Bachelor of sciences in family and consumer sciences
5	MST-GIS	Bachelor of Science in Geo-information and Earth Observation Science
6	MST-PETR	Bachelor in Petroleum Geoscience (Oil and Gas)
7	UMA-BEDHEC	Bachelor of education (human ecology)
8	MZU-BSLPP	Bachelor of Science in Land Management (Physical Planning)
9	LNR-BENE	Bachelor of Science in Environmental Engineering

10	MUB-BPP	Bachelor of Science in Physical Planning
11	MUB-BMEN	Bachelor of Science in Mining Engineering (Hons)
12	MUB-BMMP	Bachelor of Metallurgy and Mineral Processing Engineering (Hons)
13	UMA-SCIPHY	Bachelor of Science in Physics
14	MZU-BSLEM	Bachelor of Science in Land Management (Estates Management)
15	LNR-BHLD	Bachelor of science in Horticultural Sciences and Landscape Design
16	MUB-BGEN	Bachelor of Geological Engineering (Hons)
17	MST-ESC	Bachelor of Science in Earth Science (Geology)
18	MUB-BLE	Bachelor of Science in Land Ecology (Hons)
19	MST-MME	Bachelor of Engineering (Hons) in Metallurgy and Material Engineering)
20	MST-BSS	Bachelor of Science in Sports Science
21	MST-TXE	Bachelor of Engineering in Textile Engineering

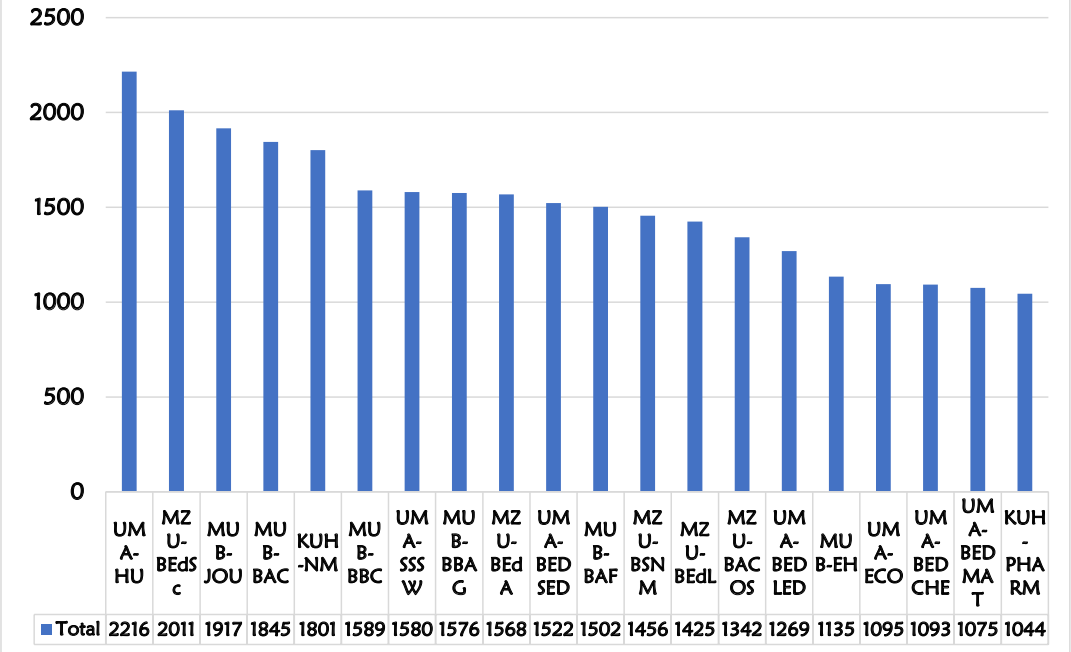

Figure 2. Top 20 Popular Programmes in Public Universities based on number of choices
Source of Data: NCHE

On the other hand, out of the 21 least popular programmes according to students' choices, 19 were STEM related programmes representing 90% while 2 were humanities and Arts programmes (Figure 3). The results imply that secondary school students prefer to pursue Non-STEM programmes at the university. This may be due to the entry requirements for STEM programmes that demand credit passes in science subjects, which most of the secondary school students, especially those

in CDSS, do not have. There is also a perception that STEM programmes are difficult and most of the students who enrol in such programmes in Public Universities are withdrawn on academic grounds. This may also discourage some students to enrol in the programmes. Malawi's economy is agro-based, but Agriculture related programmes are not popular among the students' choices and none of the agriculture related programmes was among the top popular programmes while three were among the least popular programmes. This is worrisome and a threat to achieving Malawi 2063 priority one, which is agriculture-related and requires human capacity building.

Since 2017, the public universities that are mostly science based are very unpopular among the choices of the prospective students. The five-year data on choices for public universities' programmes show that MUST, LUANAR and KUHES were very unpopular among the choices (Figure 4). These three universities offer mostly STEM-related programmes. Findings indicate that UNIMA is the most popular public university among the choices of prospective students probably because it also offers a combination of science, arts and humanities programmes. Overall, the number of students enrolled in STEM related programmes are low while the number of female students is even lower in institutions that are STEM based. This may be attributed to the low performance in science subjects at secondary school which is a requirement in such institutions.

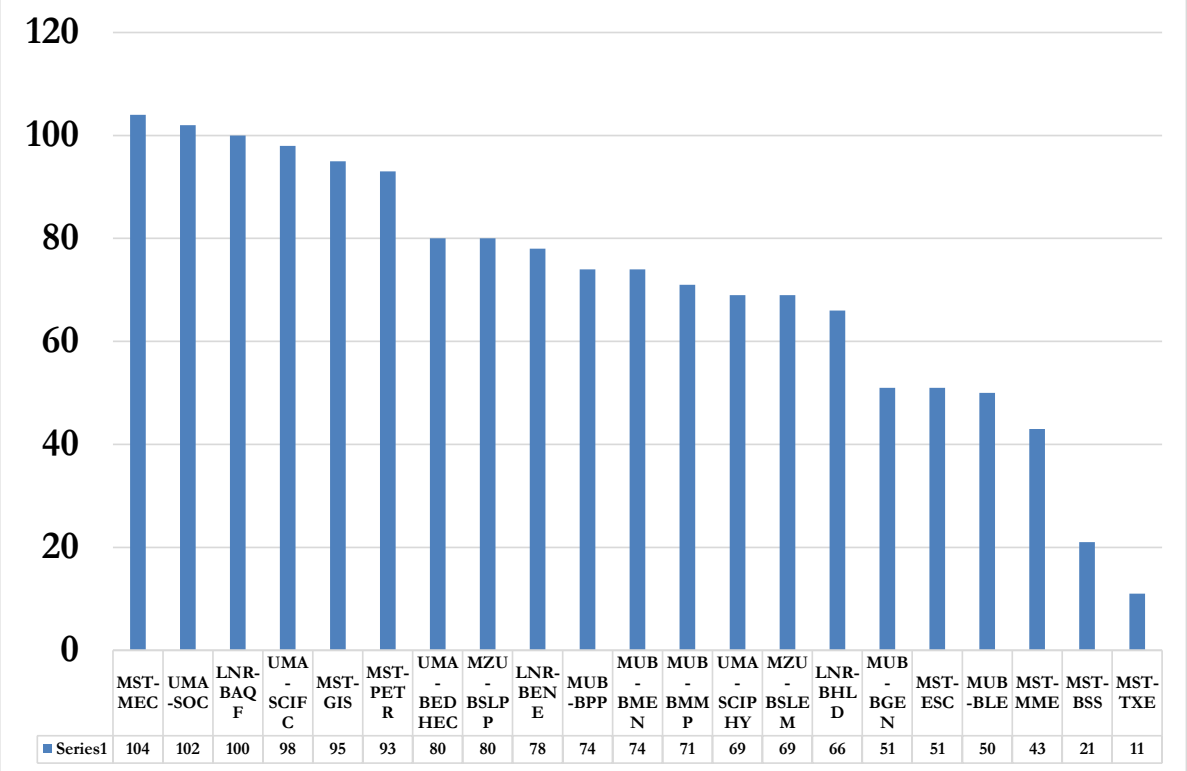

Figure 3. Least 21 Popular programmes in Public Universities based on number of choices
Source of Data: NCHE

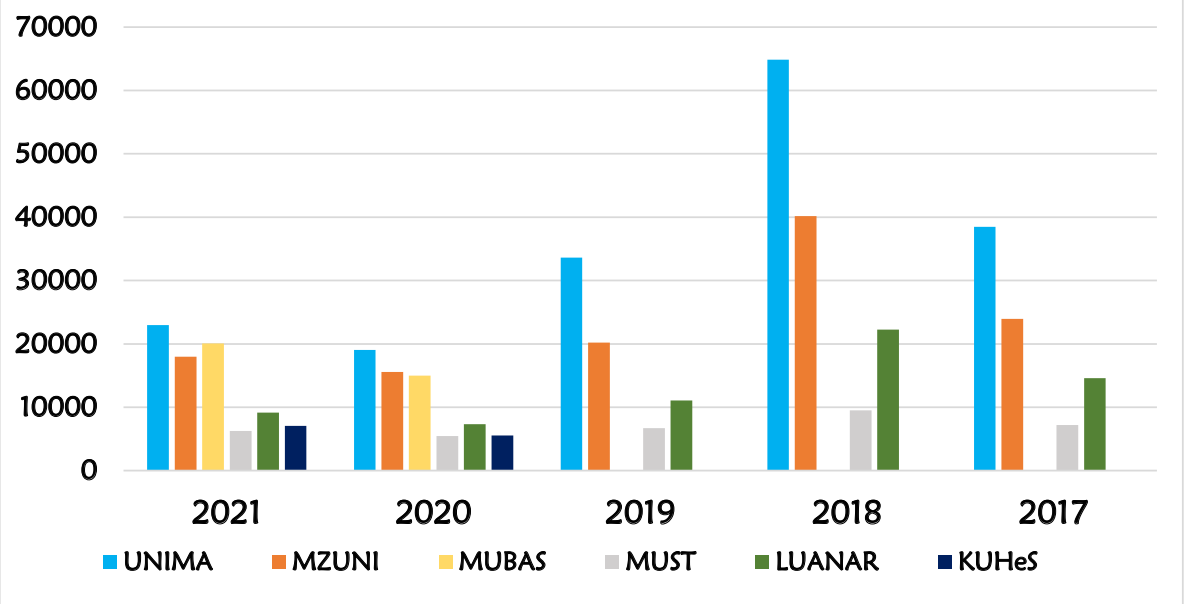

Figure 4. Institution Popularity Based on Number of Choices during Applications.
Source of Data: NCHE

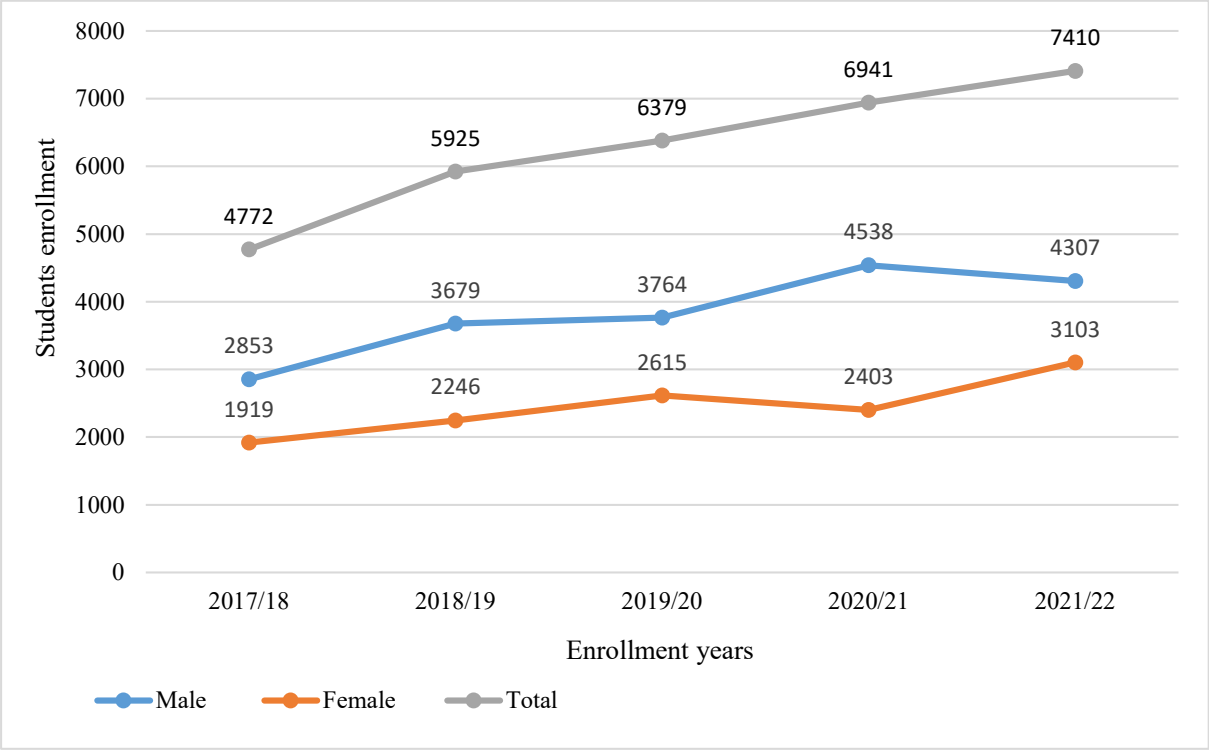

Figure 5. Enrolment of students in public universities from 2017/18 to 2021/22
Source of Data: NCHE

Trends in the enrolment of students in public universities in Malawi from 2017/18 to 2021/2022. The total number of students enrolled in public universities increased from 4,772 to 7,410 representing 36% increase in the past five years (Figure 5). The overall increase in enrolment may be attributed to delinking of UNIMA into three new universities that has resulted in increased enrolment at MUBAS and KUHeS.

The results showed the increase in the number of female and male students enrolled in public universities. It was observed that the rate of increase for female students was higher (38%) than the overall rate of increase (36%) and increase rate for male students (34%). This may be attributed to affirmative action and initiatives that were introduced to increase enrolment of female students in public universities. It should also be noted that the rate of enrolment for female students decreased within the five-year period due to other factors. For instance, there was a drop in the percentage of female students during the 2020/21 academic year (35%), the lowest in the period of five years and all the public universities registered low percentage of female students' enrolment in the academic year (Figure 6). This may have been triggered by COVID-19 related issues because this was one of the years when Malawi experienced adverse effects of COVID-19 and registered a higher percentage of female students who dropped out of primary and secondary school due to unwanted pregnancies or early marriages. The higher education was not spared with COVID-19 effects on female enrolment. The 2021/22 academic year registered the highest percentage (42%) of female students enrolled in public universities and this was a great achievement for Malawi higher education.

In general, the results show that there is a significant increase in the overall enrolment of students and female students, in particular, in public universities. This is an encouragement that the gender gap is decreasing in the enrolment of students in higher education institutions. The SADC recommendation is to have a 50:50 enrolment for male and female students in the region and there are a few countries that have reached the target, however, most of the countries including Malawi are moving in positive direction as it currently stands at 42%.

Gender Parity in ST&I Programmes in Public Universities

Gender Parity in Enrolment in natural sciences Programmes. The enrolment of students in public universities for the past five years, 2017/18 to 2021/22 shows low numbers of students enrolled in ST&I programmes. The results in Figure 7 show that for every female students, less than five enrolled in natural science programmes in 2017. This may be due to cultural and attitudinal perceptions that natural sciences are difficult courses and not suitable for girls. However, the number female students enrolled in statistics and mathematics increased over the years. The increase may be attributed to interventions that encourage participation of female students in STEM programmes.

Gender Parity in enrolment in Nursing and Midwifery Programmes. The trend on enrolment of female students is different for nursing and midwifery programmes where more female students are enrolled than their male counterparts (Figure 8). This may be the case because of the gender inequalities in the division of labour at the household level where girls have roles and responsibilities associated with taking care of children and caring for the sick. The nursing and midwifery profession is perceived as a profession for women. However, enrolment of female students in medicine programmes was at least over 30% and in some years, it was 50%. This implies that female students are competing favourably with male students in health/medicine related programmes.

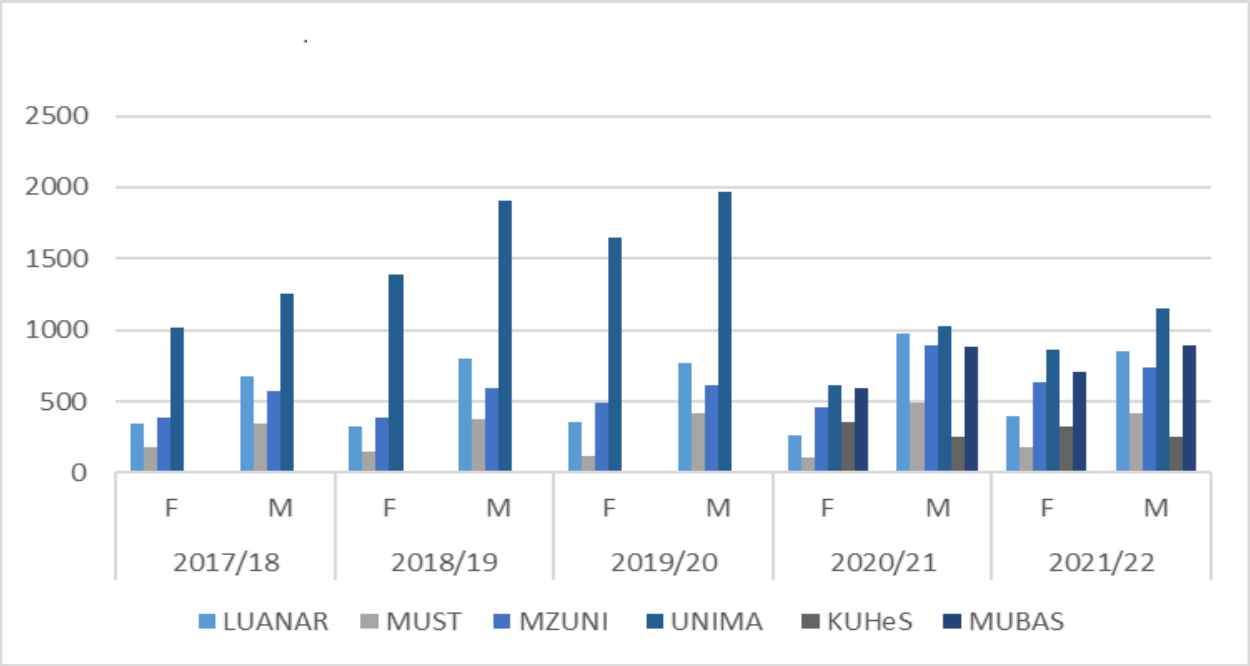

Figure 6. Trends in Enrolment of Students from 2017/18 to 2021/22
Source of Data: NCHE

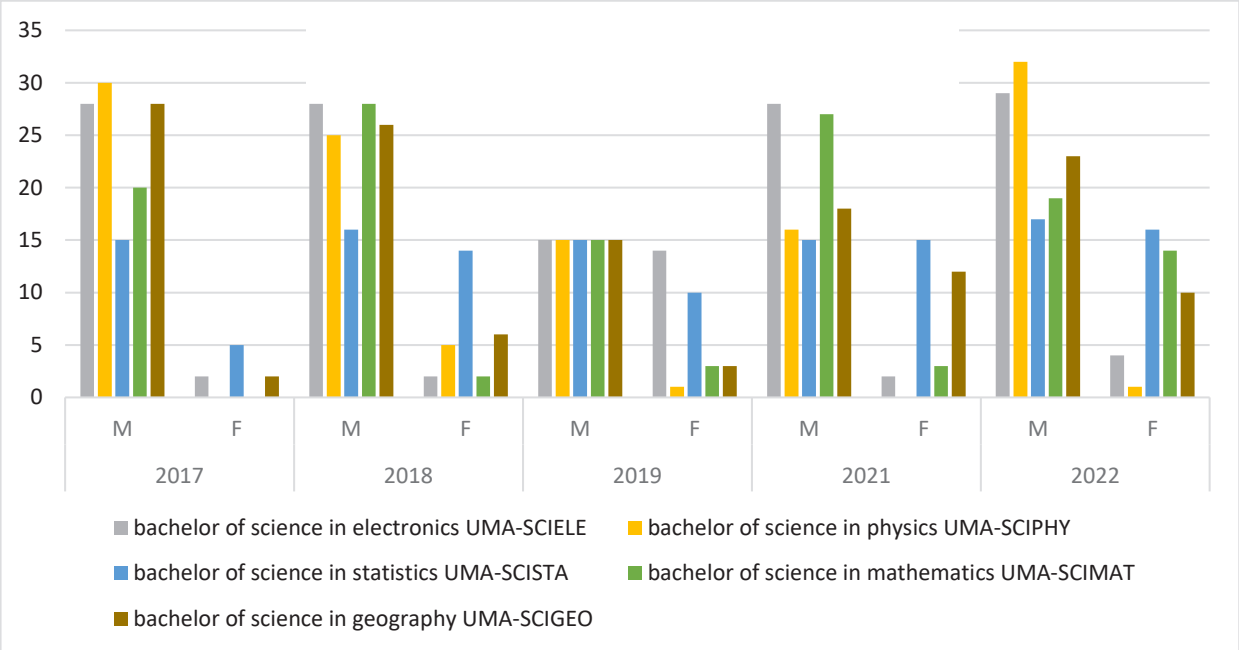

Figure 7. Students enrolment in Natural Science Programmes
Source of Data: NCHE

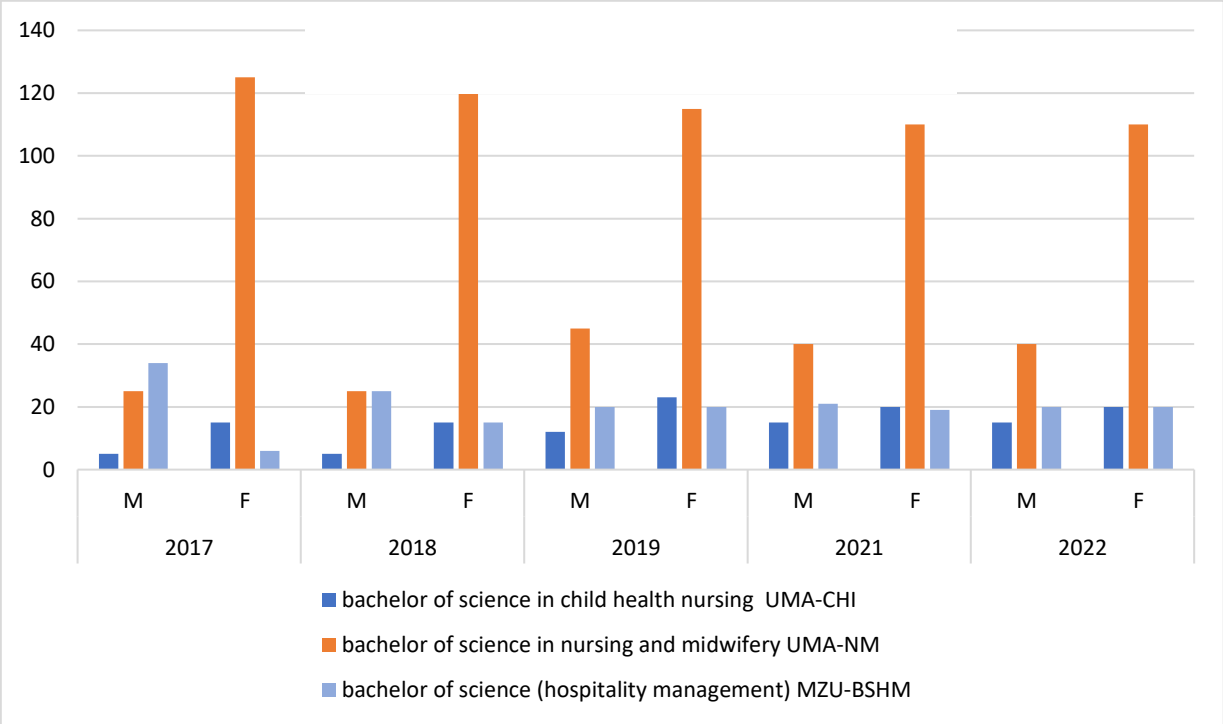

Figure 8. Students enrolment in Nursing and Midwifery Programmes
Source of Data: NCHE

Gender parity in enrolment in engineering programmes. The results showed low numbers of female students enrolled in engineering related programmes between 2017 and 2022 (Figure 9). However, the numbers of female students enrolled in computer network engineering improved over the five years. The results also showed that textile engineering is not popular among female students as it registered very low numbers and there was no female student in 2019 and 2022 selection. This is unexpected as women are associated with textiles and design and one would expect the programme to attract more female than male students. Overall, the results show that engineering programmes are still dominated by male students and no progress has been made to attract more female students over the past five years.

