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Research Application Summary

Coming to speed with the state of cassava breeding in Uganda

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Abstract

Uganda is the 5th largest producer of cassava in Africa and cassava is the second most important source of starch after banana (matooke) in terms of area occupied, total production and per capita consumption. It is an important food security crop and a source of income for smallholder farmers as well as its potential to contribute to national economic development. Cassava production in Uganda is however hindered by several constraints including use of inferior and low yielding cultivars which are susceptible to pests and diseases, slow growth and development rate under clonal multiplication, and lack of improved early bulking cutting suitable and improved varieties which meet farmer's preferences. Several efforts have been made by the Ugandan Government including establishment of breeding programmes to release new disease resistant varieties and multiplication of high yielding cassava varieties; integrated pest management; training of farmers and extension staff; infrastructure development; and policies that facilitate the development and adoption of innovations. Despite the efforts to improve cassava production, farmers are still challenged with wide spread of emerging pests and diseases leading to high yield losses coupled with low rates of adoption of improved varieties and lack of adequate clean planting materials. Additionally, although cassava breeders are making progress, they still face significant challenges in developing disease-resistant varieties that increase overall yield and respond to the needs of smallholder farmers and processors. There is therefore an urgent need to support cassava breeding towards selecting of genotypes which are high yielding with stability across several agro ecological zones and resistant to pests and diseases. This paper reviews the state of knowledge on cassava breeding in Uganda and the information generated from this review will inform the cassava variety release process.

Key words: Cassava improvement, farmer-preferred traits, Uganda

Résumé

L'Ouganda est le cinquième producteur de manioc en Afrique et le manioc est la deuxième source d'amidon après la banane (matooke) en termes de superficie occupée, de production totale et de consommation par habitant. C'est une culture importante pour la sécurité alimentaire et une source de revenus pour les petits agriculteurs ainsi que son potentiel à contribuer au développement économique national. La production de manioc en Ouganda fait cependant face à plusieurs contraintes, notamment l'utilisation de cultivars à rendement inférieur et faible qui sont sensibles aux ravageurs et aux maladies, une croissance et un taux de développement lents sous multiplication clonale, et le manque de coupes améliorées des variétés adaptées et améliorées qui répondent aux préférences des agriculteurs. Plusieurs efforts ont été fournis par le gouvernement ougandais, notamment la mise en place de programmes de sélection pour créer de nouvelles variétés résistantes aux maladies, et la multiplication de variétés de manioc à haut rendement, la lutte intégrée contre les nuisibles; la formation des agriculteurs et du personnel de vulgarisation; le développement des infrastructures; et les politiques qui facilitent le développement et l'adoption d'innovations. Malgré les efforts déployés pour améliorer la production de manioc, les agriculteurs sont toujours confrontés à une large propagation de ravageurs et de maladies émergents entraînant des pertes de rendement élevées associées à de faibles taux d'adoption de variétés améliorées et à un manque de matériel végétal propre et adéquat. En outre, bien que les sélectionneurs de manioc observent des progrès, ils sont toujours confrontés aux défis importants de développement de variétés résistantes aux maladies qui augmentent le rendement global et répondent aux besoins des petits exploitants et transformateurs. Il est donc urgent d'appuyer la sélection du manioc vers les génotypes à haut rendement, stables dans plusieurs zones agroécologiques et résistants aux ravageurs et aux maladies. Cet article passe en revue l'état des connaissances sur la sélection du manioc en Ouganda et les informations générées informeront le processus de diffusion des variétés de manioc.

Mots clés: amélioration du manioc, caractères préférés des agriculteurs, Ouganda

Introduction

Cassava (*Manihot esculenta* Crantz) is a key staple food crop in Uganda despite being introduced as a mere food security crop between 1862 and 1875. Cassava is a crop with high potential to alleviate food shortages, owing to its unique advantages of being grown with minimal inputs, but giving considerably higher yields with fertilizers and good management amidst erratic rainfall, when most crops would fail. It is now rankied second to bananas in terms of area occupied, total production and per capita consumption (Ssemakula *et al.,* 2004). It contributes approximately 11% of the total national calorific requirements of the population estimated at 132 kg per person (Balyejusa-Kizito, 2006). About 75% of farmers grow cassava for home consumption while about 25% grow it for cash and other uses such as for local beer and cementing agent in local building using brewing waste. Cassava also has the unrealised potential for industrial processing and export (Otim-Nape *et al.,* 2005). It is also used as a source of ethanol for fuel, energy in animal feed, and starch for the industry. However, most of the cassava cultivars currently grown in Uganda are unimproved low yielding and late bulking cultivars with the majority of them being susceptible to pests and diseases (Abele *et al.*, 2007).