Gender parity in Information system and geo-science Programmes. The findings showed that female students are under-represented in information systems and geoscience programmes, mostly with less than five female students (Figure 10). While the number of female students enrolled in petroleum geoscience programme kept on decreasing over the years, the number of female students enrolled in geo-information and earth observation science increased especially in 2022. Since this is slightly a new programme, the female applicants may have been motivated by other female students that are pursuing the programme. The absence of female role models in the programme may have demotivated female students to apply.

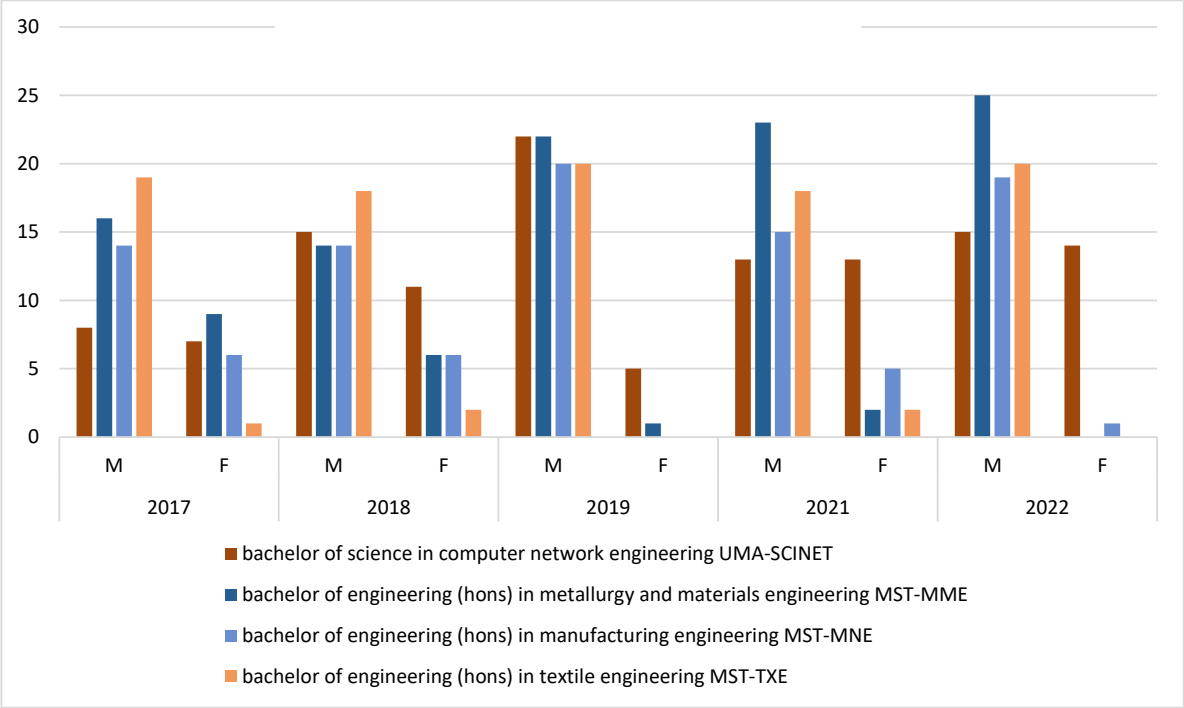

Figure 9. Students enrolment in engineering related Programmes
Source of Data: NCHE

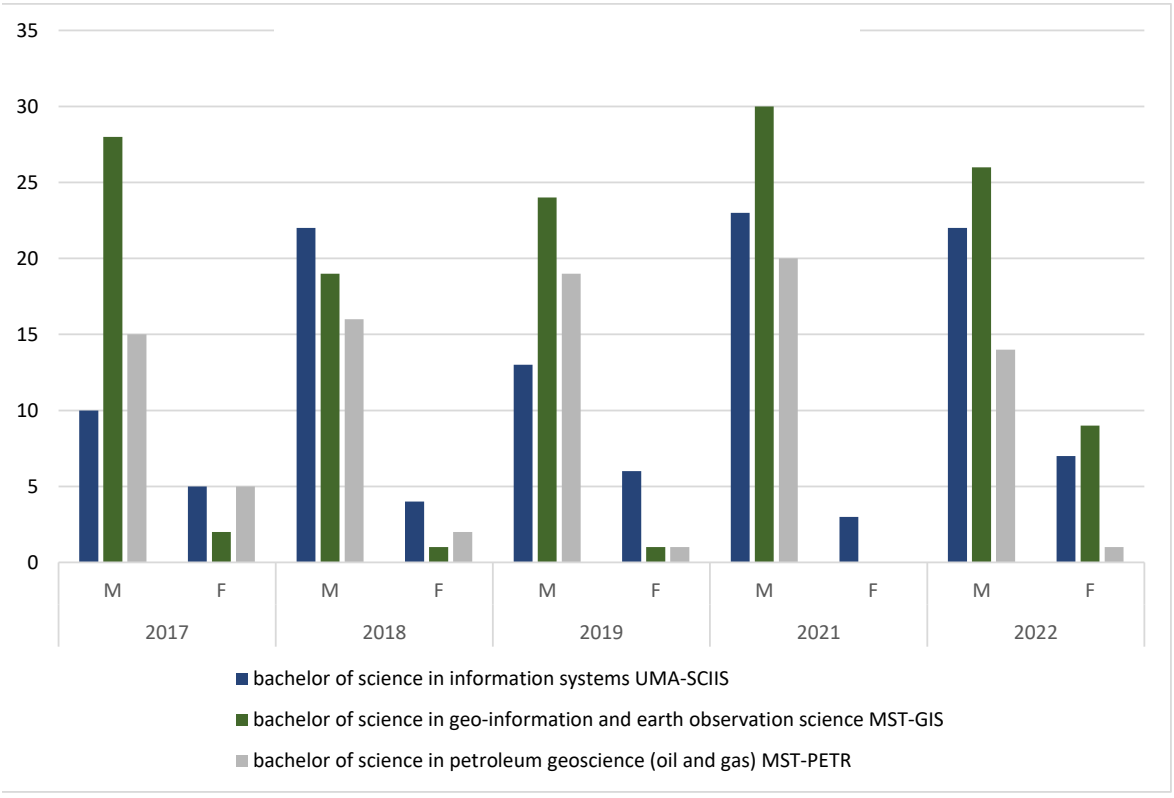

Figure 10. Students enrolment in information system and geo-science programmes
Source of Data: NCHE

Gender disparity in water and land resource management programmes. The results showed that very few female students, less than 10 enrol in water resource management and land management programmes (Figure 11). However, the number of female students enrolled in land surveying increased overtime and in 2022, there were more female than male students who were enrolled in the programme. One would expect more female students to be attracted to water resource management and development since most of the women's household roles use water, but very few female students enrol in the programme. Consequently, women are underrepresented in water utilities. The World Bank report of 2019 revealed that the percentage of women in water services in Malawi was very low. There were a total of 2328 employees in the five boards in 2018 and of these, 349 were women representing 15% of total employees (World Bank, 2019). This was due to the low number of female graduates from technical programmes such as civil engineering and plumbing. Culturally, these programs are considered to be appropriate for men.

Gender Assessment in Technical Entrepreneurial Vocational Education and Training. The overall enrolment of students in Malawi's technical colleges has increased over the past years due to introduction of the eleven new community technical colleges. However, due to the limited number of spaces available in training colleges, the number of enrolled students versus the number of applicants is still very low compared to other SADC countries. In the SADC region, TEVET Malawi ranked the lowest among its peers with only 0.2% of the population aged 15-24 years, enrolled (UNESCO, 2013).

According to TEVETA's annual reports, the enrolment of females in technical programmes is less than 40% (Figure 12). For example, the number of females enrolling in technical programmes at public and private technical colleges was 29% in 2014 and 35.5% in 2015. In 2016, the total intake was an all-time high of 1909 students with 28.4% females. In 2017, although more than 11,000 applications were received from potential students, only 1491 students (469 females [31.5%] and 1022 males) were eventually enrolled. Even with the increase in overall enrolment, the enrolment of female students and Students with Disabilities (SWD), has seen only modest changes. In 2017, the overall enrolment, as well as the number of female students, declined slightly.

The results also showed that the participation of female students in ST&I programmes at TEVET was very low. Most of the ST&I programmes were dominated by male students. The overall range of female students in the three male-dominated trades between 2014 to 2017 was 1 to 6 females per course. Most of the instructors for ST&I programmes in TEVET are males. Figure 13 indicates that male instructors dominate in capentry and joinery, auto mobile networks and electrical installation. Some programmes do not have female instructors. Role models play a key role in motivating female students to pursue programmes that are perceived to be male-dominated. The construction trades such as carpentry and joinery, electrical installation and ICT studies are also dominated by male students while tailoring, business administration and administrative studies are dominated by female students. A study by UNESCO in 2018 revealed a number of barriers to women participation in ST&I that included: traditional stereotypical attitudes and cultural beliefs; education deficits in enrolmment requirements and lack of role models.

Women Participation in Science, Technology and Innovations. There are a total of 201 Malawian women with doctoral degrees and these include those staying in Malawi and diaspora. Most of these women are working in the academia

followed by medicine and health. However, it should be noted that some of the women in the academia are teaching STEM courses. Out of the 56 women in academia, 22 are teaching STEM courses in higher education institution. They are very few women with doctorate degrees in science and technology who are working as technical experts in the industry. The other group of women in science, Technology, Mathematics and Engineering has a total of 229 members. These include women with Bachelors, Masters and PhD degrees. To date there is no proper profiling and tracking of women in STEM. It is therefore a challenge to report the accurate number of women in STEM. The National Commission for Science and Technology in collaboration with the Directorate of Science and Technology in the MOEST are working towards profiling women in science and technology.

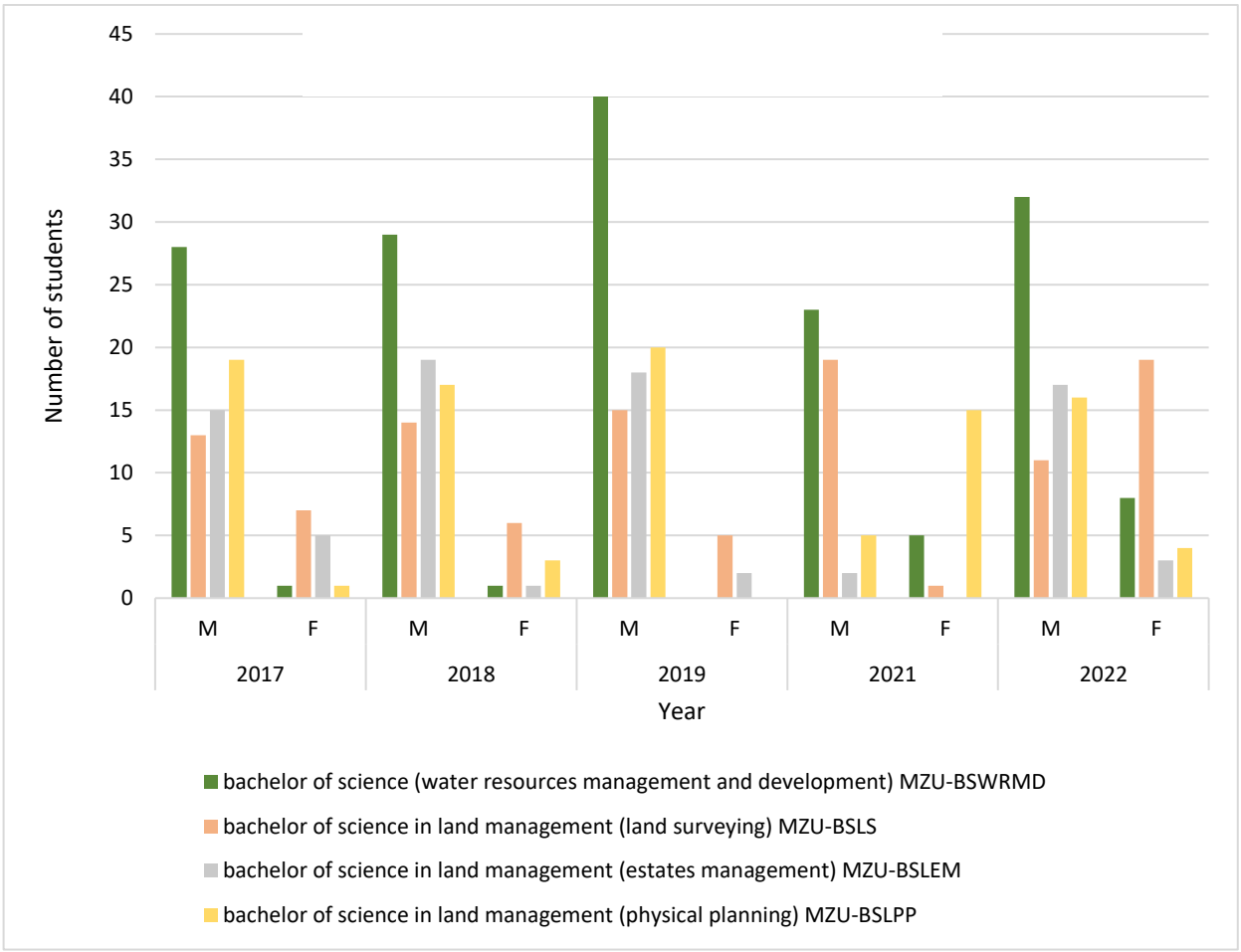

Figure 11. Students enrolment in water and land resource management programmes
Source of Data: NCHE

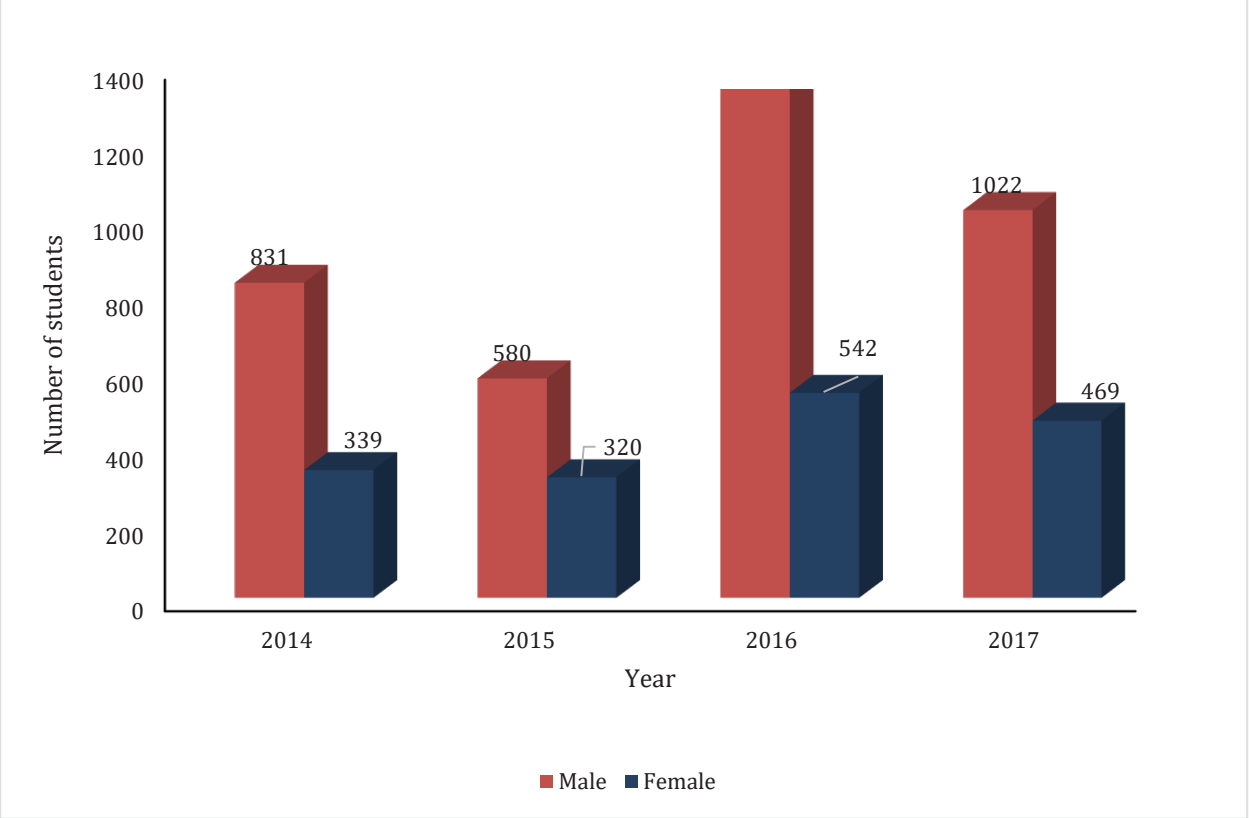

Figure 12. Students enrolment in technical colleges from 2014 to 2017
Source: The UNESCO STEP Gender equality and Inclusion report, 2018

CONCLUSION AND RECOMMENDATION

There have been initiatives to address gender parity in ST&I and increase participation of women in higher education ecosystem. The initiatives included development of policies to attract more female students in STEM programmes, increase participation of women in decision making in ST&I and higher education as well as promoting ST&I. The National Council for Science and Technology and the Directorate of Science and Technology in the Ministry of Education, Science and Technology were established to advance science, technology and innovations. However, despite the initiatives, the gender inequalities still exist in enrolment of students in higher education in STEM programmes. The analysis on students' enrolment in public universities showed that female students are underrepresented in science, technology and innovations programmes and the trend has not improved over five years. This is a threat to realisation of Malawi 2063 agenda as women may be left out in the advancement of technology and innovations that may lead to industrialisation and urbanisation. Although over 70% of full-time farmers in Malawi are women and they contribute greatly to the production of food crops, their participation in decision making in agricultural technologies, innovations and research is low because they are underrepresented in agricultural related programmes. This raises questions on how women will contribute to increased agricultural productivity and commercialisation in Malawi. This calls for holistic approach and a review on interventions targeting women participation in ST&I.

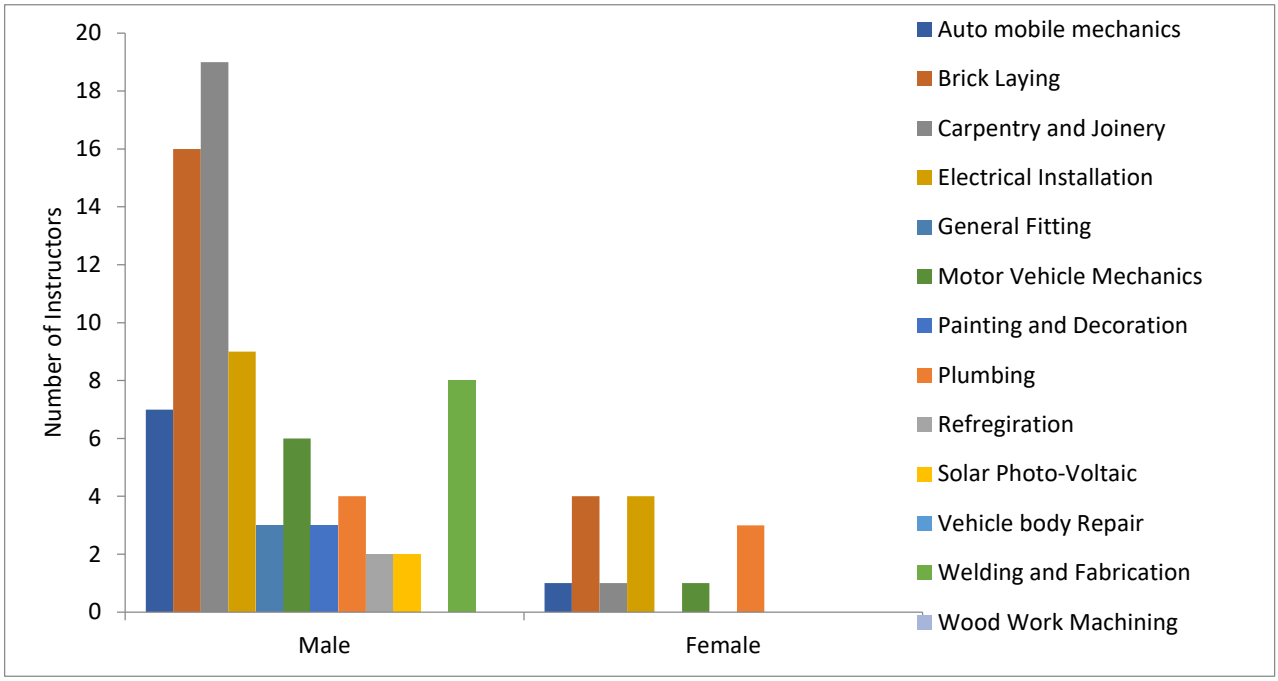

Figure 13. Priority Programmes by male and female students

Based on the findings, the following policy and programming recommendations are made:

1. Directorate of Science and Technology in collaboration with Directorate of Higher Education should develop and update policies clearly identifying strategies to increase access and success rates for female students and students with disabilities in ST&I.
2. National Council for Higher Education in partnership with Directorate of Higher Education and Directorate of Science and Technology should develop a holistic approach in addressing traditional stereotypical attitudes and cultural beliefs. A series of packages on sensitisation and career guidance materials suitable for upper primary and secondary school students, their parents/ guardians, and rural community leaders should be developed to address this issue..
3. The National Council for Science and Technology in collaboration with the Directorate of Science and Technology should have a database and profiles of women in ST&I including mapping the work they are doing.
4. Universities should strengthen initiatives to attract more female students to ST&I programmes. This should include offering scholarships for female students pursuing STEM programmes.
5. Universities should put in place students support services such as remedial lessons and tutoring for students who do not perform well in STEM programmes.
6. NCHE in collaboration with universities should develop a curriculum for bridging STEM courses to target students with low grades in sciences from secondary schools.

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STATEMENT OF NO CONFLICT OF INTEREST

The authors declare that there are no competing interests in this publication.

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Training the Next Generation of PhD Graduates in African Universities: Reflection on collaboration between RUFORUM and the Carnegie Corporation of New York, 2012-2022

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ABSTRACT
The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM, www.ruforum.org) is a network of 163 universities in 40 African countries spanning all the five regions of the African continent. RUFORUM was established to promote the integration of member universities into Africa's development processes, particularly within the Comprehensive Africa Agriculture Development Program (CAADP); provide a platform for networking, resource mobilization and advocacy to transform universities for relevance towards inclusive sustainable development; and to rationalize resource use and enhance economies of scale and scope. The RUFORUM Network is mandated to strengthen the quality and relevance of postgraduate training and research in African universities especially in agriculture, science, technology, and innovation through activities designed to improve the capacity of African universities and research centres to generate knowledge relevant to Africa's development challenges. RUFORUM acknowledges that contribution to global knowledge in all spheres by scientists from Africa requires graduate training at Masters and Doctoral levels. Hence in 2012, RUFORUM entered into partnership with Carnegie Corporation of New York (CCNY) to launch its Post-Doctoral Training Programme and to support research of Doctoral and Masters Students. To date a total of 39 Post-Doctoral Fellowships and 294 Doctoral research grants were funded. Special emphasis was placed on supporting University Faculty staff pursuing Doctoral training especially female academics. The support from CCNY enabled RUFORUM to leverage funding from other sources such as the Intra-African Academic Mobility Programme, amongst others. Staff who have graduated are now helping to strengthen training and research programmes in their home institutions.

Key words: Doctoral Research Grants, Graduate Training Assistantship, Post-Doctoral Fellowships, RUFORUM

RÉSUMÉ
Le Forum régional des universités pour le renforcement des capacités en agriculture (RUFORUM, www.ruforum.org) est un réseau de 163 universités dans 40 pays africains couvrant les cinq régions du continent africain. Le RUFORUM était créé pour promouvoir l'intégration des universités membres dans les processus de développement de l'Afrique, en particulier dans le cadre du Programme détaillé de développement de l'agriculture africaine (CAADP); fournir une plate-forme de mise en réseau, de mobilisation des ressources et de plaidoyer pour transformer les universités en termes de pertinence vers un développement durable inclusif; de rationaliser l'utilisation des ressources et d'accroître les économies d'échelle et d'envergure. Le réseau RUFORUM a pour mandat de renforcer la qualité et la pertinence de la formation postdoctorale et de la recherche dans les universités africaines, en particulier dans les domaines de l'agriculture, des sciences, de la technologie et de l'innovation, à travers des activités conçues pour améliorer la capacité des universités et les centres de recherche africains à générer des connaissances pertinentes que

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représentent les défis qui entravent le développement de l'Afrique. RUFORUM reconnaît que la contribution aux connaissances globales dans tous les domaines par des scientifiques africains nécessite une formation de deuxième cycle, aux niveaux de la maîtrise et du doctorat. Ainsi, en 2012, RUFORUM a conclu un partenariat avec Carnegie Corporation de New York (CCNY) pour lancer son programme de formation post-doctorale et soutenir la recherche d'étudiants en doctorat et en master. À ce jour, un total de 39 bourses postdoctorales et 294 bourses de recherche doctorale ont été financées. Un accent particulier était placé sur le personnel universitaires poursuivant une formation doctorale, en particulier les femmes universitaires. Le soutien du CCNY a permis au RUFORUM de mobiliser des financements auprès d'autres sources telles que le programme de mobilité universitaire intra-africaine. Les membres du personnel qui ont obtenu leur diplôme contribuent maintenant à renforcer les programmes de formation et de recherche dans leurs établissements d'origine.

Mots clés : Bourses de la recherche doctorale, Assistanat de l'enseignement supérieur, Bourses post-doctorales, RUFORUM

INTRODUCTION

In January 2003, 10 Vice Chancellors from five African countries[1] signed a Memorandum of Understanding to establish the Regional Universities Forum for Capacity Building in Agriculture and by April 2004, RUFORUM was operational. In August 2005, support for RUFORUM was formalized in an endorsement signed by the New Partnerships for Agricultural Development (NEPAD) and the Ministers for education from each of the then five member countries. That same month a 10-year strategic plan (2006–2015) was developed to designate new thrusts and operational modalities to guide the Secretariat during the transition period from a donor programme (Forum for Agricultural Resource Husbandry of the Rockefeller Foundation) to an autonomous member-based organization (Waswa *et al*., 2020). During this period in 2009, RUFORUM commenced facilitating academic mobility in Africa (Okalany *et al*., 2016; ACE, 2020) to strengthen capacity of African universities to build their own human resource capacities and to train a new generation of African scholars who know Africa better and more widely (Adipala *et al*., 2013; Chindime *et al*., 2016; Anonymous, 2018; Adidja *et al*., 2020).

In 2014, at the 4th African Higher Education Week and RUFORUM Biennial Conference, held in Maputo, Mozambique in July 2014 RUFORUM launched the Graduate Teaching Assistantship (GTA) programme (Fig. 1). It provided for the host university to waive fees, the sending university to continue providing salary and the staff member upgrading to PhD to assist with teaching at the host university (ACE, 2020; Adidja *et al*., 2020). The Biennial conference which included the African Union Commission Chair and government ministers from across Africa resulted in demand for RUFORUM to broaden its focus to include science, technology and innovation (ST&I), and a call to expand membership to West and North Africa (Waswa *et al*., 2018a; Waswa *et al*., 2020).

During the period 2014 to 2017, RUFORUM consolidated its footprints in Eastern, Central and Southern Africa, including providing targeted support to build capacity for weaker National Agricultural Research Systems in Burundi, Rwanda and Sudan with support through the Forum for Agricultural Research in Africa that coordinated the SCARDA (Strengthening Capacity for Agricultural Research and Development) project which focused on building capacities for weaker National Agricultural Research System in Africa (Waswa *et al*., 2020). In 2016, the World Bank availed an IDA credit of US$140 million to eight Eastern and Southern African countries to set up 24 centres of excellence in universities to strengthen postgraduate training and research. Eleven (11) of

[1]Makerere University in Uganda; University of Malawi in Malawi; University of Zimbabwe and Africa University in Zimbabwe; Eduardo Mondlane University in Mozambique; University of Nairobi, Kenyatta University, Egerton University, Moi University; and, the Jomo Kenyatta University of Agriculture and Technology in Kenya

these were awarded to eight of the RUFORUM member universities in five countries (ACE, 2020; Adidja *et al*., 2020; Waswa *et al*., 2020). In the same year, RUFORUM secured US$ 27.1 million from the Mastercard Foundation to support transformation of African agricultural universities and their graduates to better respond to developmental challenges through enhanced application of science, technology, business and innovation for rural agricultural transformation (Waswa *et al*., 2020).

The RUFORUM Annual General Meeting of 2016 and the organization business strategy review of 2017 demanded that RUFORUM developed a comprehensive and inclusive programme for developing Africa's Agriculture through implementing innovative and transformative initiatives in the higher education sector. Subsequently, in 2018 through systematically conducted consultation processes, RUFORUM developed the Vision 2030 and a corresponding Operational Plan implemented through four Flagship Programmes and Secretariat Coordination: TAGDev-Transforming African Agricultural Universities' growth and development; RANCH-Regional Anchor Universities for Higher Agricultural Education; CREATE-Cultivating Research and Teaching Excellence, and K-Hub: Knowledge Hub for University Networking, Partnership and Advocacy. Key to the implementation of Carnegie Corporation of New York support to RUFORUM has been the CREATE flagship (Waswa *et al*., 2018a; Adidja *et al*., 2020; Waswa, 2020).

The RUFORUM-Carnegie partnership. For a period of ten years (2012-2022), the Carnegie Cooperation of New York has been supporting RUFORUM build African Universities' training capacity by strengthening doctoral programmes and thereby ensuring that they have adequate qualified faculty staff with doctorate degrees. This partnership is in line with the Carnegie Higher Education Programme's efforts to upgrade the capacity of university faculty, to support the required human capital and locally generated research vital in sustaining and expanding social and economic gains, and increasing agricultural productivity and food and nutrition security (Adipala *et al*., 2013; Chindime *et al*., 2016; Adidja *et al*., 2020). It is also well aligned with the RUFORUM's overall mission to enhance the quality and relevance of postgraduate education in Africa (Okalany *et al*., 2016; Waswa *et al*., 2020).

The RUFORUM-Carnegie partnership achievements. The Carnegie Corporation of New York (CCNY) has increasingly invested in higher education within Africa and has been instrumental in supporting higher education advancement. The support has created a significant difference in increasing the quality of faculty at universities to obtain their doctorates and to gain experience and strengthen their networks after graduation. This has helped to improve the quality of the universities, increase Africa's contribution to global knowledge and importantly to retain these highly skilled people in Africa. Since 2012, a total of 294 PhD scholarships have been awarded competitively to support training in 36 Universities spread across the continent (Fig. 2). Of the 294 PhD grantees, 81 have already graduated and have returned to their home countries to occupy various positions. Majority of the graduates rejoined universities where they have been appointed to senior positions such as Deans of Faculties, Heads of Departments, and Coordinators of Postgraduate programmes, amongst several other positions (Okori, 2014; Waswa *et al*., 2018b; ACE, 2020; Adidja *et al*., 2019). Despite the fact that this is a great development for alumni, it also highlights the need to enhance leadership management skills that would help strengthen the performance of the gradduates in their new positions. This was incorporated in the training of subsquent Post-Doctoral fellows and graduate students. RUFORUM continued to support them through leadership coaching by its professional community. In addition to the PhD grantees, 123 master students were supported under the Carnegie Post-Doctoral

fellowship Programme which started in 2018. Out of these, 22 have completed their studies (Adipala *et al*., 2013; Chindime *et al*., 2016; Anonymous, 2018; ACE, 2020; Adidja *et al*., 2020).

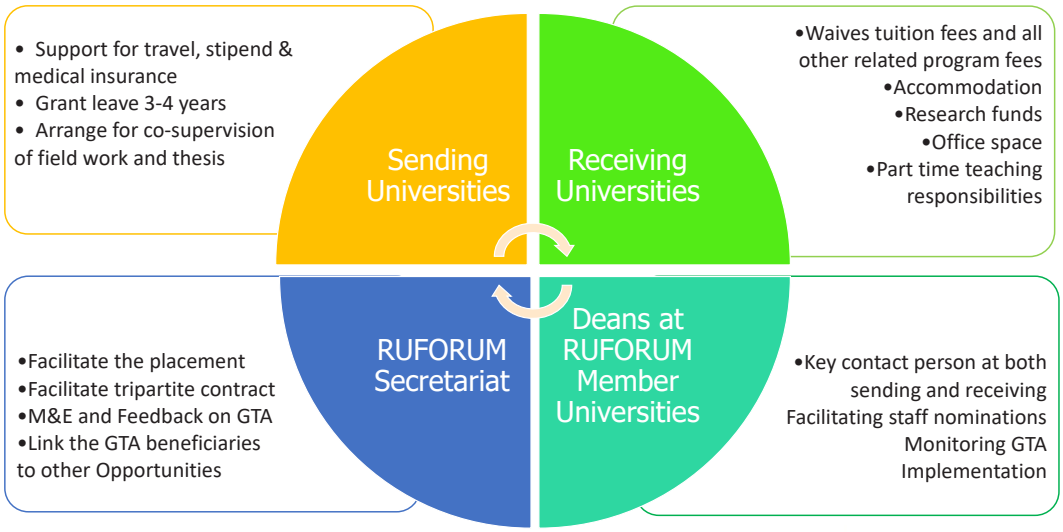

Figure 1. Key Actors and their Roles/ Responsibilities in GTA Implementation
Source: Adidja *et al*., 2019

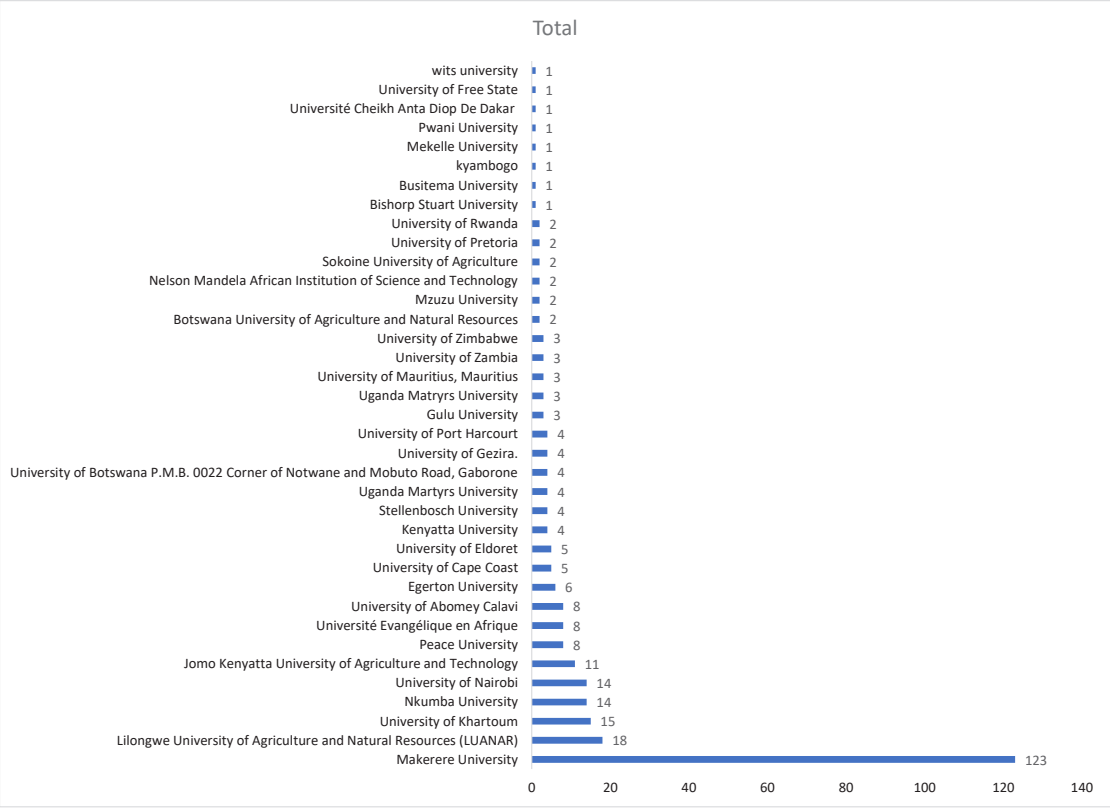

Figure 2. Universities training students under RUFORUM Exchange Programme amongst its Member Universties

Support to Regional PhD and Masters training Programmes. RUFORUM Regional PhD and Masters Programmes (Table 1) were designed to build the teaching and research capacity of member universities. They were established to address the skills gap at universities and research institutes and ultimately improve food and nutrition security and stimulate growth. Implementation of these programmes has been supported by multi-donor agencies including the Carnegie Corporation of New York by supporting recruitment of students into these programs. A total of 104 PhD and 11 MSc students have been recruited in these programmes (Okori, 2014; Mweetwa, 2021; ACE, 2020). RUFORUM also supported development of national programmes (Table 2).

These programmes focus on more than just information transfer and includes support to soft skills development and networking, thereby rendering graduates from RUFORUM supported programmes more suited to employment requirements. Many jobs today, and many more in the near future, require a combination of technological know-how, problem-solving and critical thinking, as well as soft skills and practical experience. The days of staying in one job, or with one company, for decades are waning. The new generation of graduates has different aspirations, viewing their employment ideals and options in self-employment, especially with the dwindling conventional public and private sector job opportunities (ACE, 2020; Njeru, 2014; Okori, 2014; Mweetwa *et al*., 2021). Figure 3 shows some of the skill and exposure enhancement events conducted.

Table 1. RUFORUM Regional Training Programmes as of 2022

Programme	Centre of Leadership	Year of Launch
PhD Programmes		
Dryland Resource Management (DRM)	University of Nairobi	2008
Plant Breeding and Biotechnology (PBB)	Makerere University	2008
Aquaculture and Fisheries Science (AFS)	Lilongwe University of Agriculture and Natural Resources, Malawi	2009
Agricultural and Resource Economics (ARE)	Lilongwe University of Agriculture and Natural Resources, Malawi	2009
Soil and Water Management (SWM)	Sokoine University of Agriculture, Tanzania	2010
Agricultural and Rural Innovations (ARI)	Makerere University	2012
	Egerton University	2012
	Sokoine University of Agriculture, Tanzania	2013
Food Science and Nutrition (FSN)	Jomo Kenyatta University of Agriculture and Technology	2013
Agro-ecology and Food Systems	Uganda Martyrs University	2017

Agrometeorology and Natural Risk Management	Haramaya University, Ethiopia	2011
Climate Smart Agriculture	Haramaya University, Ethiopia	2016
Climate Change and Society	Mekelle University	2014
Agrometeorology	University of Gezira	2011
Agroecology and Climate Sciences	Universite Evangelique en Afrique	2022
Agricultural and Applied Biosciences	Gulu University	2016
Climate Change and Sustainability	Makerere University	2016
MASTERS PROGRAMMES		
Plant Breeding and Seed Systems	Makerere University	2008
Plant Breeding	University of Zambia	2010
Research Methods	Jomo Kenyatta University of Agriculture and Technology	2009
Agricultural Information and Communication Management (AICM)	Egerton University	2008
	University of Nairobi	2009
	Haramaya University	2010
Agrometeorology and Natural Risk Management	Haramaya University, Ethiopia	2011
Monitoring and Evaluation	Uganda Martyrs University, Uganda	2012
Agro-ecology, Biodiversity and Climate Science	University of Antananarivo	2013
Climate Smart Agriculture	Haramaya University, Ethiopia	2016
Agroinformatics	Ndejje University	2022

Table 2. RUFORUM Supported National Training Programmes

Programme	Centre of Leadership	Year of Launch
PhD Programmes		
Natural Resource and Environmental Management	Peace University	2021
Natural Resource Management	University of Juba	2022
Masters Programmes		
Natural Resources Management	University of Juba	2019
Entrepreneurship	University of Juba	2019
Agronomy	University of Juba	2019
Animal Science	University of Juba	2019

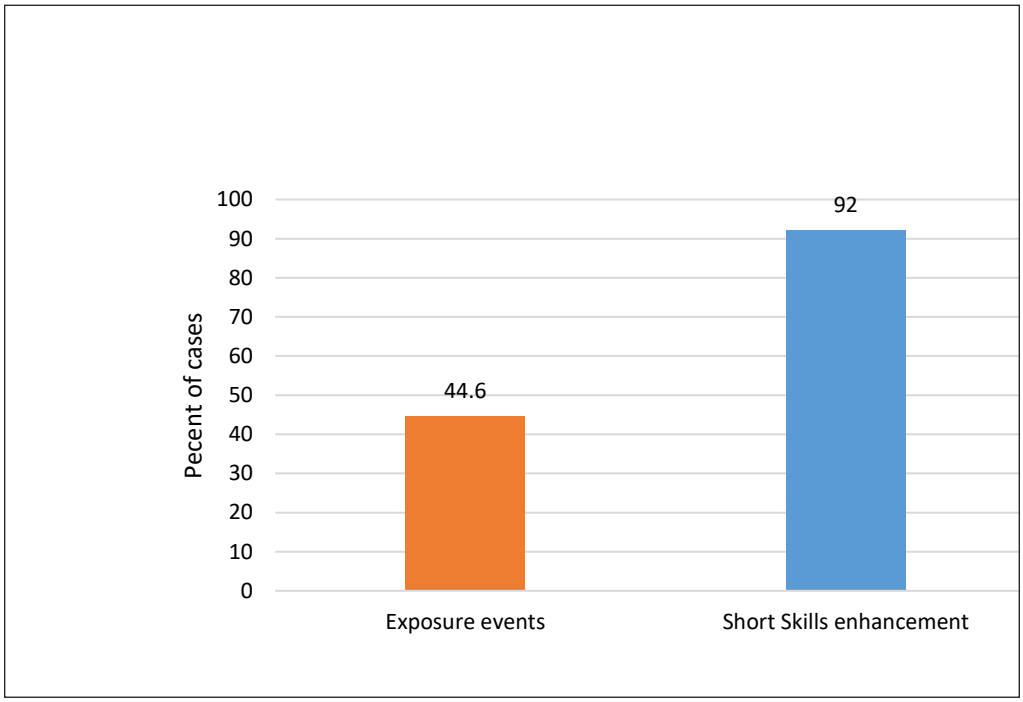

Figure 3. Distribution of alumni and graduate students reporting participation in exposure events and short skills enhancement training

University relevance improved through revamped curricula, skills enhancement, and research grounded in local reality .

A key aspect of the Carnegie Corporation of New York -RUFORUM partnership was to put in place skills enhancement programs to improve the relevance and quality of the postgraduate programmes in Africa. Accordingly, RUFORUM supported students' skills enhancement both through short skills training and mentorship received from their supervisors. Specifically, students were trained in proposal writing, journal publication, scientific data management, and personal mastery. RUFORUM supported 800+ students to participate in the scientific events during its Annual General Meetings and Triennial conferences. It organised 27+ short skills enhancement events for students, Post-Doctoral researchers and staff in member universities covering 15+ thematic areas including: leadership and management, scientific research proposal development, scientific writing skills, scientific data management using R programming language and data analysis using AMOS and STATA, financial literacy training, competitive grants project proposal development, among others. The following outputs materialised:

1. RUFORUM-funded students in the scientific events during its AGMs and Triennial conferences submitted 321 papers and 551+ posters, and made 125 oral/poster presentations.
2. A total of 11,504 individuals including students, post-doctoral researchers and staff from member universities were trained in 15 thematic areas, which has created a pool of resource persons in the region to train other scientists. According to a recent follow-up study of RUFORUM Alumni in general, 92% of the alumni/graduate students who responded to the on-line survey reported that they had participated in at least one short skills enhancement events while 45% had engaged in RUFORUM organized exposure events

The short skills enhancement events were appreciated for addressing both technical and soft skills, which are not adequately handled by the

general training curricula. These include aspects that are vital for success of the graduates such as emotional intelligence, empathy and critical/ innovative thinking. Skill-sets that were noted to be needed for future training include scientific writing, e-content development, and on-line pedagogy for interactive sessions, learner centred pedagogy (how to teach) as this would improve quality of training delivery in light of large class sizes.

Support from the CCNY helped RUFORUM test different model of human capital development and this has boosted the performance of African universities through increased numbers of staff with higher education qualifications and better pedagogical and research skills. The support towards soft skills and networking, and the imparting of multi- dimensional skill qualities render graduates more suited to employment requirements, a key challenge confronting Africa's universities today.

RUFORUM further collaborated with the African Women in Agricultural Research and Development (AWARD) to offer targeted leadership and skill enhancement training for especially female researchers and midi-career university administrators (Waswa *et al*., 2018b). Over the time, RUFORUM also supported establishment of leadership development programmes as refresher courses to strengthen university leadership and management.

Quality of teaching and learning improved through academic mobility and mentoring. Collaboration with the Carnegie Corporation of New York resulted in enhanced regional cooperation and networking among RUFORUM member universities. Students and faculty had opportunities, through mobility, to learn about various countries and formed close relationships that were consolidated through formal RUFORUM structures and social networking initiatives. For instance, staff exchanges within the RUFORUM Network created opportunities for universities in Africa to collaborate particularly in terms of strengthening research and visiting lectures. This provided opportunity for faculty cross learning. Through these collaborations, joint proposals were developed for funding by the EU Intra-ACP and Intra-Africn academic mobility programs. As a result, more than US $10.5 million was raised to facilitate over 36 staff exchanges and training of 179 MSc. and 75 PhD students across Africa (Table 3). Such partnerships respond to the need to harness capacities existent in various universities to serve the wider higher education and research sector. It also promotes professional networking across the relevant scientific disciplines and within the private and public sectors to transform African economy into a knowledge-based economy (Chindime *et al*., 2016; Okalany, 2016; Anonymous, 2018; ACE, 2020; Adidja *et al*., 2019).