Ever since the introduction of cassava to the East African region by Portuguese explorers and traders from Brazil during the late 1700s, cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) have been a perennial challenge limiting its optimal productivity (Legg *et al.,* 2011). These viruses cause immense damage to cassava which registers up to 100% yield losses in high disease prevalent areas (Kizito *et al.,* 2005). Over the years, genetic gains in fresh root yield and resistance to diseases have been low (Okechukwu *et al.,* 2008).

In order to improve local cultivars, cassava breeding programmes generate crosses to increase the frequencies of specific desirable traits. Sexual propagation creates high genetic heterogeneity through recombination leading to variation among seedlings which provides the breeder with opportunity to select materials with good qualities of the traits of interest (Ceballos *et al.,* 2004). However, one of the major problems in cassava breeding is the difficulty in producing recombinant seeds due to high flower abortion rates, poor seed sets and seedling germinability. Therefore there is a need to critically assess the extent of seed sets and abortion rates in cassava crossing nurseries used to generate hybrid progenies for new breeding populations.

Although there has been great effort by plant breeders to improve the agronomic traits of cassava, a great gap remains in the quality traits that are preferred by farmers. Society preferences for fresh and/or processed cassava products further play a pivotal role in variety adoption, alongside breeding interventions strategized towards combining disease resistance with superior root qualities to suit the needs of the consumers (Kawano, 2003; Hershey, 2011). In Uganda, boiling is the most preferred method of cassava preparation, and other universal traits attributed to boiled cassava include texture, flavour and taste (Favaro *et al.,* 2008). Traditional plant breeding mostly involves farmers at the varietal evaluation stage and this approach eliminates the evaluation for root processing quality traits. Breeding programmes therefore need to involve small holder farmers in the whole selection process to incorporate farmer preferred cassava traits in development of new varieties.

Cassava Research and Development in Uganda

Cassava genetic improvement research has been conducted by farmers and researchers in colonial and post-independent research stations and by scientists in international research centres such as IITA and Centro Internacional de Agricultura Tropical (CIAT). Farmers selected self-seeded plants from local varieties that possessed the superior attributes which they desired such as high yield, early bulking, in-ground storage, pest and disease tolerance, processing qualities, large canopy and low cyanogens level (Otim-Nape *et al.,* 2005). Globally, however serious cassava breeding research was inspired by the appearance and rapid spread of CMD in East Africa. In response to the challenge, the colonial governments set up cassava research programmes in various countries in West, Central and East Africa, but the most successful was the one set up at the Amani Research Station in Tanzania in the 1930s and these materials served as the foundation for IITA's research programme on cassava in the 1970s and 1980s (Otim-Nape *et al.,* 2005). The center developed cassava mosaic resistant varieties like Bukalasa 8 and 11 which provided most of the background genetic material for cassava breeding work in Eastern Africa. This managed to contain the cassava mosaic epidemic in the East African region between the 1930s-40s (Otim-Nape *et al.,* 2005).

In Uganda cassava breeding began during the early twentieth century, with research stations in Serere, Kawanda, Kalengere, Ngetta and Namulonge (Hershey, 2011). The Government of Uganda later established the National Agricultural Research Organization (NARO) and

National Agriculture Research Systems (NARS), to conduct, promote and manage cassava research. Four years later, the Namulonge Crop Resource Research Institute (NaCRRI), was established to develop appropriate varieties for farmers, and develop IPM strategies for major pests and diseases (Otim-Nape and Zziwa, 1990). Other cassava research institutions which contributed to cassava development in Uganda was the International Society for Tropical Root Crops - African Branch (ISTRC-AB) founded in 1978 by IITA to facilitate cooperation among scientists in national programmes.