Further, six EDULINK projects were conceived through staff exchanges and collaborations, including; PASUFONS[2]; ii) ADECEA[3]; iii) AGRIBUSINESS[4]; iv) ARI[5] II; v) PhD Aquaculture[6]; and, vi) Online Networking Platform[7].

The PASUFONS project facilitated strengthening of academic collaboration amongst three universities namely Makerere University in Uganda, Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kenya, and Stellenbosch University in South Africa. The three universities used satellite technology to facilitate virtual teaching. The hardware for receiving signals was provided by Stellenbosch University and installed at JKUAT and Makerere University. Using the telematic system, students at Makerere University, JKUAT, and Stellenbosch University attended lectures recorded at the Telematic Centre at Stellenbosch University. In addition to virtual teaching, PASUFONS facilitated sharing of expertise among partners through staff exchange.

[2]Partnerships to strengthen university food and nutrition sciences training and research in Eastern and Southern Africa
[3]Establishing and piloting postgraduate programmes for supporting agricultural development in post conflict countries of Central and Eastern Africa
[4]Strengthening University capacity to enhance competitiveness of agribusiness in Eastern and West Africa
[5]Strengthening Human Resource Capacity to Foster Agricultural and Rural Innovation in Eastern Africa
[6]Concerted Fit-for-purpose PhD training in aquaculture and fisheries to improve food security and livelihoods in Sub-Saharan Africa
[7]Deploying Interactive On-line Networking Platform for Improving Quality and Relevance of African University Graduates to Labour Markets

Table 3. Projects conceived out of inter-university collaboration amongst RUFORUM Member Universities

Project Name	Staff exchange	PhD students in mobility	MSc students in mobility
METEGA	8	19	44
CSAA	10	19	44
P4PHT	8	18	47
SHARE	10	19	44
COTRA	10	12	24
REFORM	6	11	23
SCIFSA	4	12	24
MASTET	6	12	22
MIRET	5	12	33
GTA Programme	-	216	36

Source: Mweetwa *et al*., 2021

Through the ADECEA project coordinated by Makerere University, demand driven MSc programmes were developed and piloted by Université d'Antananarivo in Madagascar, Université du Burundi in Burundi, and Université Catholique de Bukavu in DRC; three countries emerging from conflicts. The three RUFORUM member universities were backstopped by Agreenium and SupAgro-Montpellier in France and University of Ghent in Belgium.

The AGRIBUSINESS project coordinated by Egerton University sought "to improve the relevance of agricultural science teaching and outreach to the needs of agribusiness and enhance the collaboration between universities and the private sector". Through this project, four RUFORUM member universities – namely Mekelle University (Ethiopia), Gulu University (Uganda), and University of Port Harcourt (Nigeria) – collaborated with the University of Copenhagen in Denmark to increase competences of Faculty in terms of Agri-entrepreneurship to equip them to teach courses appropriately and build the entrepreneurship skills of graduates. Through this project, an entrepreneurship fund scheme was also established to help students develop agri-enterprises as practical hands on training to engage in entrepreneurship activities.

Through ARI II project, three RUFORUM member universities- Makerere University, Egerton University, and Sokoine University of Agriculture (Tanzania) jointly ran a Regional PhD Programme in Agricultural Rural Innovations in partnership with Wageningen University and Research Centre in the Netherlands, Agreenium in France, and University of Copenhagen in Denmark. The programme was offered both on site and online to offset the cost of students and staff mobility.

The On-line Networking Platform project was coordinated by Egerton University, which partners with JKUAT, Makerere University, RUFORUM, and AGRINATURA in Europe to increase interaction between academic world and labour market through an innovative interactive online networking platform, thus improving the relevance of universities to communities. The project involved several associate partners representing various segments of the agriculture sector.

Due to the COVID-19 pandemic there was no movement across the borders and all the activities were done online which included proposal development and refinement and technical backstopping of the African Higher Education Centres of Excellence. Students were supported to develop proposals for submission to their respective universities. The virtual mobility faculty provided technical backstopping to Regional Centers of Excellence by undertaking mentoring, teaching and training of students (both graduates and undergraduates) and also supported the review of the RUFORUM initiated Regional MSc and PhD programmes. The staff also participated in the development of new PhD programmes on Agro-ecology and Climate Science, and Natural Resources and Environment Management.

Improved research Capacity. Over the past ten years, RUFORUM has with funding from Carnegie Corporation of New York supported early career scientists to find their footing within the academic and research environment and to have opportunity to advance their work and initiate new research. Below are profiles of some of the supported research which has been able to directly impact the agricultural research and development in Africa.

1. Improved cassava and soybean varieties (Namsoy 4M, Maksoy 1N, Maksoy 2N, Maksoy 3N, Maksoy 4N, Maksoy 5N) now grown widely in Africa and have been taken up seed companies in Kenya, Sudan, Ghana and Zimbabwe.
2. Banana macro propagation for the production of disease free banana seedlings in central and eastern Kenya; and, consequently strengthening farmer associations in several countries including Kenya.
3. Molecular makers for Peste des petits ruminant's virus (PPRV) diagnostic targeting the nucleoprotein, fusion and hemagglutinin genes. These markers are being used to map the PPRV distribution in South Kivu (Eastern of DR Congo) and for characterizing the PPRV lineages circulating in eastern DRC (PPRV Lineage III).
4. Fifteen (15) Kersting's groundnut elite lines with resistance to storage bruchids have been developed and are undergoing advanced trials and will soon be released in Benin (West Africa).
5. Pearl millet genotypes with resistance to witch weed (*Striga asiatica*). These genotypes are being used as sources of resistance in breeding pearl millet genotypes for marginalized farming areas of Zimbabwe and are also being used in the ongoing project under the Future Grains for Africa.
6. An environmentally benign botanical fungicide for the control of late blight in Solanaceous crops (Neemox) has been developed. The development of the botanical fungicide is now embedded in the University of Zimbabwe innovation hub and being commercialized.
7. SIPROSA, an Artificial Intelligent (AI) based chicken disease chatbot, which is able to diagnose, and recommend the best treatment based on the current best practices. This has been installed on 25,788 farmers' devices/ phones and is actively being used by farmers in Kenya.
8. Developed foundation seeds of six cowpea varieties resistant to aphid and Striga yielding 2600-2800 kg/ha. The foundation seed is being sold to seed companies for the production of commercial seed in Benin.

Reflections on achievements and challenges

1. The mobility approach is increasingly becoming popular and has potential to provide quality education, research, and regional integration across Africa through internationalization and opening up of Programmes. To effectively harness this need, African universities should put in place measures for quality assurance and credit accumulation equivalence and transfer modalities.
2. Graduates published over 150 papers in high impact journals, thus contributing to increasing visibility of Africa's research outputs.

3. Regular interaction among the beneficiaries, RUFORUM, and the Carnegie Corporation of New York project implementation was very critical for success. Regular communication fostered trust, confidence, and ownership by the grantees and RUFORUM.
4. Training with regional scientific and thematic networks is an important way to ensure that students have adequate support locally and regionally. This approach can also build professional communities of practice that have wider knowledge and experience with the continent development needs. It also promotes regional integration.
5. The collaboration increased the diversity of Fellows and students on postdoctoral and doctoral Programmes, which is an opportunity in itself. Thus, the Fellows and students established friendship and linkages that will be useful throughout their professional and personal life. These Programmes have provided effective platforms for networking, collaboration and mentorship.
6. The supported graduates have added to the pool of well-trained scientists that are serving research institutions and universities across Africa, contributing to building capacity for capacity development in Africa. A snapshot of the deployment of some of the graduates is shown in the Figure 4.
7. The CCNY grant support to RUFORUM contributed to increasing the number of University staff with PhDs, enhancing quality training, research relevance, and visibility of African institutions through publications, conference attendance, and academic mobility.
8. The CCNY support strengthened the RUFORUM network capacity to win grants from various development partners.

Challenges

1. Unequal ability of applicants to compete for scholarships opportunities. Since most of the applicants were from universities, this is probably reflective of the weakness of some universities in terms of training in proposal writing.
2. At both the Masters and PhD levels, female participation was at 40.8 %, below the targeted 50% female recruitment. The challenge is not unique to this programme but a general one that RUFORUM has experienced with almost all its training programmes.
3. The COVID-19 restrictions instituted by most countries such as lockdowns and social distancing measures resulted in delays and interruptions of fieldwork of Fellows and doctoral students.
4. Most doctoral programs run for 3-5 years in Africa, which is longer than that of the grant period. There is thus need to explore opportunities supplementary for finding of especially Doctoral students; and,
5. Scheduling of the short skills courses was sometimes not well aligned with activities in the member university calendars, hence some would-be participants ended up missing the on-line course due to conflict of time with commitments in their degree programs.

Opportunities for future engagement with the Carnegie Corporation of New York. Carnegie Corporation of New York has invested much over the years to increase the number and quality of the qualifications of university faculty. These efforts have helped to strengthen regional post-graduate programmes and encourage the sharing of resources across Africa. They have also taken the lead in ensuring that women are prioritized and this has helped RUFORUM shift from 08% female student intake in 2004 to 45.8% female participation in 2022. Nevertheless support is needed for post-graduate scholarships and post-doctoral fellowships. These should focus on increasing the participation of women and building capacity for less endowed institutions and fragile States. There is also need to support the regional programmes and the mobility of people, and thus enhancing ideas and shared skills, across Africa. Special attention is also still needed to increase the pool of PhD trained faculty in African universities so as to build capacity for capacity development.

Figure 4. RUFORUM impact in African countries

There is need to support universities to engage in locally relevant research, networking and collaboration so as to enhance effectiveness of African universities within countries. RUFORUM has programmes that strengthen collaboration between universities for both teaching and research and programmes that effectively integrate universities into their societies. It is also important to strengthen self-help initiatives such as RUFORUM Graduate Teaching Assistantship Programme to increase the pool of PhD trained Faculty and promote African Academic mobility. There are also new ideas that could help to identify where the greatest opportunities and challenges lie such as in the suggestion of a Research Excellence Barometer for Africa.

Critically important is the need to strengthen post-graduate programmes to deliver relevant graduates, and also to promote leadership and mentoring, and to help universities adopt more digital and 4IR to increase their reach (97% of university students have access to mobile phones so adapted access is possible, although access to smart phones and laptops is still much lower). In addition to providing support to strengthen university programmes, philanthropists can also help to link universities and, in particular their post-graduate programmes, to resources to improve their facilities. There are other needs such as:

1. Building capacity to respond to emerging challenges and opportunities. Globally, but more so in Africa, climate change is grossly impacting negatively on the wider society and economies, especially for the rural communities. Targeted investment is needed to develop Africa's response capacity and innovations that reduce and mitigate the impact of climate change vulnerabilities, declining sol fertility and productivity and for addressing emerging challenges such as human-animal health related epidemics and pandemics.
2. Strengthening capacity to harness digital technologies as eluded to above.
3. There is also still the wider need to escalate doctoral training in the continent to service the increasing demand for staffing at African Universities, research institutions, and other bodies. While each university needs to increase its capacity for PhD training, regional initiatives based on thematic focus such as being done under the RUFORUM Regional Training Programmes would enhance access to quality programmes across the continent and promote regional integration.

CONCLUSION

The CCNY grant support to RUFORUM contributed to increasing the number of University staff with PhDs, enhanced quality of graduate training, research relevance, and visibility of African institutions through publications, conference attendance, and academic mobility. Additionally, the support has enabled the strengthening of the RUFORUM network to win grants from various development agencies. Given the success of this partnership, CCNY and other development partners should consider working with African universities to generate science solutions such as for strengthening Agri-food Systems and responding to emerging challenges such as climate change, natural resource degradation and animal-human health paramedics, amongst others. There is also still need to escalate doctoral training in the continent to service the increasing demand for staffing at African Universities, research institutions, and other bodies. While each university needs to increase its capacity for PhD training, regional initiatives based on thematic focus such as being done under RUFORUM would enhance access to quality programmes and regional integration.

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STATEMENT OF NO-CONFLICT OF INTEREST

The author declares that there is no conflict of interest in this paper.

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Transformation towards problem-based learning in East and Southern Africa: Perceptions from the field

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ABSTRACT
Student-centered learning methods, such as problem-based learning (PBL) are suggested as a method to provide future graduates with the 21st century skills needed in the rapidly changing world and working life. Transformation from traditional lecture-based teaching towards PBL requires role transformation from all the main university stakeholders: teachers, management staff and students, yet this change is not easy. To understand how to enhance and assist the transformation towards competence-based learning, we examined teachers' perceptions towards learning and teaching, with special focus on PBL. The data were collected through short anonymous surveys with open-ended questions, during problem-based learning program organized for East and Southern African university teachers. The results show that teachers clearly recognize the need for role and responsibility transformation when converting to PBL, and acknowledge that this transformation require wider mind-set and policy changes in the whole academic community. Teachers are able to pinpoint the practical elements needed for, and elements limiting, education paradigm shift towards PBL. To overcome the current challenges and to encourage adoption and implementation of PBL, teachers will require institutional support and capacity development, especially in terms of pedagogical trainings. Themes and concerns raised by teachers themselves should be prioritized and should be at the core of all projects and interventions promoting PBL.

Key words: Higher education, problem-based learning, Sub-Saharan Africa

RÉSUMÉ
Les méthodes d'apprentissage centrées sur l'étudiant, telles que l'apprentissage par résolution de problèmes (PBL), sont des méthode suggérées pour fournir aux futurs diplômés les compétences nécessaires liées au 21e siècle dans un monde et une vie professionnelle en évolution rapide. La transformation de l'enseignement magistral traditionnel vers le PBP nécessite l'implication de tous les principaux parties prenantes des universités: les enseignants, le comité de direction et les étudiants, néamoins ce changement n'est pas facile. Pour comprendre comment améliorer et accompagner la transformation vers un apprentissage basé sur les compétences, nous avons examiné les perceptions des enseignants à l'égard de l'apprentissage et de l'enseignement, en mettant l'accent sur le PBL. Les données étaient recueillies au moyen de courtes enquêtes anonymes en utilisant des questions ouvertes, au cours d'un programme d'apprentissage par résolution de problèmes organisé pour les enseignants universitaires d'Afrique orientale et australe. Les résultats montrent que les enseignants reconnaissent clairement la nécessité d'une transformation des rôles et des responsabilités lors de la conversion au PBL, et reconnaissent que cette transformation nécessite des changements de mentalités et de politiques plus larges dans l'ensemble de la communauté universitaire. Les enseignants sont en mesure d'identifier les éléments pratiques nécessaires et les éléments limitant le changement de paradigme de l'éducation vers le PBL. Pour surmonter les défis actuels et encourager l'adoption et la mise en œuvre de le PBL, les enseignants auront

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besoin d'un soutien institutionnel et d'un renforcement des capacités, notamment en termes de formations pédagogiques. Les thèmes et les préoccupations soulevés par les enseignants eux-mêmes devraient être prioritaires et devraient être au cœur de tous les projets et interventions promouvant le PBL.

Mots clés : Enseignement supérieur, apprentissage par résolution de problèmes, Afrique subsaharienne

INTRODUCTION

The world is facing multiple complex ecological and socio-economic challenges. To solve these challenges and adapt to inevitable changes require competent and innovative experts and workforce. Higher education and higher education institutions (HEIs) play a crucial role in producing these experts: the future problem-solvers and change agents. Indeed HEIs are expected to provide solutions to local and global challenges and prepare graduates to the world of work (Watson *et al*., 2011). While HEIs value in societal development is recognized globally (Watson *et al*., 2011; McCowan, 2018), it can be considered especially crucial withing the Global South, such as in Sub-Saharan Africa (SSA), confronting low income, economic productivity and industrialization, high unemployment rates, harsh environmental conditions and rapid changes in relation to environment and demography. Indeed, many national and inter-African strategies and vision statements emphasize the importance of higher education in enhancing and achieving socio-economically and ecologically sustainable development (e.g. Republic of Kenya, 2006; Republic of Zambia, 2006; The Republic of Uganda, 2012; The African Union Commission, 2016).

However, despite the improved quantity and access to higher education, the educational system in SSA has been unsuccessful in providing its graduates with 21st century skills and preparing them for self- and wage-employment (McCowan, 2018; Monga *et al*., 2019). Higher education in SSA is largely based on lecturing and rote learning (Muganga and Ssenkusu, 2019), that inhibit, or at least hamper, the development of hands-on and generic skills, such as problem-solving, planning and comprehending complexity (McCowan, 2018). Many higher education graduates in SSA face unemployment, as they lack knowledge application skills and other competencies demanded by employers and for self-employment (McCowan, 2018; Monga *et al*., 2019). The African Development Bank (Monga *et al*., 2019) calls for paradigm shift in higher education to equip students with skills enhancing employment opportunities.

Problem-based learning (PBL) and collaboration with external partners are recommended methods for reforming curricula to be more relevant for world of work and keeping up with the rapidly changing demands of business life (Watson *et al*., 2011; Easterly *et al*., 2017). As such, PBL is based on constructivist learning theory that presumes people to construct knowledge, i.e., learn through experiences (Bada, 2015). Thus, it emphasizes practical, authentic and hands-on learning (Jumaat *et al*., 2017). In practice, PBL is an example of student-centered learning methods that put student needs in the core of the learning (Weimer, 2002). In PBL students learn by solving real-life problems, often faced by external partners, within teams. The core idea is for students to integrate theory with practice by acquiring and evaluating information, and ultimately applying knowledge and skills to solve the problem (Major and Palmer, 2001; Ding *et al*., 2014).

Problem-based learning changes the roles of the educational actors compared to traditional lecture-based learning, as students transform from passive information recipients to active knowledge constructors, and teachers transform from information providers to facilitators of learning (Biggs and Tang, 2011). In practice, PBL has been associated with, among others, improved learning outcomes on generic skills, such as

critical thinking, communication and teamwork skills (e.g. Major and Palmer, 2001; Tan *et al*., 2014; Abbey *et al*., 2017). Students have also reported PBL to increase motivation, leading to increased class attendance and reduced course drop-outs (Major and Palmer, 2001; Abbey *et al*., 2017).

In this article we discuss the roles and requisites of the main actors within PBL: the teachers, students and management staff. We focus especially on the transformation of the roles and responsibilities when transitioning from conventional lecture-based teaching to problem-based learning. The article utilizes data collected within AgriSCALE (www.agriscale.net/) and PBL-BioAfrica (www.pbl-bioafrica.net/) projects, coordinated by Häme University of Applied Sciences. The projects have eight partnering universities in sub-Saharan Africa, with focus on improving higher education in the African continent. The project, and thus this article, focuses only on higher education in agriculture, following the African Union (2017) strategy to prioritize agricultural sector in providing employment for the increasing number and share of youths in the African continent.

The roles and role transformation of main actors in problem-based learning. Teachers as facilitators of problem-based learning. In traditional lecture-based teaching, also known as teacher-centered approach, the teacher has the control and authority of the classroom (Weimer, 2002). The teacher's role is only to provide information to students (Major and Palmer, 2001). In PBL teachers transform from information providers to facilitators of learning. Facilitators do not give direct answers nor resources, but instead they guide and monitor students, helping students to learn and teach themselves (Major and Palmer, 2001; Weimer, 2002). Facilitating requires a task shift from lecturing to designing of various student activities and assignments (Weimer, 2002). In PBL, the teacher's main role is to motivate students and create a setting and learning framework conducive to learning. Being a PBL facilitator requires set of skills and resources, such as time, patience, emotional intelligence and tolerance of messiness or chaos (Weimer, 2002; Abbey *et al*., 2017).

Students as active core of problem-based learning. Compared to lecture-based learning, where students are passive recipients of information and dependent on the teacher, in PBL, as in other student-centered approaches, students are active participants of the learning process (Major and Palmer, 2001; Weimer, 2002). Accordingly, PBL switches the control and responsibility of learning from teachers to students. Students learn by doing; by discovering and constructing information themselves (Weimer, 2002). In order for students to take the responsibility and ownership of learning, they need to develop and possess skills such as independence, autonomy, maturity and self-regulation (Weimer, 2002). These skills develop during the PBL-process.

Management as enablers of problem-based learning. By being responsible of the curricula design and resource provision, HEI's management play a crucial role in enabling adoption and implementation of new teaching methods, such as PBL. As such, HEI managements' or faculty's role in PBL is to provide teachers the flexibility and opportunity to implement the method, and create and maintain an environment enabling student activity and autonomy (Weimer, 2002). Management staff should encourage cooperation between peers, both students and teachers, and enable and organize activities and events that guide students and teachers to learn and work with new approaches (Weimer, 2002). Management creates the framework for PBL, and this requires flexibility from the management staff and HEI policies, as there is no one standard method to implement nor evaluate PBL process and outcomes.

MATERIALS AND METHODS

As part of AgriSCALE project activities, an online-based teacher training-program on PBL was organized to teachers of the AgriSCALE and PBL-BioAfrica projects' partner universities between April and November 2021. More information on the training programme can be

found in the article by Määttänen *et al*. (2022). A total of 78 teachers from seven universities from Kenya, Uganda and Zambia participated to the program at least to some extent. However, not all teachers were present in all of the online sessions. During online training sessions within Zoom software, short voluntary and anonymous surveys with open-end questions were administered to the participants, using Mentimeter-software. This article utilizes data collected from five of these surveys. Number of survey responses varied from 12 to 51 responses (see Figure captions for details). The data were analyzed by using thematic coding with inductive approach. A quantitative aspect was added to the data analysis by calculating the number of mentions received by each theme.

RESULTS AND DISCUSSION

University teachers' perceptions on problem-based learning

Enjoyable learning. When teachers were asked to recall enjoyable learning experiences in their previous learning history, and state factors making them enjoyable, most mentioned practical, hands-on, experiences that enabled utilizing theory (Fig. 1). " -- industry visits and practicals (labs, field trips) etc. I saw things practically and the theory became reality!"; "Field/Industrial visits. I could experience first hand what we learnt from books"; "hands on and relevant to an issue at hand". Teachers also enjoyed interactive and collaborative learning, i.e., working with others and sharing experiences and viewpoints. The following quotation synthesizes well the responses "The discussions and collaboration with colleagues. The gaining of different experiences all over the world". Other themes emerging from the responses were: learning of new things: "learning something new that I really was interested in --"; learner-centered methods: tailored to each students' objectives, and delightful: lively and pleasant learning atmosphere with incorporation of humor and drama to teaching. Few respondents also mentioned self-reflection: i.e., gaining self-awareness and understanding of oneself, as most enjoyable experience.

What teachers find most enjoyable and appreciate in learning does not correspond to the dominant teacher-centered and lecture-based approach of most of SSA universities. In fact, the responses include many core elements of PBL: student-centered approach, practicality, real-life relevancy, working in teams and self-reflection of one's skills and their development. Teachers thus seem to appreciate the principles of PBL, even though the approach itself, and the theory behind it, is rather weakly known among them (Laitinen *et al*., 2023). This indicates motivation and potential among teachers to transform to alternative teaching approaches, such as PBL, with adequate capacity building. It is likely that teachers themselves want to be or become the enablers of enjoyable learning experiences. Teachers of the same universities have indeed showed great interest towards PBL in general (Laitinen *et al*., 2023), and on applying it in their teaching – after receiving initial training of the practice within the AgriSCALE and PBL-BioAfrica projects (Määttänen *et al*., 2022).

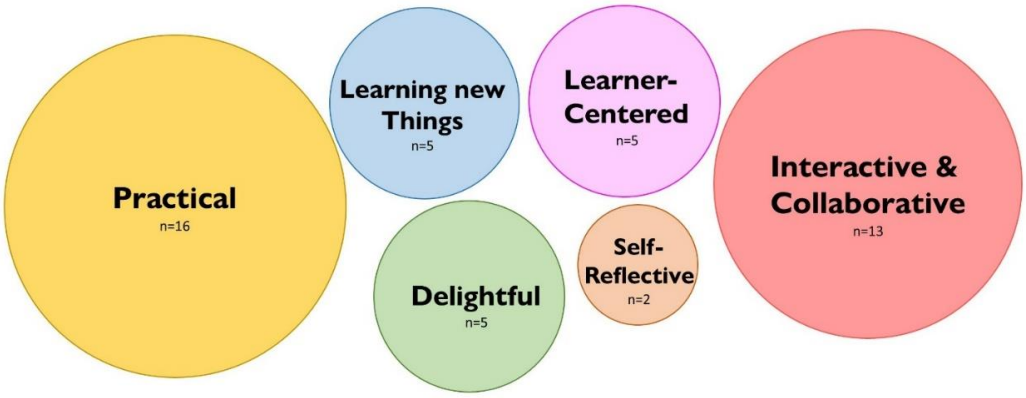

Figure 1. Themes emerging from responses to the question: What is your most enjoyable learning experience? What made it enjoyable? Total number of responses = 44. The size of each bubble represents the number of mentions, i.e., the bigger the bubble, the more mentions within that theme. Note that withing one response there may have arose multiple themes.

Constraints of PBL. Teachers clearly perceive lack of resources and student-related challenges as the main concerns of PBL and its adoption (Fig. 2A). Of the resources, teachers are especially concerned of time, finance, infrastructure, and low teacher/student ratio. Most of the African HEIs indeed struggle with limited resources and bad networks (McCowan, 2018) that constrain the teaching and learning in general. Moreover, PBL has been associated with higher monetary and time costs compared to lecture-based learning (Abbey *et al*., 2017). In research of the Kenyan higher education, McCowan (2018) noticed that teachers do not have enough time to develop their teaching practices. Weimer (2002) blamed "race to cover content" leading to teacher-led teaching and subsequently role learning. Indeed, when the teachers were asked about the support needed to adopt PBL, most of them stated the need for additional resources: more and better infrastructure, more time and either smaller class sizes or more teachers (Fig. 2B).

Teachers recognize that in PBL, they cannot totally control students and their learning, but the success depends also on students, as student-related challenges received many mentions. As stated by Weimer (2002), it is up to students to decide whether and what they want to learn, teachers can only influence students in their decisions, but not control nor force them. Teachers were concerned of "lack of collaboration" among students or "free-riders", student resistance towards new approach and lack of student activity; "lazy students". One respondent was also concerned whether students themselves have enough time, if all teaching is problem-based. Many previous studies have noticed initial student resistance when transforming from conventional learning to PBL (e.g. Weimer, 2002; Abbey *et al*., 2017; McCowan, 2018). However, the same studies found the resistance to decrease with more experience with PBL, as students become more used to and comfortable with the practice.

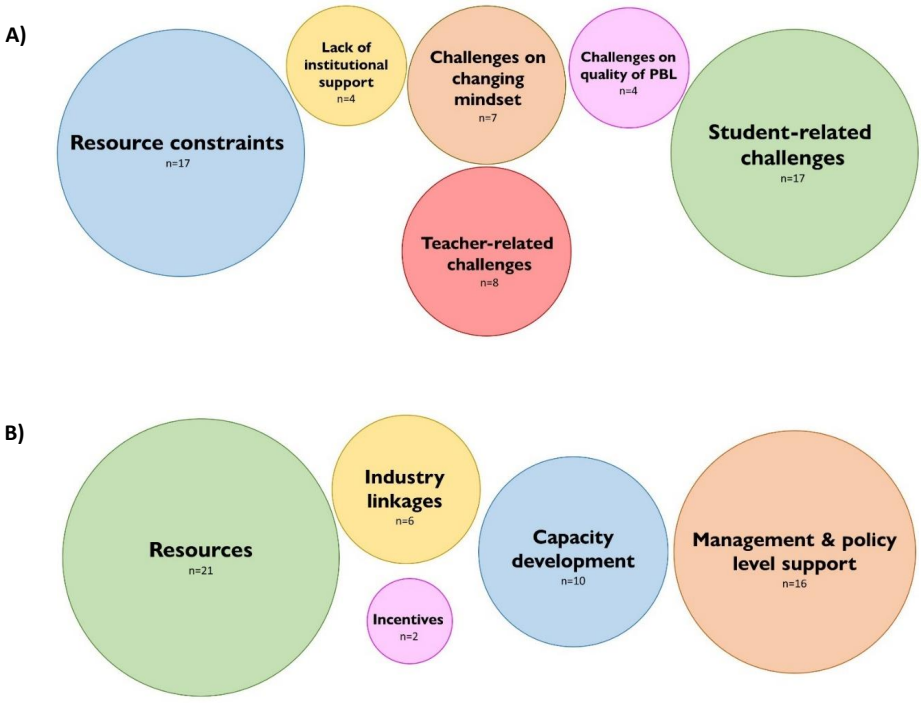

Figure 2. A) Themes emerging from responses to the question: What is your most concern of PBL? What risk do you see in PBL? Total number of responses = 49. B) Themes emerging from responses to the question: What kind of support would you like to have when becoming a PBL tutor? Total number of responses = 51. The size of each bubble represents the number of mentions, i.e., the bigger the bubble, the more mentions within that theme. Note that withing one response there may have arose multiple themes.

Teachers noticed constrains also among themselves. Problem-based learning was perceived to require lots from a teacher, and teachers were feeling incompetent, "not being able to control the class" with "facilitator inadequacies". Evaluation of students in PBL was found challenging. It is thus no wonder that teachers perceived a need for capacity development, especially in the means of training, to become tutors of PBL. The emerging concern of the quality of PBL and the learning outcomes may also partly relate to the perceived incompetency of teachers. As one responded put it: "Poorly designed PBL lessons may lead to ambiguous learning outcomes". Respondents, however, feared that PBL may detach students from theory "-- This can make some learners lose interest in theory and prefer to go practical instead. The risk is to produce half baked students who are not well grounded in theory". Studies on learning outcomes of theoretical knowledge of PBL versus lecture-based learning have mixed results, with some studies showing lecture-based teaching learning to better theoretical knowledge compared to PBL, while other studies showed no significant differences on the theoretical learning outcomes between the approaches (Major and Palmer, 2001). To utilize the benefits of both practices, combination of PBL and lecture-based learning can be adopted (Abbey *et al*., 2017). This may be especially useful for both teachers and students that are first-timers in PBL.

Respondents do not only perceive lack of knowledge and practical skills of teachers and students to constrain PBL, but the challenge of changing one's mindset is perceived to be constraining. Teachers are concerned on "whether majority of lecturers can buy the PBL approach" and "how to help change the mindset of the learners".

Finally, lack of institutional support, e.g. "Inadequate facilitation by institution" and "Limited adoption of the approach by faculty" is perceived as a concern or a risk of PBL. Teachers call for support from the faculty and institutional level, but also from wider societal scale, from communities and government. Institutional support and policy changes are needed to transform the evaluation methods, namely "removing exam focus", and to allow teachers more "free thinking" and "flexibility". These findings are in line with results from a Kenyan study that concluded that faculty resistance and wider structural elements in higher education hinder the transformation of educational practices (McCowan, 2018). Additionally, teachers report a need for incentives and motivation to change, "financial or other --", as well as linkages to industries to be able to present real-life problems to students.

Role of students and teacher requirements. Teachers capture and recognize well the role transformation needed among students and teachers in PBL as compared to traditional teacher centered methods (Fig. 3). When asked how PBL changes the role of students, half of the teachers mentioned PBL transforming students from passive recipients to "active participants" and "doers". Teachers also recognized the responsibility of students within PBL, describing students to become "in charge" and "responsible" of their learning as well as "independent learner(s)". The need for students to become "team player(s)" was mentioned multiple times, as well as students thinking and problem-solving skills usage and development: "Student -- to become a problem solver and solution seeker", "Transforms student into a systems thinker", "-- Students become co-thinkers in class -- free thinking is encouraged--".

Teachers' requirements for PBL were only asked from participants of one partner university. Three themes emerged from these responses. Teachers recognized the need to find suitable problems to present to students, as well as external partners to collaborate with: "I need to be aware of the problems existing on the ground. This would be made possible by working closely with industry/ farmers/consumers etc.". Almost as many times was mentioned the requirement of enhancing one's own skills and practices: "Enhance my practicals and demonstrations", "I would have to revise my practical periods to enhance the quality of practicals being done". Finally, teachers also mentioned PBL to require them to enhance and encourage student activity, "to provide room for more student participation".

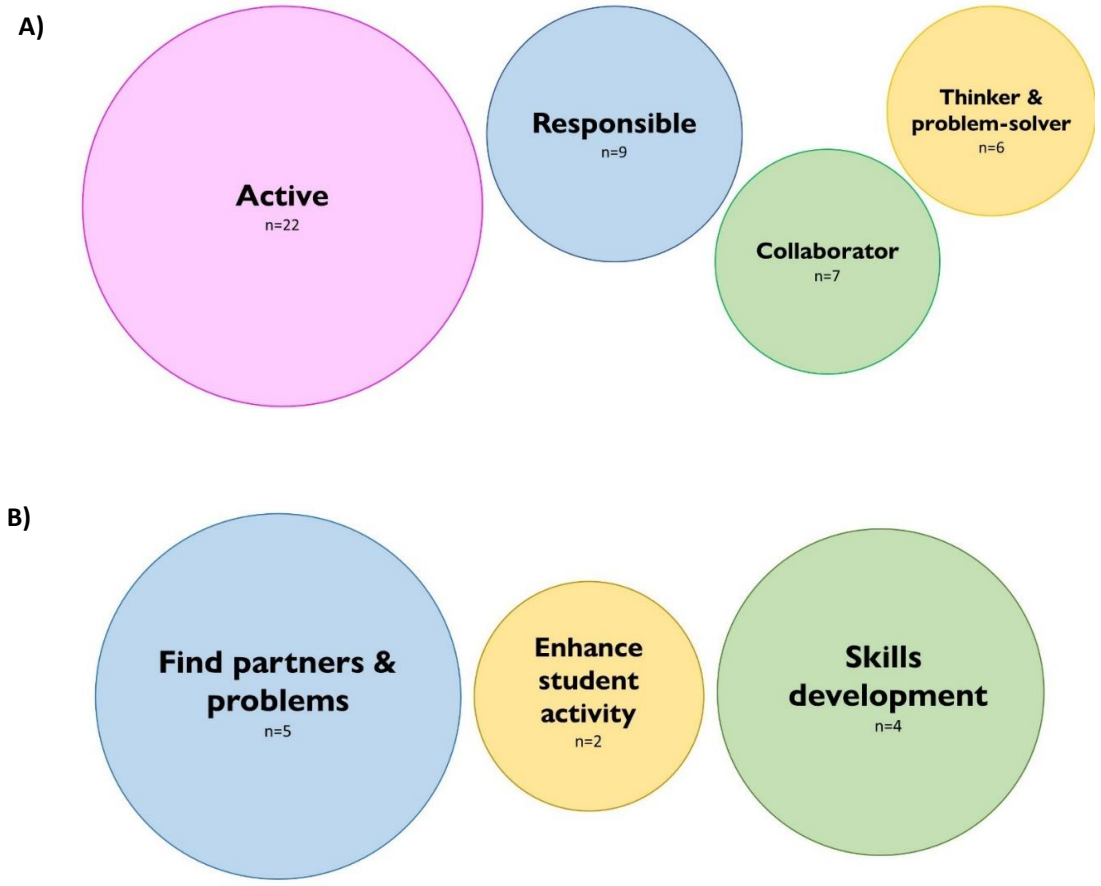

Figure 3. A. Themes emerging from responses to the question: How does PBL change the role of a student? Total number of responses = 41. B. Themes emerging from responses to the question: What would PBL require from me as a teacher? Note, that only teachers from one participant university have responded to this question. Total number of responses = 12. The size of each bubble represents the number of mentions, i.e. the bigger the bubble, the more mentions within that theme. Note that withing one response there may have arose multiple themes.

Teachers seem to understand the importance of the role transformation of students and themselves when switching to and successfully implementing PBL. Firstly, teachers recognize many practical elements that are required from students and teachers in PBL. Secondly, as came up with the response to question regarding potential risks/constraints of PBL (Fig. 2.A), teachers acknowledge that the failure to fulfill or to transform to these roles poses challenges to PBL, i.e., lack of collaboration or activity and resistance towards responsibility among students, as well as teacher incompetency. Indeed, PBL requires a complex set of competencies from teachers to be able to implement the process and guide students through it. In addition to emotional skills, successful PBL implementation requires teachers to understand the principles of PBL and its enhancing an impeding factors (Abbey *et al*., 2017). Teachers recognized their need for capacity building, especially in terms of training, when transforming to PBL tutor (Fig. 2B). The responses of teachers to all the survey questions suggest that training should focus on the a) basic principles of PBL and its implementation to provide teachers feeling of competency, b) how to enhance student activity and responsibility in learning, c) how to find external partners and

come up with real-life problems, d) how to hold practicals and demonstrations, and e) how to evaluate students in PBL.

CONCLUSION

Teachers of Kenyan, Zambian and Ugandan universities acknowledge that switching to PBL requires transformation on the roles of themselves, students and the management staff. They understand that transformation is not easy, but it requires change in mindsets, change in practices and policies, development of competencies and skills and physical and time related resources. Teachers recognize the practical elements needed to enhance the transformation and can point out the limiting factors of the adoption of and their concerns towards PBL. However, to overcome the constraints of and enable PBL adoption and implementation, teachers require support in the means of capacity development, especially training, and institutional support, in the means of policies and adequate resources. In teachers' capacity building, themes and concerns raised by teachers themselves, such as principles of PBL to enhance general competency and PBL's practical elements, including evaluation, should be prioritized. No single stakeholder can alone convert to PBL, but effort from all three stakeholders: teachers, management staff and students is needed. Thus, in projects and initiatives aiming to promote PBL, all these stakeholders should be included in the activities.

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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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Evaluation of tropical maize inbred lines for resistance to Fusarium Ear Rot in Uganda

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ABSTRACT
Fusarium Ear rot (FER) caused by *Fusarium verticilliodes* is a worldwide threat to maize production causing both yield losses as well as producing a mycotoxin that is harmful to the safety of both human food and animal health. Although host resistance is the most suitable strategy for disease management, no resistant varieties have been identified, and the first step in introducing resistance into maize germplasm would be to find sources of genetic resistance. This study evaluated a genetically diverse collection of maize inbred lines as potential sources of resistance to Fusarium Ear Rot caused by *Fusarium verticilliodes* by artificial inoculation using the toothpick method in the field for two seasons. At harvest, the ears were scored and assessed for FER development. Twelve inbred lines were found to be moderately resistant. The inbred lines CKL150038, CKL150105, CKL150109, CKL150105, JPS25-11, JPS26-4, JPS25-40, JPS25-36, JPS25-14, JPS25-11, DL141392 and WL429-24 had consistently low disease severity across the two seasons. These lines could be potential sources of resistance in breeding programs against *F. verticilliodes*.

Keywords: *Fusarium verticilliodes*, host-plant resistance, mycotoxin, *Zea mays*

RÉSUMÉ
La pourriture de l'épi (FER) causée par *Fusarium verticilliodes* est une menace mondiale pour la production de maïs, entraînant à la fois des pertes de rendement et la production d'une mycotoxine nocive pour la sécurité de l'alimentation humaine et de la santé animale. Bien que la résistance de l'hôte soit la stratégie la plus appropriée pour la gestion de la maladie, aucune variété résistante n'a été identifiée, et la première étape de l'introduction de la résistance dans le matériel génétique du maïs serait de trouver des sources de la résistance génétique. Cette étude avait évalué une collection génétiquement diversifiée de lignées consanguines de maïs comme sources potentielles de résistance à la pourriture de l'épi causée par *Fusarium verticilliodes* par inoculation artificielle en utilisant la méthode du cure-dent dans le champ pendant deux saisons. À la récolte, les épis étaient évalués pour le développement du FER. Douze lignées consanguines se sont avérées modérément résistantes. Les lignées consanguines CKL150038, CKL150105, CKL150109, CKL150105, JPS25-11, JPS26-4, JPS25-40, JPS25-36, JPS25-14, JPS25-11, DL141392 et WL429-24 présentaient constamment des faibles intensités de la maladie au cours des deux saisons. Ces lignées pourraient constituer des sources potentielles de résistance dans les programmes de sélection contre le F. verticilliodes.

Mots-clés : *Fusarium verticilliodes*, résistance de la plante-hôte, mycotoxine, *Zea mays*

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INTRODUCTION

Maize is the world's third most important cereal crop after wheat and rice (Lobulu *et al*., 2019). In Sub-Saharan Africa (SSA), maize is the most important cereal crop as food, feed, and industrial crop, grown on over 40 million hectares of land (Cairns *et al*. 2021), and it accounts for 30-50% of low-income household expenditures in Eastern and Southern Africa (Chemiat and Makone, 2015). Despite its importance in the world as whole, its production is constrained by many factors, both biotic and biotic stresses that lead to lower yields than expected, one of them being Fusarium Ear Rot caused by *Fusarium verticilliodes*. Fusarium ear rot (FER) is one of the most prevalent fungal diseases in maize worldwide, affecting grain yield and quality, causing yield reduction estimated between 10 and 30% (Lanubile *et al*., 2017) with losses reaching 50% in severe conditions (Ding *et al*., 2008; Yao *et al*., 2020). Infected kernels are covered with white or pink mold (Lanubile *et al*., 2017). This fungus can cause disease at all developmental stages of the plant. In addition, *Fusarium vericilliodes* produces a mycotoxin, primarily Fumonisin B1 (FB1), (Balconi *et al*., 2014) which affects the quality and marketability of grains. Another increasing concern about Fumonisins is the mounting evidence of their involvement in a number of human and animal diseases including esophageal cancer and neural tube birth defects (Robertson *et al*., 2006) in humans, equine leukoencephalomalacia (Ross *et al*., 1992) and porcine pulmonary oedema (Robertson *et al*., 2006) in animals. Contaminated feeds have been reported to cause leukoencephalomacia in horses as well as pulmonary oedema and hepatic syndrome in swine (Ross *et al*., 1990; Lanubile *et al*., 2017). This situation is further complicated by the common occurrence of fumonisins in symptomless infected kernels (Munkvold *et al*., 1997; Afolabi *et al*., 2007). Unfortunately, high levels of Fumonisin contamination in maize have been reported in a number of African countries including Algeria, Ghana, Kenya, Ethiopia, and Uganda, among others (Afolabi *et al*., 2007; Yli-Mattila and Sundheim, 2022). This implies that a significant portion of the maize crop in several parts of Africa could be affected when environmental conditions are suitable for fumonisin accumulation in grain. Therefore, there is a great need to control FER in maize so as to obtain good quality grain and thus reduce the potential health effects associated with the consumption of fumonisin-contaminated grain.

Breeding for disease resistance is the best strategy to control FER because it is efficient, economically sound and environmentally safe (Chen *et al*., 2016), and many studies have focused on the search for resistance (Clements *et al*., 2004; Lanubile *et al*., 2011; Lanubile *et al*., 2017; Maschietto *et al*., 2017), but unfortunately, there is no evidence of complete resistance to the pathogen. Despite the advantage of using resistant genotypes, there are a few resistant genotypes on the market and this is attributed to the complexity of the genetic architecture of resistance to FER (De Jong *et al*., 2017). The problems associated with Fusarium ear rot of maize can be prevented by proactively screening maize germplasm for resistance to *F. verticillioides*. In addition, sources of resistance should be identified preferably in locally adapted inbred lines for use in breeding programs (Tembo *et al*., 2022). Existing maize cultivars in Uganda are not known to have resistance to Fusarium ear rot or fumonisin contamination, and limited information is available on the inbred lines. Therefore, this study evaluated maize lines adapted to tropical conditions for resistance to Fusarium Ear Rot. The Inbred lines possessing resistance to FER would provide a valuable breeding stock for use as parents of hybrids and synthetics that can be grown by farmers.

MATERIALS AND METHODS

Genetic materials. A total 151 diverse maize inbred lines collected from the National Agricultural Research Organization (NARO) in Uganda, and CIMMYT maize breeding programs were used in this study. The lines were screened for FER resistance for two seasons at the National Crops Resources Research Institute (NaCRRI), Namulonge, Uganda, which falls in the mid-altitude agro-ecological zone, located at 0º 32'N

and 32º 35´E, at 1150 meters above sea level. Alpha lattice experimental design was used, with two replications. The plots consisted of two 5m long rows, with spacing of 0.75m by 0.5m between rows and plants, respectively. Two seeds per hill were planted and later thinned to one plant per hill four weeks after emergence. The recommended agronomic and cultural practices were followed, including weeding and fertilizer application at a rate of 77 kg N and 27 kg/ha^{-1} split over two applications at planting and for topdressing four weeks after planting, respectively. Planting was done under favorable conditions; supplemental irrigation was also provided as necessary for optimal disease development.

Pathogen culture, inoculation, and disease assessment. We isolated the pathogen from infected ears got from the Institute fields. Infected grains were sterilized for three minutes in 10% commercial bleach of the JIK brand which contains 0.39% sodium hypochlorite (NaClO) solution (Langa *et al*., 2012), rinsed three times using distilled water, and then 2 – 3 seeds were plated on 3% potato dextrose (Becton Dickinson, Sparks, MD, USA) agar plates and incubated at 28 – 30 C. Sub-culturing was done after four days and the fungal cultures were ready for transfer to disinfected toothpicks after 5 – 7 days. Fungal plugs from pure cultures were then placed in a flask together with toothpicks. Before use, the toothpicks were first autoclaved. The flask containing the fungal plugs and the toothpicks was then sealed and left for three weeks for the fungus to grow throughout the toothpicks (Chambers, 1988).

After the toothpicks were fully colonized, we used them to inoculate the maize cobs approximately seven days after flowering. Inoculation was done by piercing through the middle of the primary ear, using the colonized toothpicks and these remained until harvest. Inoculation was done on 10 plants of each inbred line, and paper bags were used to cover the ears to avoid allo-infection.

At maturity, when the moisture content was approximately less than 20% (Balconi *et al*., 2014), the ears were harvested by hand, de-husked, and individually scored for Fusarium Ear Rot symptoms (Fig. 1) using a nine-point scale; FER scores 1=0%, 2=1%, 3=2-5%, 4=6-10%, 5=11-20%, 6=21-40%, 7=41-60%, 8=61-80%, 9=81-100% (Guo *et al*., 2020) of kernels exhibiting visual symptoms of infection, such as brown, pink, or reddish discoloration of kernels and pinkish or white mycelial growth (Clements, 2003).

Statistical analysis. Effects of seasons and selected inbred lines on the severity of Fusarium ear rot were analyzed using R software (R Core Team 2021). Analysis of Variance was performed where the inbred lines were considered fixed effects, whereas replications and seasons were considered random effects. Fisher's protected least significant difference test at $p \leq 0.05$ was used to determine significant differences between the inbred lines.

Score 1 Score 9

Figure 1. Maize cobs showing the FER scoring done at harvest

RESULTS

Fusarium ear rot severity for all 151 inbred lines across the two seasons ranged from 2 (1% ear rot symptom) to 9 (i.e., 81 to 100% ear rot symptom). The average visual rating of Fusarium ear rot infection of maize ears was 4 for season one and 2.8 for season 2. Analysis of variance showed that there was significant variation ($P < 0.05$) among the inbred lines used in this study, and there was significant variation across seasons as well as for the genotype by season interaction (Table 1). The significant difference observed across seasons and genotype X season interaction could be due to seasonal factors. In the combined analyses of variance, differences among environments and inbred lines were significant for FER. Twelve inbred lines showed the lowest scores for FER across the two seasons and these were CKL150038, CKL150105, CKL150109, CKL150105, JPS25-11, JPS26-4, JPS25-40, JPS25-36, JPS25-14, JPS25-11, DL141392 and WL429-24.