The creation of two International centers (IITA and CIAT) has greatly benefited cassava research in Uganda (Kawano, 2003; Ceballos *et al.,* 2004). To demonstrate its impact, since 2012 to 2017 the IITA in collaboration with Cornell University initiated the Next Generation Cassava Breeding Project. The project aims at improving global cassava research to shorten the breeding cycles for new cassava varieties by improving flowering using genomic selection. This has led to the development of over 30 clones with high dry matter which led to up to 50% genetic gain. The project has also developed a cassava database accessible to Cassava researchers for comparing results and improving breeding programs without duplicating efforts. The NextGen Project is now on a second Phase to disseminate the research findings to increase impact and leverage the exchange of germplasm and genotypic and phenotypic data from each other http://www.nextgencassava.org/

Cassava breeding objectives in Uganda

The key mandate of the national cassava breeding programme in Uganda is to improve cassava production through identification and development of new technologies, however, in the recent past, these objectives have evolved and are mainly focused on yield improvement through harvest index selection (Kawuki *et al.,* 2011). The specific objectives include: 1) development and dissemination of improved varieties acceptable to farmers; 2) developing sustainable approaches for disease and pest management; and 3) development of improved production technologies for utilization of the crop. These strategies have led to the release of new genetically improved varieties resistant to pests and diseases like CMD and CBSD for use both by farmers and the NARS.

These objectives will partly contribute towards the African vision for cassava whose aim is to improve cassava food system leading to increased incomes for producers, processors and traders, and enhanced rural and industrial development. Ultimately, improved cassava production will promote rural development and contribute more to the food and niutrition security status and use as a cash crop to its producing and consuming households.

Some key lessons learnt by efficient breeding programmes elsewhere, include: 1) development and implementation of phenotyping methodologies that significantly reduce errors, and thus result into higher and better trait heritabilities and rational resource allocation, 2) having robust selections schemes that are mindful of genetic traits, environmental influences and target groups (Hahn *et al.,* 1980); and 3) undertaking innovative approaches that reduce breeding cycles, i.e., the rapid recurrent selection scheme used in enhancement of beta-carotene in cassava at Centro International de Agricultura Tropical CIAT and International Institute of Tropical Agriculture (IITA) (Kawano, 2003). These research interventions have led to increased cassava productivity across the globe, including in Uganda, where 19 varieties have been officially released, some of which are still surviving to date.

Cassava Evaluation

Cassava breeding is a long process and the release of a new cassava variety can take between eight to ten years given the large genetic variation generated with each cross due to heterozygous nature of the crop (Ceballos *et al.,* 2004). The cycle begins with crossing a large pool of genotypes and ends with a few superior clones for variety release (Wolfe *et al.,* 2017). Typically, cycles of selection take 3 to 6 years from seedling germination to multi-location yield trials and additional years are required to evaluate promising genotypes before variety release. A recurrent selection programme is conducted in a progressive set of stages. As the stages continue more emphasis is given to low heritability traits since more planting material for each genotype is available and the evaluation can be conducted in bigger plots with replications (Ceballos *et al.,* 2004). To shorten the breeding cycle and improve variety adoption by farmers and also to reduce costs, CIAT and IITA have modified the scheme by eliminating the need for preliminary yield trials, increasing the number of traits evaluated in the Clonal Evaluation Trials (CET) which is often conducted at a single location; and conducting location-specific selection for local adoption of cassava modified uniform yield trial (MUYT), with farmers participating in the evaluation and selection stages (Ceballos *et al.,* 2004). This modified scheme is currently used to accelerate development of locally adapted varieties through the speed cassava breeding project and it has successfully released varieties for use by farmer (Kawuki *et al.,* 2011).

Cassava Varieties

Ever since cassava improvement started in the 20th Century, various breeding programmes have released several varieties with desirable qualities like fresh root yield, dry matter content, early maturing and resistance to pests and diseases. Most local varieties in Uganda are susceptible CMD and CBSD which has led to the extinction of some of the local varieties. However, in other CSBD affected countries especially Tanzania and Kenya, some cultivars like Kibaha, TMS varieties, Namikonga, Kigoma Red, Nachinyaya, Kiroba, Kalulu and Kitumbua have been screened and identified to be tolerant to CBSD (Hillocks, 2006). A study by Tumuhimbise *et al.* (2012) demonstrated that farmers preferred quality regardless of the duration the crop takes in the field. The early storage cultivars include: Taso, Mercury, Mufumbacayi, Ebwanatereka, Selefu, MH97/2961, Mwezigumu and TME14 while the late maturing cultivars include Akena and Ofwono.