DISCUSSION

Developing adapted maize germplasm with resistance to Fusarium Ear Rot is an important breeding objective. Ear rot caused by *Fusarium* spp. affects maize production and grain quality. The use of resistant germplasm is the most cost-effective and durable means of reducing the damage from ear rot (Chen *et al*., 2012).

This study assessed the response of 151 maize inbred lines to FER under artificial inoculation for two seasons. Results revealed significant differences among lines for FER, indicating the presence of sufficient genetic variation that can be utilized in breeding for resistance to Fusarium Ear Rot. Similar results were reported by Afolabi *et al*. (2007) and Balconi *et al*. (2014). In this study, the mean of disease severity was affected by the season and genotype-by-season interaction effects. Thus, evaluations for selecting resistant lines should be conducted across several seasons to expose the genotypes to a wide range of environmental conditions (Tembo *et al*., 2022).

A number of inbred lines with low or high disease severity in season 1 did not have a correspondingly similar level of disease severity when re-evaluated in season 2, implying that the interaction between genotype and environmental factors plays an important role in determining Fusarium ear rot symptoms (Parsons and Munkvold, 2012; Balconi *et al*., 2014). Maize inbred lines with potential resistance to Fusarium ear rot caused by *F. verticillioides* were identified though no lines were found to be completely resistant and this is in agreement with a previous study by Small *et al*. (2012). According to Chen *et al*. (2016), although genetic variation for resistance to FER exists among maize inbred lines and hybrids, there is no evidence of complete resistance to either FER or fumonisin contamination in maize.

Table 1. Combined ANOVA of 151 maize inbred lines evaluated under artificial *F. verticilliodes* inoculation at Namulonge across two seasons

SOV	Df	Sum Sq	Pr(>F)
Rep	1	4.86	0.02459
Season	1	276.08***	< 2.2e-16
Genotype	150	331.02 ***	2.273e-08
Rep:Block	109	120.36	0.17699
Season:Genotype	149	374.67 ***	1.232e-10
Residuals	192	181.78	
CV	34.49		

*, **, ***Significant at the .05, .01, and .001 probability levels, respectively
SOV: Source of Variation, Df: Degrees of freedom

Finally, while many plant breeders may rely on natural infection when assessing maize germplasm for resistance to FER, there are a few locations that offer sufficient uniformity to make efficient and successful selections (Mesterházy *et al*., 2012). In addition, there is likely to be season-by-season variation in the degree of fungal attack and to overcome this disadvantage, artificial infection is a suitable approach for testing genotypes for resistance to the fungus (Balconi *et al*., 2014).

CONCLUSION

This study identified 12 inbred lines that showed considerable resistance to FER and these will be important in the development of hybrids with good levels of resistance to Fusarium Ear Rot. The resistant lines could also be used to develop mapping populations to fine-map QTLs for FER resistance. Furthermore, since the inbred lines were derived from different crosses, they can be used to widen genetic diversity in other tropical maize breeding programs.

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STATEMENT OF NO CONFLICT OF INTEREST

The authors declare that there are no competing interests in this publication.

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Comparative genomics as a tool for rapid identification of elite indigenous soybean nodulating Rhizobia in South Kivu, D.R. Congo

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ABSTRACT

The use of indigenous rhizobia as inoculants is the best option for improving soybeans productivity and Biological Nitrogen Fixation (BNF). The selection method to date of effective rhizobia nodulating legumes among indigenous population to be included in inoculants formula is time consuming. We sequenced 24 genomes of indigenous Soybean nodulating rhizobia (SNR) isolated from soybean's root nodules grown in South Kivu province of DRC in order to identify rapidly candidate elite strains. Full genomes sequences of 24 indigenous rhizobia were obtained on Miseq, libraries prepared using Nextera xt protocols and compared with genome of the commercial strain *Bradyrhizobium japonicum* USDA 110 (accession number CP011360.1). The genomic features were determined and the presence of nitrogen fixation genes detected. Out of 24 samples, we obtained 14 high quality genomes of indigenous SNR, of mean size of 8.383 Mb ±0.762 bp with mean GC content of 62%. These SNR belonged mostly to *Bradyrhizobium* (64%) genus and few to *Rhizobium*, *Microvirga* and *Kosakonia*. Their chromosomes comprised a mean of 8063±975 genes and 99% of these were protein-coding genes. The full set of nodulation genes (*nod and nif*) were detected in 11 out of 14 indigenous strains and eight genomes of indigenous strains (NAC53, NAC46, NAC22, NAC76, NAC37, NAC17, NAC28 and NAC42) were close to the commercial strains USDA110 and can be considered as candidate elite strains. We conclude that comparative genomics can be used is a tool for rapid identification of elite strains.

Key words: Genomics, *Glycine max*, indigenous rhizobia, rhizobia selection, South Kivu

RÉSUMÉ

L'utilisation de rhizobiums indigènes comme inoculants est la meilleure option pour améliorer la productivité du soja et la fixation biologique de l'azote (BNF). La méthode actuelle de sélection des légumineuses rhizobia nodulantes efficaces parmi la population indigène à inclure dans la formule des inoculants est longue. Nous avons procédé au

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séquencage de 24 génomes de rhizobium indigènes nodulant le soja (SNR) isolés à partir de nodules racinaires de soja cultivés dans la province du Sud-Kivu en RDC afin d'identifier rapidement les souches potentielles le plus performantes. Les séquences complètes des génomes de 24 rhizobiums indigènes étaient obtenues sur Miseq, à partir des bibliothèques préparées à l'aide du kit Nextera xt et étaient comparées au génome de la souche commerciale *Bradyrhizobium japonicum* USDA 110 (numéro d'accès CP011360.1). Les caractéristiques génomiques étaient déterminées et la présence de gènes de fixation de l'azote était détectée. Sur 24 échantillons, nous avons obtenu 14 génomes de SNR indigènes de haute qualité, de taille moyenne de 8,383 Mb ± 0,762 bp avec une teneur moyenne en GC de 62 %. Ces SNR appartenaient majoritairement au genre *Bradyrhizobium* (64%) et peu à *Rhizobium*, *Microvirga* et *Kosakonia*. Leurs chromosomes comprenaient en moyenne 8063 ± 975 gènes et 99 % d'entre eux étaient des gènes codant pour des protéines. L'ensemble complet des gènes de nodulation (*nod et nif*) a été détecté dans 11 des 14 souches indigènes et huit génomes de souches indigènes (NAC53, NAC46, NAC22, NAC76, NAC37, NAC17, NAC28 et NAC42) étaient proches des souches commerciales USDA110 et peuvent être considérées comme des souches potentielles élites. Nous concluons que la génomique comparative peut être utilisée comme outil d'identification rapide des souches élites.

Mots clés: Génomique, *Glycine max*, rhizobium indigène, sélection de rhizobium, Sud Kivu

INTRODUCTION

The Rhizobium–legume symbiosis, characterized by the formation of root nodules, is the most important bacteria–plant interactions (Hirsch *et al*., 2001). It is an important process in sustainable agriculture, as this symbiotic association is able to enhance soil nitrogen status and legume productivity (Alves *et al*., 2003). The symbiosis involving soybean is the most exploited in the world because it produces as much as 300 kg of N ha^{-1} in addition to the release, in the soil, of 20–30 kg N ha^{-1} (Hungria *et al*., 2013). This system is of more benefit in Developing World and particularly in South Kivu province (Eastern DRC) where most farmers are poor with very limited possibilities to improve soil fertility (Walangululu *et al*., 2011). Thus, yield of important crops including legumes remains very low (FAO, 2018). Soybean (*Glycine max*) is an important legume for its high protein and edible oil content; it has been considered for long time as "meat for the poor" (Hartman *et al*., 2011).

Successful Biological Nitrogen Fixation (BNF) by symbiosis legume-rhizobia depends on both good legume genotype and dominating nodule occupancy with highly and adapted efficient rhizobia strains (Alves *et al*., 2003; Checcucci *et al*., 2017). There exist numerous studies on selection of highly effective rhizobia among indigenous populations (O'Hara *et al*., 2002). The empirical approach of selecting highly effective and competitive rhizobia strains consists of 1) native rhizobia strains collection, isolation and authentication, 2) isolates screening against reference strains for symbiotic effectiveness, 3) competitiveness for nodules occupancy testing, and 4) isolates performance testing under varied field conditions (Yates *et al*., 2005). This selection method is time consuming and thus, there is need for an adequate and rapid selection approach.

Some studies have demonstrated recently the effectiveness of genomic approaches on detection of genetic component associated with nodules formation in rhizobia, nitrogenase regulation and other processes involved in BNF (Amadou *et al*., 2008). In this study, we sequenced and analysed the sequences of 24 indigenous Soybean Nodulating Rhizobia isolated from South Kivu in the DRC in order to identify genetic components associated with high N and high productivity in

these rhizobia and detect highly effective strains.

MATERIALS AND METHODS

Genomic DNA extraction, libraries preparation and sequencing. Rhizobia cultures were obtained from N2 Africa project of International Institute of Tropical Agriculture. Subquently, DNA was extracted using Qiagen Plant Mini kit following the manufacturer's instructions (Qiagen, Hilden, Germany) (Ghimire *et al*., 2010; Di Bella *et al*., 2013). The DNA quality check was performed on 0.8% agarose-buffer TAE and read on UV light using GelDoc-It2 imager (Batista *et al*., 2017). The concentration of DNA was measured using Qubit High Sensitivity (Batista *et al*., 2017). In brief, a mean of 450 base-pair libraries preparation was done by the Nextera™ XT Library Prep Kit following the manufacturer'instructions (Illunina, San Diego) (Ring *et al*., 2017). Genomes sequencing was conducted at the Bioscience Eastern and Central Africa of International Livestock Research institute (BecA-ILRI), Nairobi Kenya. Reads were generated on an Illunima MiSeq instrument.

Analysis of Sequences. Raw reads obtained from MiSeq sequencer were analyzed for quality using fastqc software (Leggett *et al*., 2013). Low quality reads were removed by Trimomatric and loaded in CLC main Workench version 7 for denovo assembling (Li *et al*., 2010). Assembled sequences were assembled first in contigs and then in scaffolds using SSPACE Basic software version 2.0.and Unicycler version 0.4.7. Scaffolds were mapped to references genomes *Bradyrhizobium diazoefficiens* USDA110 (accession number CP011360.1) (Sablok *et al*., 2017).

Genome annotation and data analysis. Improved scaffolds were submitted to Blastn program available in NCBI genebank (www.ncbi.nlm.nih.gov/blast) for strains identification and were used for gene prediction and annotation using Prokka bacteria annotation tool which uses Prodigal. Descriptive statistics were performed in XLstat version 2014. Genomes were compared to the commercial strain based on genome size, chromosome number and sizes, number of proteins-coding genes, C-G content and number of nitrogen fixation genes.

RESULTS AND DISCUSSION

Genomes quality. From 24 genomes sequences, 14 yielded higher quality genomes were considered for this study. The Figures 1 presents the per base quality scores of the sample NAC22. From this Figure the quality is scored using 0-38 scale, the acceptable quality scores starting from 20 to 38. From the Figure, most of the sequences were of highest quality. Quality control of sequences is very important for meaningful analysis. In a study conducted by Degnan and Ochman (2012), up to 85% of sequences were removed because they did not meet the treshhold accuracy.

General genomic features. Genomes characteristics are summarized in Table 1. Indigenous rhizobia strains nodulating soybeans from South Kivu belonged mostly to Bradyrhizobium (62%) and few to Rhizobium, *Agrobacterium, Kosakonian* and *Microvirga*. *Bradyrhizobium* genus was the most represented genus and this genus is mostly associated with soybean. These findings corroborate those of other authors who found that soybean is nodulated mostly by *Bradyrhizobium* genus in tropical soils (Wasike *et al*., 2009; Li *et al*., 2011; Chibeba *et al*., 2017; Gyogluu *et al*., 2018). Genomes size varied considerably (CV=14.6%) among indigenous strains and ranged from 5.669Mb and 9.963Mb with the mean genomes estimated at 8.383 Mb in size (Table 1). This size is consistent with other findings, for example those of Kaneko *et al*. (2011) and Bromfield *et al*. (2019). From this study, seven indigenous strains (NAC1, NAC22, NAC76, NAC37, NAC17, NAC28 and NAC42) hold a genome size closer to the commercial strain USDA110.

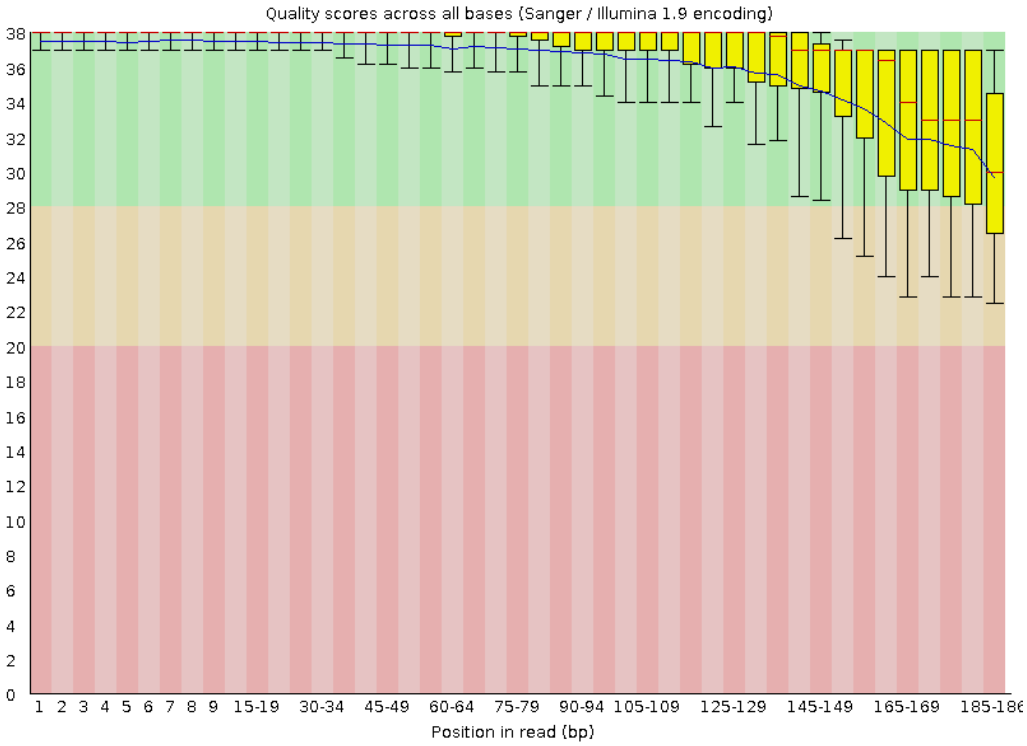

Figure 1. Quality score of sample NAC22

Identification of candidate elite strains by comparative genomics. The genes involved in nitrogen fixation such as nod, fix and nif were detected in genomes to identify candidates elites strains. The number of nod, fix and nif genes recorded in indigenous soybean-nodulating rhizobia and soybean-nodulating commercial strain USDA110 are presented in Table 2. The nif genes number recorded in indigenous strains varied from 0 to 2 while 2 to 11 were recorded for fix genes 4 to 11 for nod genes. In this study, 11 soybean-nodulating rhizobia strains (NAC53, NAC46, NAC37, NAC17, NAC28, NAC42, NAC69, NAC71, NAC72, NAC11, NAC94) out of 14 (Table 5) possess the full set of the nitrogen fixation and could be considered for a program of selection of effective rhizobia to be included in the inoculants commercial. The presence of the full set of nitrogen fixation genes is equivalent to higher capacity of both nodulation and nitrogen fixation. Many authors sustain that the presence of nitrogen fixation is essential for nodules formation and consequently for nitrogen fixation. For example, Okazaki *et al*. (2015) found *Bradyrhizobium* sp. DOA9 strain of particular biological interest because it possessed divergent nod genes compared with other bradyrhizobia and consequently a broader host range.

In addition, indigenous and commercial strains were compared based on their 16S rRNA region approximating 1400bp. Based on this phylogeny tree (Figure 2), indigenous soybean-nodulating rhizobia and the commercial strain USDA110 were partitioned into two main clusters. From this classification, six indigenous strains (NAC28, NAC42, NAC46, NAC76, NAC37 and NAC17) clustered together with the commercial strain USDA110 (98% bootstrap value) suggesting that they may have similar genomic features and thus could be considered as candidate elite strains. This finding corrobotes past studies that demonstrated that indigenous rhizobia are similar to commercial rhizobia in terms of legume grain yield improvement (Tena *et al*., 2016; Aboushanab *et al*., 2019) and genetically (Kawaka *et al*., 2018; Mwenda *et al*., 2018)

Table 1. Summary of genomics features

Strain	Identity (NCBI)	genome size (Mb)	G-C content (%)	number of genes	Protein-coding genes	tmRNA	tRNA
NAC1	*Agrobacterium* sp.	9.247	58.04	8747	8667	2	78
NAC53	*Bradyrhizobium diazoefficiens*	7.722	60.53	7376	7325	1	50
NAC46	*Bradyrhizobium diazoefficiens*	8.327	63.12	8200	8148	1	51
NAC22	*Bradyrhizobium elkani*	9.082	63.58	8567	8516	1	50
NAC76	*Bradyrhizobium japonicum*	9.963	63.47	9656	9597	1	58
NAC37	*Bradyrhizobium ottawaense*	9.567	63.68	9031	8973	1	57
NAC17	*Bradyrhizobium ottawaense*	9.312	63.27	9224	9174	1	49
NAC28	*Bradyrhizobium* sp.	9.469	63.90	9015	8962	1	52
NAC42	*Bradyrhizobium* sp.	9.024	63.95	8893	8840	1	52
NAC69	*Kosakonia oryzae*	5.640	54.25	5390	5314	1	75
NAC71	*Microvirga ossetica*	6.973	62.27	6830	6757	2	71
NAC72	*Microvirga ossetica*	7.019	62.28	6887	6847	2	71
NAC11	*Rhizobium jaguaris*	7.557	59.48	7170	7119	1	50
NAC94	*Rhizobium leguminosarum*	7.740	60.54	7390	7337	1	52
USDA110	*Bradyrhizobium diaazoefficiens* (Kaneko *et al*., 2002)	9.110	64.10	8571	8317	1	50
Min		5.640	54.25	5390	5314	1	49
Max		9.963	64.10	9656	9597	2	78
Mean		8.383	61.76	8063	7992	1,20	57.73
CV(%)		14.61	4.49	14.51	14.61	34.50	18.05

Table 2. Number of nif, nod and fix genes

Strain	nif	Nod	fix
NAC1	0	5	2
NAC53	1	8	7
NAC46	1	7	4
NAC22	0	11	5
NAC76	0	10	10
NAC37	1	7	10
NAC17	1	9	11
NAC28	1	8	6
NAC42	1	8	6
NAC69	1	4	2
NAC71	1	9	7
NAC72	1	10	7
NAC11	2	7	6
NAC94	1	8	7
Min	0	4	2
Max	2	11	11
Mean	0.85	7.92	7,57
CV	62.36	23.96	41.14

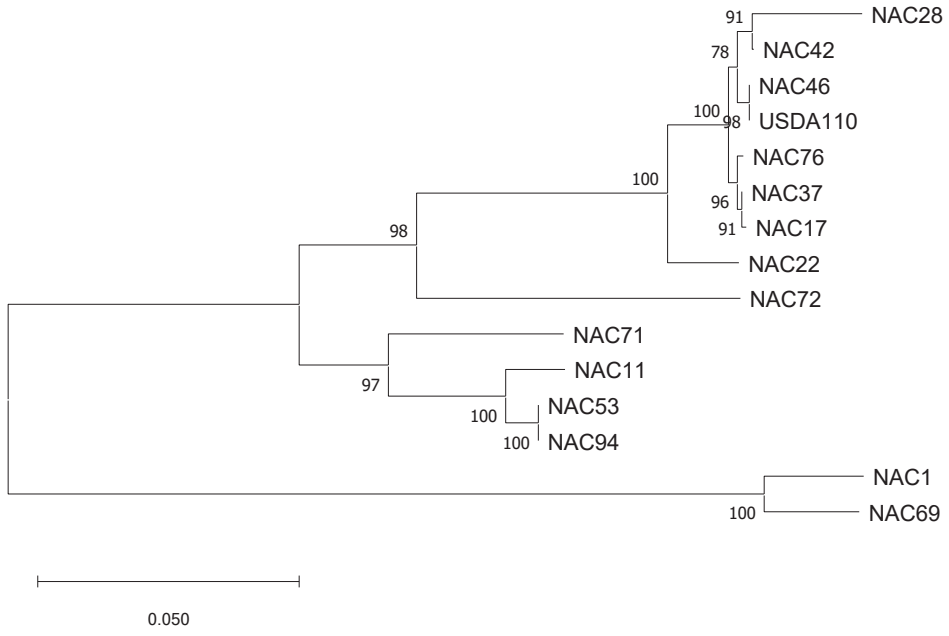

Figure 2. Phylogeny tree based on 16SrRNA constructed using Tamura-Nei model and Maximum Likelihood method. Bootstrap values are shown next to the branches

CONCLUSION AND RECOMMENDATIONS

This study has demonstrated the existence of indigenous soybean-nodulating rhizobia in South Kivu soils that have same genomics characteristics as the commercial rhizobia USDA110. These indigenous rhizobia strains exhibited comparable nitrogen fixation characteristics comparable to the commercial strain USDA110. We suggest further investigations and testing of these indigenous rhizobia under different environmental conditions to confirm their nitrogen fixation superiority. Finally, comparative genomics can be considered for rapid selection of effective rhizobia to be included in commercial formulation but must always be coupled with field testing.

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STATEMENT OF NO CONFLICT OF INTEREST

The authors declare that there are no competing interests in this publication.

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The promise of a fast-cooked healthy meal: common genomic regions for cooking time and iron and zinc content in beans revealed by meta-analysis

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ABSTRACT

Short cooking time (CT) is a highly desired trait in common beans, and several quantitative trait loci (QTL) were identified for bean grain quality traits (GQT), including CT. However, although several correlations were reported among these traits, these genomic regions were limitedly integrated and characterized. In this study, we collected 245 QTL for bean GQT from 12 mapping studies, of which 55 were for CT. A consensus map of the QTL was built based on the *Phaseolus vulgaris* G19833 genome v2.0, using QTL flanking positions when only these are available or physical positions corrected with study-reported linkage disequilibrium (LD) extent or a standard LD of 300 kbp to define QTL end and start positions. Then, the genes with the genomic regions concerning CT were prioritized through a series of in-silico analyses, such as keyword searches and protein-protein interaction networks. We resolved the map to 106 genomic regions, of which 27 were associated with multiple traits. Seventeen multi-trait (MTGR) and 17 single-trait genomic regions (STGR) involved QTL for CT. Nine CT-related MTGRs involved either or both Fe and Zn content, indicating a possibility of combining these traits in new varieties. These results generally agree with a previous meta-analysis conducted for Fe and Zinc QTL. We prioritized 566 that showed a significant PPI at the default confidence level of 0.4 (PPI enrichment p-value<1.0e-16), of which 122 were coexpressed, 138 experimentally determined, 298 based on database annotation, and 480 based on text-mining. All four specific interactions involved 537 genes, and 54 presented all these. We conclude that CT is genomically linked to Fe and Zn content, controlled by multiple genes operating in a biological network. Therefore, multi-omics-assisted genomic selection methods would be the best approach for combining short CT with other essential GQT in new end-user accepted varieties to promote bean consumption and consumers health.

Keywords: Candidate gene prioritization, hard-to-cook phenomenon, in-silico genomics analyses, *Phaseolus vulgaris*, quantitative trait loci

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RÉSUMÉ

Un court temps de cuisson (CT) est une caractéristique très recherchée chez le haricot, et plusieurs loci de traits quantitatifs (QTL) ont été identifiés pour les caractéristiques de qualité du grain de haricot (GQT), y compris le CT. Cependant, bien que plusieurs corrélations aient été rapportées entre cest caractéristiques, ces régions génomiques ont été peu intégrées et caractérisées. Dans cette étude, nous avons rassemblé 245 QTL pour le GQT du haricot à partir de 12 études de cartographie genomique, dont 55 pour le CT. Une carte consensuelle des QTL a été construite sur la base du génome Phaseolus vulgaris G19833 v2.0, en utilisant les positions des flancs des QTL lorsque seules celles-ci sont disponibles ou les positions physiques corrigées avec l'étendue du déséquilibre de liaison (LD) rapporté par l'étude ou un LD standard de 300 kbp pour définir les positions de début et de fin des QTL. Ensuite, les gènes localisee dans les régions génomiques concernent le CT ont été classés par ordre de priorité à l'aide d'une série d'analyses in-silico, telles que des recherches par mots-clés et des réseaux d'interactions protéine-protéine. Nous avons résolu la carte à 106 régions génomiques, dont 27 sont associées à des traits multiples. Dix-sept régions génomiques à caractères multiples (MTGR) et 17 régions génomiques à caractère unique (STGR) impliquent des QTL pour le TC. Neuf MTGR liés à CT impliquaient soit la teneur en Fe et en Zn, soit les deux, ce qui indique une possibilité de combiner ces caractères dans les nouvelles variétés. Ces résultats sont en grande partie en accord avec une méta-analyse précédente menée pour les QTL de Fe et de Zinc. Apres leclassement par ordre de priorité, 566 genes presentant des PPI significatives suivant le niveau de confiance par défaut de 0,4 (valeur d'enrichissement duPPI p<1,0e-16), dont 122 étaient coexprimées, 138 déterminées expérimentalement, 298 basées sur l'annotation de bases de données et 480 basées sur l'exploration de texte. Ces quatre interactions combinées ont impliqué 537 gènes, dont 54 presentant toutes ces type de PPI. Nous concluons que le CT est génomiquement lié à la teneur en Fe et en Zn, contrôlée par de multiples gènes opérant dans un réseau biologique. Par conséquent, les méthodes de sélection génomique assistée par des techniques multi-omiques seraient la meilleure approche pour combiner le CT court avec d'autres GQT essentiels dans de nouvelles variétés acceptées par les utilisateurs finaux afin de promouvoir la consommation de haricots et la santé des consommateurs.

Mots clés: Analyses génomiques in-silico, hiérarchisation des gènes candidats, loci de traits quantitatifs, *Phaseolus vulgaris*, phénomène de difficulté de cuisson

INTRODUCTION

Common bean (*Phaseolus vulgaris*) is an essential food crop worldwide, especially in the developing world, where it serves as the primary source of protein and a crucial contributor to daily calorie uptake of resource-limited sections of the population. Also, beans provide nutrients such as complex carbohydrates, essential micronutrients, dietary fiber, vitamin B, and antioxidants to rural and urban populations (Castro-Guerrero *et al*., 2016). Therefore, beans contribute significantly to maintaining public health in regions where public hospital services are rudimentary and populations usually cannot afford to use these facilities (Hayat *et al*., 2014).

Bioavailability and quality of bean nutrients and their consumption through bean meals are highly affected by the long cooking time (CT) that characterizes most bean varieties either through denaturation or consumer deterrence owing to high woodfuel cost (Feitosa *et al*., 2018; Wiesinger *et*

al., 2018, 2020). These disadvantages of the hard-to-cook phenomenon in beans have spurred several breeding programs targeting the development of fast-cooking varieties. These breeding programs also improve other grain quality traits (GQT) that are essential to consumers and processors along CT, especially iron (Fe) and zinc (Zn) content and bioavailability and seed coat postharvest darkening (PHD) (Haman *et al*., 2020; Hummel *et al*., 2020). Reports exist of various significant correlation levels among bean GQTs (Wiesinger *et al*., 2018; Saradadevi *et al*., 2021). We hypothesize that these levels of correlation are at least partly underlined by gene pleiotropy or close linkage, which eventually translates into overlaps of the different genomic regions or quantitative trait loci (QTL) controlling these traits.

In genomics-assisted breeding (GAB) of beans GQTs, several QTL have been detected in various genetic and environmental backgrounds for CT and water absorption capacity (WAC) (Cichy *et al*., 2015; Berry *et al*., 2020; Bassett *et al*., 2021; de Almeida *et al*., 2021; Delfini *et al*., 2021; Diaz *et al*., 2021; Sadohara *et al*., 2022), Fe and Zn content and bioavailability (Caproni *et al*., 2020; Diaz *et al*., 2020; Gunja a *et al*., 2021; Katuuramu *et al*., 2018; Nazir *et al*., 2022), and SCPHD (Bassett *et al*., 2021; Sadohara *et al*., 2022). Also, the biochemical pathways controlling these traits were extensively studied (Astudillo-Reyes *et al*., 2015; Izquierdo *et al*., 2018; Wiesinger *et al*., 2021; Toili *et al*., 2022), prompting their intergration in beans breeding programs targeting one or several of these traits. However, this information (data) has not yet been integrated, limiting its usefulness in GAB, especially in breeding programs targeting simultaneous improvement and combining several GQTs in superior bean varieties. Integration of QTL data can generally be done through meta-analysis using statistical software such as BioMercator (Sosnowski *et al*., 2012) when QTL flanking marker information is sufficient and common across studies, as was done for bean grain Fe and Zn content (Izquierdo *et al*., 2018). In the cases of diverging flanking markers or insufficient information, a workable approach is aligning the QTL regions to a reference genome using various criteria (Wisser *et al*., 2011). Therefore, in this study we meta-analyzed QTL for cooking time (CT), iron (Fe) and zinc (Zn) content, and seed coat postharvest darking, and prioritized candidate genes within the CT-related genomic regions using in-silico approaches.

METHODOLOGY

A flowchart of the methodology is presented in Figure 1. Briefly, we collected 245 QTL for bean GQT from 12 mapping studies, of which 55 were for CT, 72 for WAC, 54 for Fe content (5 for Fe bioavailability), 58 for Zn content, and 6 for PHD. We built a consensus map anchoring the physical positions of the QTL on the *Phaseolus vulgaris* G19833 genome v2.0 available on the Legumes Information System (LIS, https://legacy.legumeinfo.org/genomes/gbrowse/phavu.G19833.gnm2). For that, we used QTL flanking positions when only these are available or physical positions corrected with study-reported linkage disequilibrium (LD) extent or a standard LD of 300 kbp upstream and downstream of the QTL physical position to define QTL end and start positions. We defined single-trait (STGR) and multi-trait genomic regions (MTGR) based on the overlapping of QTLs from different studies for different traits in the same regions. Genes within the CT-related MTGRs and STGRs were retrieved as pre-candidate genes (pCG), and their gene features, including gene descriptions, gene ontology, and protein domain information, and protein sequences, were retrieved through the BioMart tools of EnsemblPlants (https://plants.ensembl.org/biomart/). The gene features were used to select pre-CT-related CG (pCT-CG) using the cell wall biosynthesis and Fe and Zinc accumulation-related keywords identified from a literature review (Astudillo-Reyes *et al*., 2015; Izquierdo *et al*., 2018; Wiesinger *et al*., 2021; Toili *et al*., 2022). The protein sequences of these pCT-CGs were used to identify the biologically connected genes through a protein-protein interaction network performed on STRING 11.5 (Szklarczyk *et al*., 2019), which were selected as final CGs.

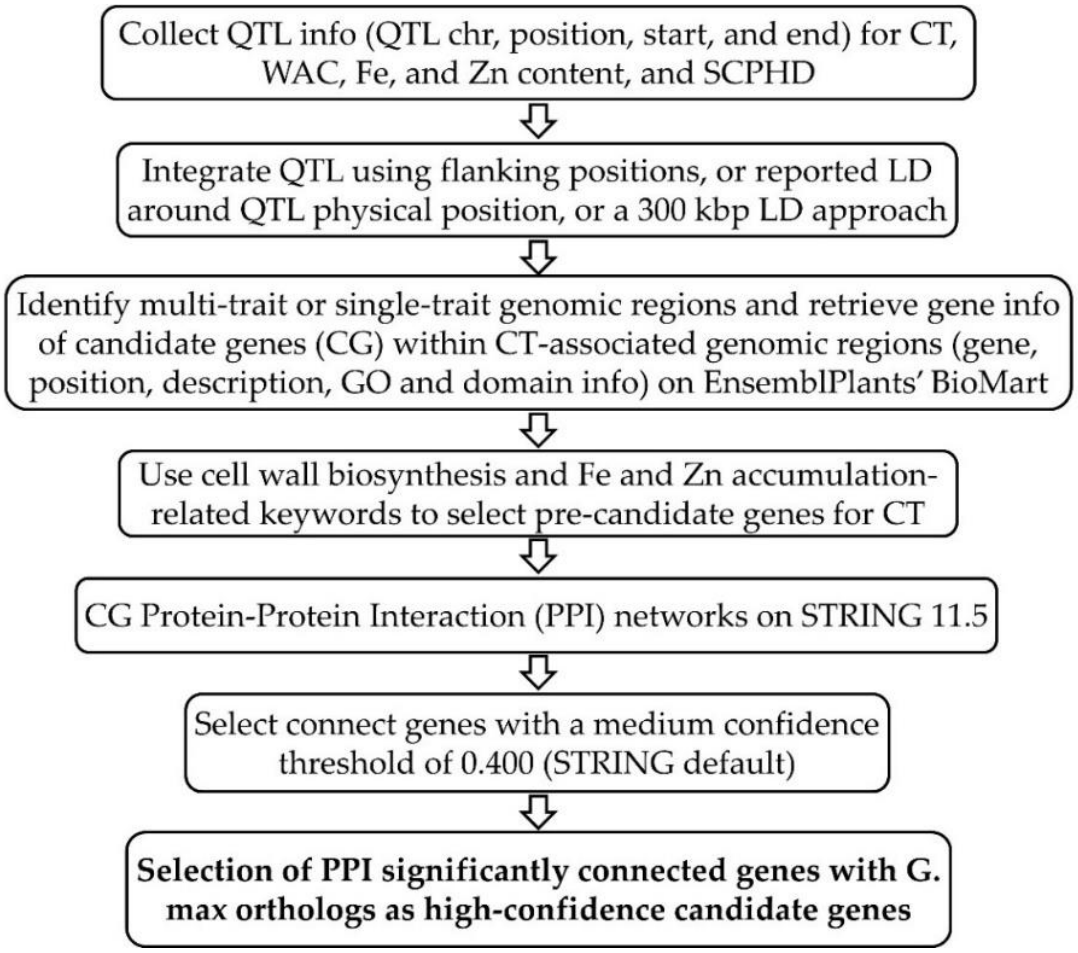

Figure 1. Flowchart of the methods used to integrate the QTLs and prioritize candidate genes for cooking time-related MTGRs and STGRs

RESULTS AND DISCUSSION

Genomic regions for combining short cooking time and high iron and zinc contents. Bean GQT, such as cooking time and color, are highly desired by consumers and processors, which determines the crop's commercial value. However, regarding health, the mineral content of the grain, mainly Fe and Zn, is highly valued. Therefore, breeding efforts are underway to combine these traits in new bean varieties worldwide (Mukankusi *et al*., 2019). This research generates foundation information for using genomics-assisted breeding (GAB) to combine cooking time with nutrient (Fe and Zn) content in bean varieties. The QTL meta-analysis resolved the physical map to 106 genomic regions (Figure 2), of which 28 are associated with multiple traits. Seventeen multi-trait genomic regions (MTGR) and 18 single-trait genomic regions (STGR) involved QTL for CT.

Furthermore, nine CT-related MTGRs involved either or both Fe and Zn content, indicating a possibility of combining these traits in new varieties. These colocalizations between QTL for cooking time and iron and zinc content substantiate the correlations reported between these traits (Wiesinger *et al*., 2018; Saradadevi *et al*., 2021). Multivariate GWAS analyses

would allow deciphering the true nature of these colocalizations, whether gene pleiotropy or close linkage controls these trait correlations (Schulthess *et al*., 2017; Chebib and Guillaume, 2019). It is essential to characterize these genomic regions further to pinpoint the true nature of the colocalization, as this will guide future breeding ventures aiming at combining short cooking time with high bioavailable iron and zinc content (Sibov *et al*., 2003; Schulthess *et al*., 2017). There was no colocalization between cooking time and seed coat PHD, despite the two traits sharing similar molecular mechanisms under the phenylpropanoids biosynthetic pathway (Wiesinger *et al*., 2021). However, this could be due to the extent of LD assumed to define QTL flanking positions. For common bean, reported LD decays vary largely from around 50 kbp (Wen *et al*., 2019) to 4 Mbp (Gunja a *et al*., 2021).

Comparing our results with another meta-analysis focusing on Fe and Zn content in common beans (Izquierdo *et al*., 2018) revealed several convergences of the genomic regions controlling these two traits (Figure 3). However, some of the meta-QTL that Izquierdo *et al*. (2018) identified were not present in our map because their study covered some QTL for Fe and Zn that we did not include in our study because of the unavailability of marker sequence and physical positions. Given the high number of genomic regions involved in the control of bean cooking time and iron and zinc content, it is clear that traditional marker-assisted selection approaches are not appropriate for improving these traits either individually or in combination (Izquierdo *et al*., 2018). The plethora of genes, biochemical pathways, and molecules determining bean cooking time and iron and zinc content, and bioavailability supports the need for multivariate genomic selection approaches to combine these traits in novel varieties (Astudillo-Reyes *et al*., 2015; Izquierdo *et al*., 2018; Wiesinger *et al*., 2021; Toili *et al*., 2022).

The genes with the CT-related genomic regions evidenced significant interactions. We identified 4191 genes within the CT-related MTGR and STGR, which were further reduced to 1092 genes using the keyword-based approach. Of these, 566 showed evidence of protein-protein interaction (PPI) at the default confidence level of 0.4 (PPI enrichment p-value<1.0e-^{16}), of which 122 for co-expression (p-value=2.77e-^{05}), 138 experimentally determined (p-value=0.00017), 298 based on database annotation (p-value=3.87e-^{09}), 480 based on text-mining (p-value=1.78e-^{08}), with all four specific interactions involving 537 genes (p-value<1.0e-^{16}) (Figure 4). The highly significant interaction levels among the proteins of the CGs with CT-related genomic regions that also involve other GQT, such as Fe and Zn content, indicate that these traits are genomically and biologically connected, controlled by multiple genes operating in a biological network, which is characteristics of genes involved in large biosynthetic pathways. These findings underscore the necessity of using multivariate and multi-omics-assisted genomic selection approaches for combining short CT with other essential GQT in new end-user accepted varieties.

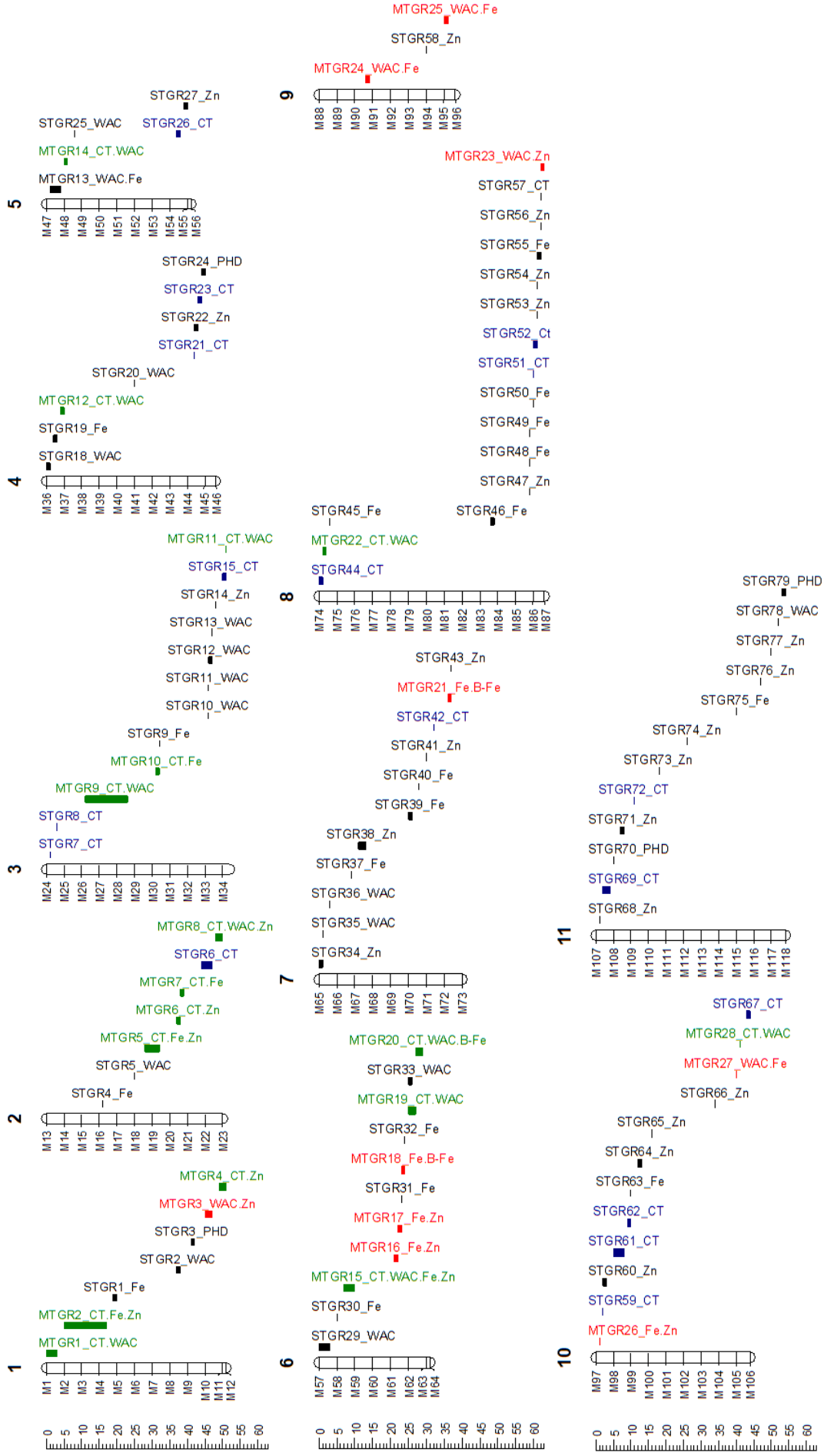

Figure 2. Meta-map of Multi-trait (MTGR) and Single-trait (STGR) genomic regions controling grain quality traits (GQT). In green: MTGR combining cooking time (CT) and other GQT, in blue: STGR unique to CT, and in red: MTGR involving other traits

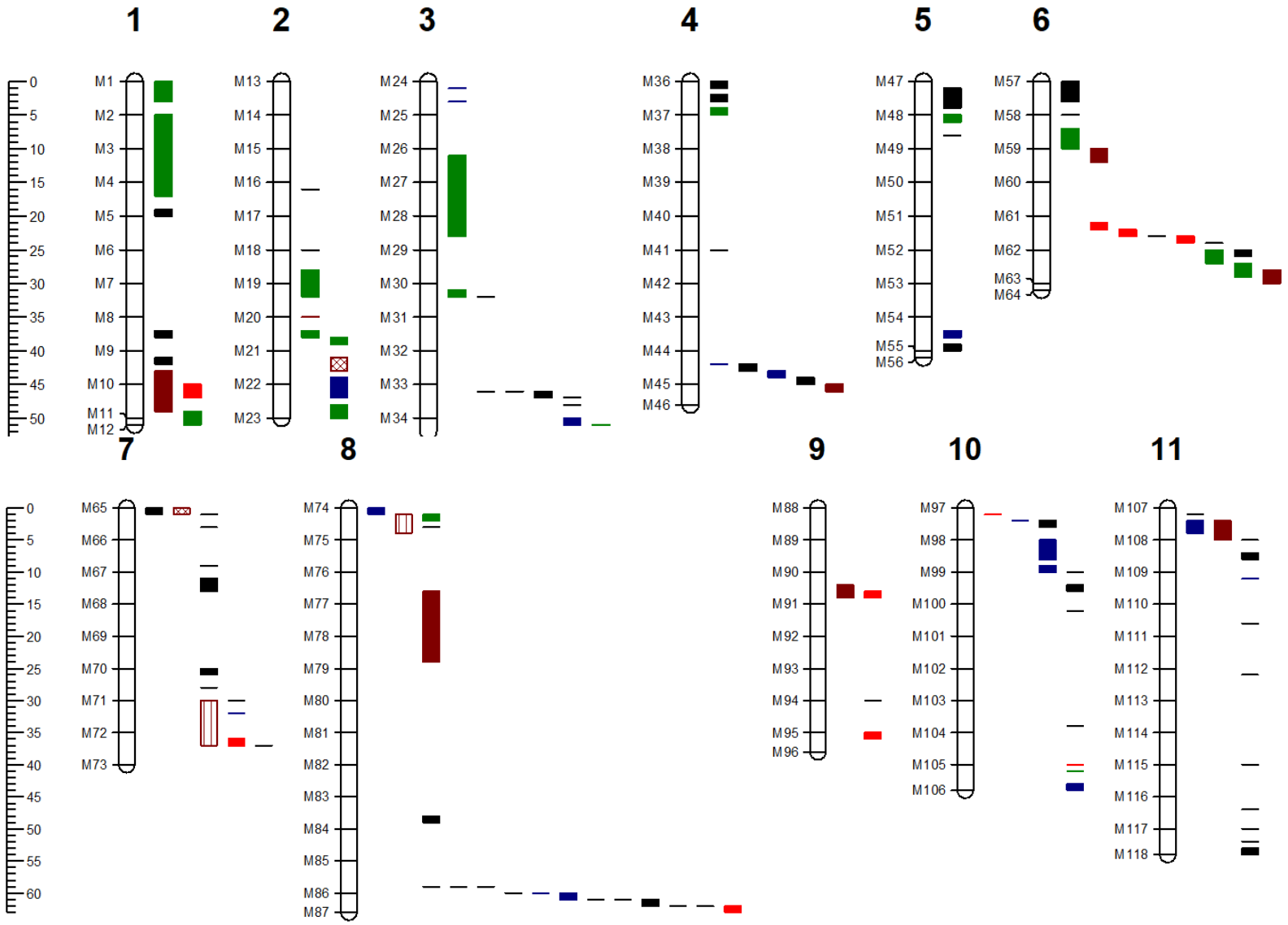

Figure 3. Meta-map positioning the MQTL for iron and zinc content (brown [in full brown: MQTL for Fe and Zinc; in brown with vertical strips: MQTLs for Fe, and in brown with crossed strips: MQTL for Zn]) from (Izquierdo *et al.*, 2018) relative to the MTGR and STGR GQT identified in this study.