These cultivars have potential for use as parental genotypes in the breeding program in Uganda. Typical to most farmers in Uganda, 2-6 sweet cassava varieties will be planted in their fields, these include local varieties such as Bao, Nyaraboke, Fumba chai, Alodo-alodo (Tim-tim), and Ebwanateraka and recently released varieties which are processed for other commercial uses such as Akena (MH91/0067), NaROCAS, NASE 3, NASE 14, and NASE 19. Farmers however, still reject newly released varieties due to lack of desirable traits for cooking for instance in Northern Uganda they continue to grow susceptible local varieties, which pose a threat to food security. Breeding efforts are now focused on incorporating farmer preferred traits through involving farmers in the selection process.

Conservation and preparations

Most cassava germplasm in cultivation is still based on landrace varieties and wild Manihot species which are conserved mainly in seed gene banks or as plants in the field. Seeds can also be conserved at low temperature and humidity and with cryopreservation techniques. Genes can also be maintained for further use in the form of DNA or cryopreserved pollen (Hillocks *et al.,* 2002). It is estimated that nearly 2/3 of the genetic diversity of cassava exists only *in situ*, with only 1/3 being securely conserved *ex situ*. Germplasm can be maintained vegetatively in fields or screen houses (field banks) or in vitro (slow growth tissue culture or cryopreservation).

Pests and diseases

The key cassava pests and diseases in Uganda include the green mite, mealybug, CMD, CBSD and Cassava bacterial blight (CBB) control. The mealybug and greenmite have been successfully managed through biological (Yaninek, 1994). The CBSD is caused by two distinct viruses: cassava brown streak virus (CBSV) and Ugandan cassava brown streak virus (UCBSV) (Winter *et al.,* 2010). In terms of virulence, UCBSV has been reported to cause lower pathogenicity than CBSV, and also milder symptoms (Vanderschuren *et al.,* 2012). The economic losses are often associated with damage to the aboveground parts characterized by leaf chlorosis and necrosis, elongated necrotic lesions on stems and secondary and tertiary vein chlorosis (Hillocks and Jennings, 2003). Root spoilage is characterized by formation of necrotic lesions and/or discoloration of the roots making them unmarketable and unpalatable posing a threat to food security (Nichols, 1950).

Some of the agronomic practices to manage the pests and diseases include fallow rotation, crop rotation and application of pesticides. However, due to costs and the limited access to chemicals farmers usually do not attempt to control the cassava pests and diseases with pesticides. Breeding for resistance is therefore the most pragmatic method of managing CBSD. The Namikonga (Kaleso) from the Amani Research Station is a key source of resistance in many breeding populations. This variety has been reported to have the highest general combining ability for CBSD resistance (Kulembeka *et al.,* 2012). The CMD infection on the other hand is associated with deformed leaves with a mosaic-like chlorosis and general plant stunting, leading to reduced tuberous root production (Alabi *et al.,* 2011). Most CMD-affected cassava plants produce few or no tuberous roots depending on the severity of the disease and the age of the plant at the time of infection (Alabi *et al.,* 2011). Cassava Mosaic Disease causes up to 47% yield losses equivalent to nearly 14 million tonnes (Legg, 2008). Studies exploring the potential of CMD resistance have shown that a single resistance gene is responsible however it lacks durability rendering its long-term effectiveness risky, given the fast-paced evolutionary rate.

Genomic studies

In order to avert prospect for genetic erosion and emergence of new biotypes, and the resultant potential disaster, and to contribute to sustainable food security in Uganda research objectives are now focused on combining both the quantitative and qualitative disease resistance to ensure durability. As a result, several gene expression studies in host-pathogen interactions including; introgression of resistance to CMD in local germplasm or dissection of the pathway leading to post-harvest physiological deterioration in cassava roots, construction of cassava genetic map and application of marker assisted selection in cassava breeding for resistance to CMD are being intensified. These applications have successfully contributed to cassava breeding, however, impact on fresh root yield has been limited (Egesi *et al.,* 2006; Okogbenin *et al.,* 2007; Rabbi *et al.,* 2014).

Conclusion

Cassava improvement has seen tremendous progress owing to the release high yielding cassava varieties with resistance to pests and diseases. This progress can be attributed to the modification of the evaluation trials which has shortened the breeding cycles and global exchange of resistance materials between NARS, availability of funding and favourable government policies. Measures therefore should be taken to improve quarantine inspection to prevent further introduction of new pest and disease problems. A strategy for dissemination of the improved varieties should be put in place to avail clean planting materials to the farmers.

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