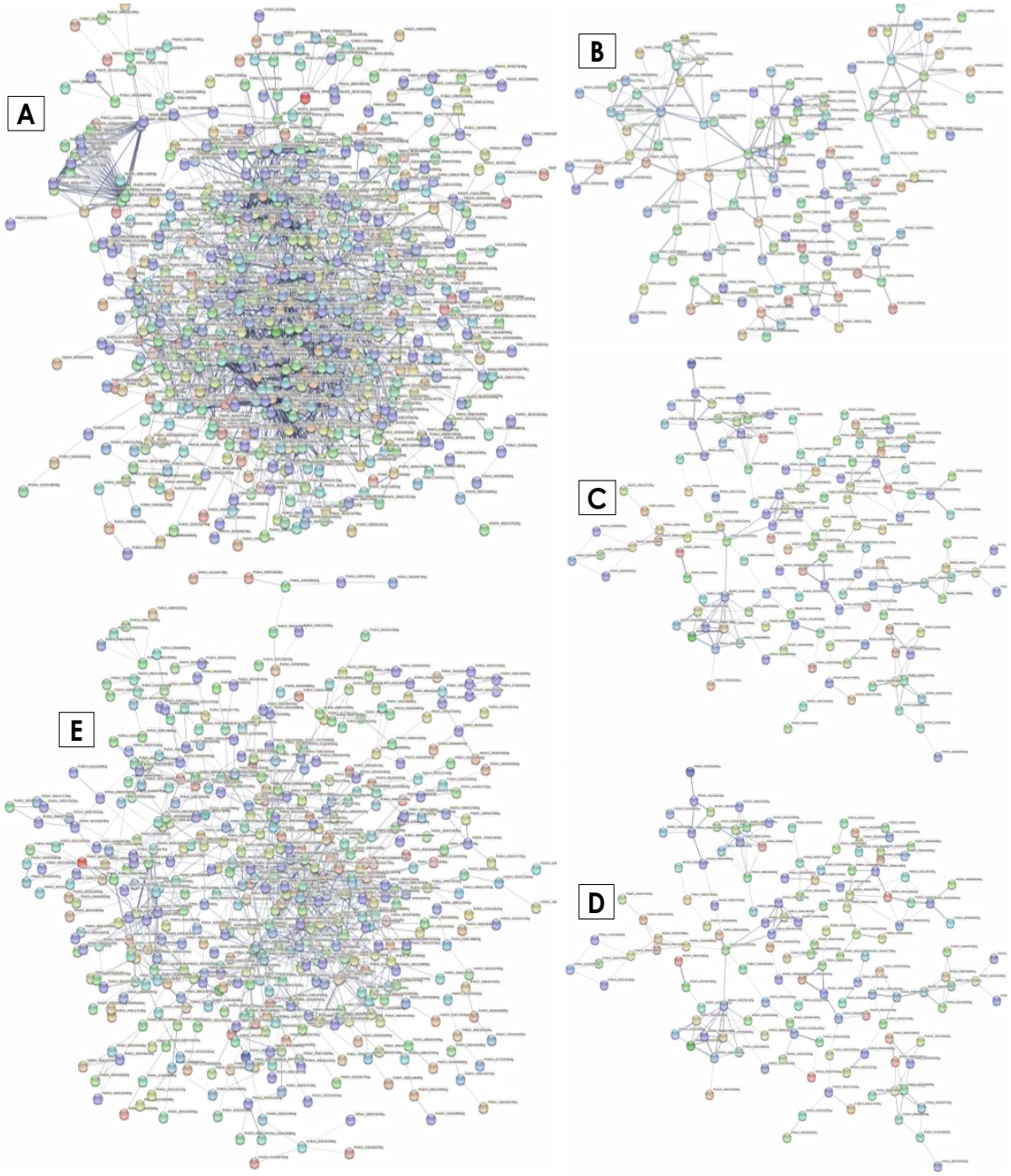

Figure 4. Protein-Protein interaction networks among the 566 candidate genes (excluding non-connected genes). A: Overall interaction, B: Coexpression, C: Database-determined, D: Text-mining, E: Experimentally-determined.

CONCLUSION

We conducted the first meta-analysis study investigating the genomic and gene-based relationship between cooking time and other GQT, such as cooking time, mineral (Fe and Zn) content, and seed coat PHD. Several colocalizations between CT and both or either Fe and Zn were revealed, and genes under these genomic regions shared extensive protein-protein interactions. There were no common genomic regions between CT and PHD, although

these two types of QTL were in the vicinity of one another. Based on these findings, we recommend using multivariate and multi-omics-assisted genomic selection approaches to combine these GQT in novel end-users accepted bean varieties to promote consumption and consumers' health.

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STATEMENT OF NO CONFLICT OF INTEREST

The authors declare that there are no competing interests in this publication.

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Genetic variability and heritability of starch content among white fleshed and provitamin A cassava in Uganda

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ABSTRACT

High starch content and dry matter of cassava are important drivers in the application of cassava to different uses. However, information on starch content variation and heritability in Ugandan cassava cultivars is limited. Accordingly, this study was conducted to determine the variability and heritability of starch content in 112 cassava clones. The effect of genotype was investigated for one season, at two locations; Namulonge and Serere. Harvesting was done at 12 months after planting. Considerable variations were observed among clones at both sites ($P < 0.001$). Starch content ranged from 23.94 % to 75.23% dry basis at Namulonge, whereas at Serere, it ranged from 21.34% to 76.32% dry basis. Likewise, clone by location interaction was significant ($P = 0.001$). Furthermore, high broad sense heritability ($H^2 = 0.76$) was obtained. Therefore, these findings suggest that there is a significant variation for starch content in Ugandan cassava germplasm and that starch content is a heritable trait, Thus, it is important to support ongoing efforts to breed for desired high starch content cassava varieties.

Keywords: Cassava genotypes, heritability, starch content, Uganda

RESUME

La teneur élevée en amidon et en matière sèche du manioc sont des facteurs importants dans l'application du manioc à différentes utilisations. Cependant, les informations sur la variation de la teneur en amidon et l'héritabilité des cultivars de manioc ougandais sont limitées. En conséquence, cette étude était menée pour déterminer la variabilité et l'héritabilité de la teneur en amidon dans 112 clones de manioc. L'effet du génotype était étudié pendant une saison, sur deux sites ; Namulonge et Serere. La récolte était effectuée 12 mois après la plantation. Des variations considérables étaient observées entre les clones des deux sites ($P < 0,001$). La teneur en amidon variait de 23,94 % à 75,23 % de matière sèche à Namulonge, alors qu'à Serere, elle variait de 21,34 % à 76,32 % de matière sèche. De même, l'interaction entre le clone et le site était significative ($P = 0,001$). De plus, une héritabilité au sens large élevée ($H2 = 0,76$) était enregistrée. Par conséquent, ces résultats suggèrent qu'il existe une variation significative de la teneur en amidon dans le germoplasme de manioc ougandais et que la teneur en amidon est un trait héréditaire. Il est donc important de soutenir les efforts en cours pour sélectionner les variétés de manioc à haute teneur en amidon.

Mots clés : Génotypes de manioc, héritabilité, teneur en amidon, Ouganda

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INTRODUCTION

Cassava (*Manihot esculenta* L.), usually grown for its starchy tuberous roots, is a vital source of calories to many of the people in Africa (Bayata, 2019). Furthermore, the roots are used for industrial application such as for formation of products like starch, glucose, pastries, adhesives and feed, among others (Verma *et al*., 2022). Most of the cassava applications require starch. It suffices to note that the growing interest in cassava starch has seen the global cassava starch market increase three fold over the years (Howeler, 2015). Nevertheless, four to five tons of cassava are needed to produce one ton of starch, but the ratio may be as high as ten to one depending on quality of root (Prakash, 2011). For this reason, high starch content is the more often considered trait for adoption of new cassava varieties (Nakabonge *et al*., 2017).

Given the potential and high importance of starch content as a trait, breeding programmes in Uganda, initiated cassava improvement aimed at producing cassava varieties with high starch quantity and quality. As the first stage in breeding, genetic variation studies have been done to evaluate starch content variability among cassava genotypes in a segregating population (Nuwamanya *et al*., 2009), and also starch yield was evaluated in provitamin A clones (Atwijukire *et al*., 2017). However, these were limited to a few genotypes. The huge diversity range for the trait has not been fully explored. In addition, starch content heritability, an important aspect of breeding was not captured. This study therefore assessed variation and heritability of starch content in a diverse set of cassava germplasm comprising introduced germplasm in Uganda.

MATERIALS AND METHODS

Experimental design. Materials used in the study comprised 89 white flesh clones from CIAT Columbia, Latin America and 112 provitamin A clones from West Africa. These were introduced germplasm, sourced from Uganda's cassava breeding population.

The experiment was laid out in an augmented design, 7 blocks with 17 plots per block and three checks per block, with plots of two rows of 10 plants per row at 1m x 1m spacing. The clones were evaluated at two sites; Namulonge (0 31'47N and 32 36'9'E, 1133m above sea level) at the National Crop Resources Research Institute (NaCRRI) and Serere (1 29'57.85"N and 33 32'56.43"E, 1126 m above sea level) at the National Semi-Arid Resources Research Institute (NaSARRI). Harvesting was done at 12 months after planting and root samples for starch content analysis were sourced from plants in the middle rows.

Data collection

Sample preparation and analysis. Due to non-uniform germination, unavailability of appropriate roots for sampling and effect of cassava brown streak disease that affects roots, not all planted clones were sampled. Accordingly, out of one 201 cassava clones, 88 and 98 were sampled from Namulonge and Serere, respectively.

A sample of two fresh healthy-looking storage roots were randomly selected. Of interest were disease free, roots of 25-30 cm in diameter. Each root was washed, then the whole root was grated into paste. These were then oven dried at 105°C for 24 hours, and there after processed into flour for starch content analysis. Starch content was estimated based on acid hydrolysis and determination of sugars method according to Dubois *et al*. (1956). Duplicate samples were analyzed according to the procedure as follows. Initially, 0.5 g of cassava flour sample was weighed and transferred into a falcon tube. To the sample, 2 mls of 95% ethanol was added, then thoroughly mixed, and thereafter decanted off the filtrate. Next, 5 mls of 10% sulphuric acid was added, then incubated at 80°C for 30 minutes and samples were allowed to cool after incubation. Next, 0.5 mls of hydrolysate followed by, 1 ml of distilled water, and 0.5 ml of 5% phenol was added. Finally, 1 ml of concentrated sulphuric acid was added and mixed thoroughly. Upon cooling, absorbance at 490nm wavelength was read. A glucose standard (laboratory grade A) was then prepared. This was done by preparing varying concentrations of glucose dissolved in distilled water, namely; 40%, 35%, 30%, 25%,

20%, 15%, 10%, 5%. From these, 0.05mls of glucose, followed by 0.95 ml of distilled water, and 0.5 ml of 5% phenol was added. Finally, l ml of concentrated sulphuric acid was added and mixed thoroughly. Upon cooling, absorbance at 490nm wavelength was read. From the absorbance and concentration of the glucose solution, a standard curve of concentration against absorbance was developed. A regression equation generated from the standard curve was used to estimate starch content as follows:

$$[1] \quad \%\,Starch = \frac{(A-I)\text{x DF x } 100}{B}$$

Where A = Absorbance of sample, I = Intercept of sample, B = Slope of the standard curve, DF = Dilution factor (Dubois *et al*., 1956).

Statistical data analysis. Analyses of variance (ANOVA) for starch content were performed by least squares regression using the anova and l m function available in R stats package to test for significant differences in clone means (R Core Team, 2020). The model used to analyze data collected at single site had clone, population, root and technical replicates, as fixed effects and interaction of all other terms from the simple linear model described above. Thereafter, pooled data from Namulonge and Serere were used to determine clone by location interaction. The Tukey-Kramer honest significance (HSD) test (P-value < 0.05) was used to determine if varieties were significantly different from each other (R Core Team, 2020).

Heritability of starch content was determined on pooled data for both provitamin A and white-flesh Latin America clones. This was obtained using variances from mixed linear model fitted, considering clone, location, population, and root as random effects, while technical replicate considered as a fixed effect using lmer function in lme4 package in R (Kuznetsova *et al*., 2017).

Variance components obtained were used to estimate broad sense heritability (repeatability) on an entry-mean basis (Holland *et al*., 2003). Heritability was estimated as the broad-sense heritability, calculated using the formulae below:

$$H^2 = \frac{genotypic\ variance}{phenotypic\ variance}$$

$$H^2 = \sigma^2 G/(\sigma^2 G + \sigma^2 error)$$

Where σ2 *G* is the genotype variance and σ^2 *error* is the error variance

RESULTS

Genetic variation of starch content. There was significant variation in starch content among both white fleshed-LA and provitamin A-WA clones ($p < 0.001$) at both locations (Namulonge and Serere), (Table 1). Furthermore, there was a strong clone by location interaction ($p < 0.001$), implying that starch content was dependent upon location. Populations were significantly different ($p < 0.001$) at Serere, however, not significantly different at Namulonge (Table 1).

At Namulonge, provitamin A clones had slightly wider variability of starch content ranging from 24.71 to 75.23 % dry basis compared to white flesh-LA clones whose starch content ranged from 23.94% to 73.93 % (Table 2). Furthermore, provitamin A clones had a higher mean (56. 14%) compared to white flesh-LA clones with a mean of 50.86 (Table 2, Figure 1).

At Serere, white-flesh-LA clones had slightly wider starch content variability (22.43 % to 76.32%) than provitamin A clones (21.34 % to 73.66%), (Table 2). Furthermore, white flesh-LA clones had a higher mean (51.19%) than provitamin A clones with a mean of 49.22% (Table 2, Figure 1).

Generally, for the cassava accessions (both white flesh and provitamin A clones), there was higher performance at Namulonge with average starch content of 54.07% than at Serere where mean starch content of 50.52 % was registered (Figure 1). However, there was a higher starch content diversity range at Serere (21.34% to 76.32%) than at Namulonge from (23.94% to 75.23%), (Figure 1). The mean value of starch content between Latin America clones and PVAC clones was significantly different at Namulonge ($p = 0.00$, 95% C.I. = [0.93, - 6.82]), and Serere ($p = 0.03$, 95% C.I. = [-6.39, - -0.13]), implying differences in locations and populations (Table 3).

Table 1. Mean squares associated with starch content (dry matter basis) of cassava accessions planted in two locations

	Namulonge		Serere	
SOV	d.f	Mean Square	d.f	Mean square
Clones	88	1205.47***	97	1612.8***
Population	1	99.34NS	1	3958.0***
Rep	1	77.79NS	1	2.8NS
Tech-rep	2	2.39NS	2	0.1NS
Accession X Rep	88	60.64**	97	42.4***
Error	521	38.1	449	25.8
Mean		54.07		50.52
CV		11.47%		10.06%
H^2		0.82		0.62

SOV = source of variation; d.f = degrees of freedom; *** represents significance at p = 0.001; CV = coefficient of variation, H^2 = broad sense heritability. Data based on analysis in two locations; Namulonge (central region) and Serere (eastern region); data on starch content, dry basis on 89 and 98 genotypes of both white flesh-Latin-American germplasm and provitamin A Clones-West Africa planted in Namulonge and Serere, respectively

Table 2. Distribution of starch content among cassava genotypes

		Starch content			
Location	Clones	No of clones	Mean (%)	SD	Range (%)
Namulonge	White flesh-LA	37	50.86	6.26	23.94 - 73.93
	Provitamin A-WA	52	56.14	6.05	24.71 - 75.23
Serere	White flesh-LA	60	51.19	6.34	22.43 - 76.30
	Provitamin A-WA	38	49.22	0.688	21.34 - 73.66

Data based on analysis in two locations; Namulonge (central region) and Serere (eastern region); data on starch content, dry basis. LA-Latin America; WA-West Africa

Table 3. Tukey post -hoc multiple comparison table of cassava starch content by location and population

					95% CI	
Location	Population(I)	Population (J)	Mean difference (I-J)	sig	lower bound	Upper bound
Namulonge	Latin America	PVAC-WA	3.80	0.00	0.93	6.82
Serere	Latin America	PVAC-WA	-3.26	0.03	-6.39	-0.13

PVAC- provitamin A, WA- West Africa, sig – significance, CI – confidence Interval

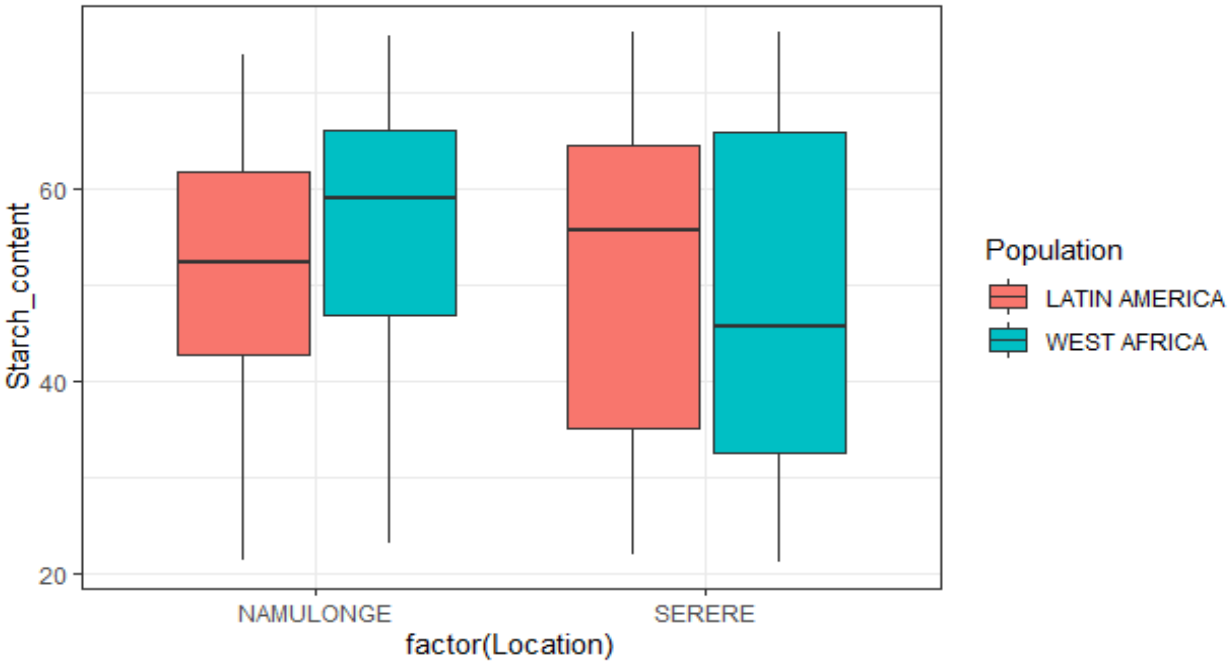

Figure 1. Cassava starch content distribution at Namulonge and Serere

Table 4. Mean squares associated with starch content (dry matter basis) of cassava accessions planted in two locations

	Starch content	
SOV	D.f	Mean Square
Clones	146	1470.7***
Location	1	6201.0***
Population	1	1113.2***
Rep	1	27.1NS
Tech_rep	2	1.6NS
Clone*location	39	1163.1***
Location*population	1	2969.9***
Error	1158	35.3
Mean		52.00%
CV		11.39%
H^2		0.76

SOV = source of variation; D.f = degrees of freedom; *** represents significance at P = 0.001; CV = coefficient of variation, H2 = broad sense heritability. Data based on analysis in two locations; Namulonge (central region) and Serere (eastern region); data on starch content, dry basis on 89 and 98 genotypes of both white flesh-Latin-American germplasm and provitamin A Clones-West Africa planted in Namulonge and Serere, respectively

Starch content was significantly different across locations (P = 0.001) and there was a highly significant clone by location interaction (P = 0.001), (Table 4). Entry mean-based single site broad sense heritability estimates were moderate to high (H^2= 0.62 – 0.82), (Table 1). Highest heritability (H^2=0.82) was obtained at Namulonge and moderate heritability was observed at Serere (H^2=0.62), (Table 1). Overall, heritability was high (H^2 = 0.76), implying that starch content is a highly heritable trait (Table 4).

DISCUSSION

Appreciable variability in starch content was observed among clones at both locations (Table 1). Related studies have indicated that the genetic composition of the cultivars, cultural practices on the field as well as a combination of environmental factors influence starch content (Benesi *et al.* (2004). Starch content ranged from 21.34% to 76.30 % with most of the clones ranging from 41.35% to 75.23% (Figure 1). This is consistent with findings by Nuwamanya *et al.* (2009), who observed similar trends, i.e., starch yield percent ranged from 47% to 90% starch content on dry matter basis.

There were no significant differences in starch content among the provitamin A clones and the white flesh clones at Namulonge, however, significant differences were observed at Serere (Table 1). These differences could be attributed to differences in the distribution of rainfall at the two locations (Benesi *et al.,* 2008). Extended dry weather at Serere might have forced the plants to use their food reserves by breaking down some of the starch into sugars for survival during the dry season (Benesi *et al.,* 2008). Furthermore, an impact of disease might have influenced the differences.

Higher mean performance was observed at Namulonge (54.07%) than at Serere (50.52%), (Table 1 and 3, Figure 1). These differences could be attributed to root bulking in the different locations. Studies by Tumuhimbise *et al*. (2014), showed that locations effects were significantly different for fresh storage root yield (bulking).

Overall, White flesh-LA clones performed better than Provitamin A-WA at both locations (Figure 1). These differences could be due to the fact that there was increased utilization of glucose for carotenoid synthesis that could impact on the amount of glucose available for starch synthesis among provitamin A-WA clones. Synthesis of phytoene, a carotenoid precursor in plants, requires isopentenyl pyrophosphate (IPP). The IPP is synthesized either from acetyl-CoA or from pyruvate and glyceraldehyde-3-phosphate(Cunningham and Gantt, 1998) , all of which are obtained from metabolism of glucose. Thus, it is very likely that the lower performance of provitamin A clones could have resulted from the higher utilization of glucose for carotenoid synthesis.

Very low starch contents (< 30% dry basis), were observed in some clones (Table 2). This could be due to the high dry matter displayed by these progenies and, hence, low digestibility and creation of side products during hydrolysis such as isomaltose and maltose (Van Der Veen *et al*., 2006) which are not detected by glucose specific tests used in this analysis.

There was a highly significant clone by location interaction (Table 4), suggesting that when and where cassava is grown and harvested for starch extraction and starch content determination will be important in maximizing the starch yield and content from tubers.

Generally, there was high broad sense heritability for Namulonge (H^2=0.812), and moderate broad sense heritability at Serere (H^2=0.62), (Table 4.1). This difference could be due to variations in sample handling effects at Serere, since it is an off-station site, that contributed to the lower repeatability than at Namulonge. Overall heritability was high (across both locations, H^2 = 0.76), (Table 4). This is in line with results obtained by Oliveira *et al*. (2014), where broad sense heritability estimates for starch yield were

reported to be of medium magnitude, that is (0.50 ± 0.05). However, heritability obtained in this study was much higher, and this could be due to accuracy of the phenotyping method (Dubois *et al*., 1956; Moorth and Padmaja, 2002).

CONCLUSION

There is indeed significant variation in starch content among cassava germplasm in Uganda. Both white flesh-LA clones and Provitamin A clones are diverse enough for starch content assessment. Nonetheless, white flesh clones had higher starch content than Provitamin A clones, thus should be considered as parents in breeding for the traits. Most of the clones had starch content ranging from 41.35% to 75.23% on dry basis which is a typical range for most cassava varieties. Furthermore, starch content is a highly heritable trait ($H^2 = 0.76$), thus, there is good genetic control of the expression of the trait, and this shows great potential for selection in breeding. There is significant variation in starch content among introduced cassava germplasm in Uganda and thus, justifying systematic genetic improvement for starch content, a key end-user quality trait.

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STATEMENT OF NO CONFLICT OF INTEREST

The authors declare that there are no competing interests in this publication.

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