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Opportunities to Commercialize Cassava Production for Poverty Alleviation and Improved Food Security in Tanzania

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Abstract

Cassava is the world's fourth most important staple crop after rice, wheat and maize, and plays an essential role in food security. Due to cassava's growth characteristics and ability to grow in poor soils and regions prone to drought, it is preferred by resource-poor farmers in many tropical countries. While cassava plays an important role as a food security crop for subsistence farmers, it is prone to rapid postharvest deterioration. Processing cassava for starch is another strategy for overcoming post-harvest losses, can add value to end products and has the potential to create additional employment opportunities along the supply chain. Cassava starch is an important source of biomaterial for different food and non-food industrial applications. Moreover, farmers producing cassava can increase their income by finding alternative end uses to home consumption. To meet the high demand for cassava in Tanzania, cultivar selection, production and processing all need to be improved. Enabling policies that create satisfactory business opportunities for small holder farmers, traders and processors for starch industries is also critical. The aim of this review is to explore the potential of the cassava subsector to contribute to the economy of sub-Saharan countries, particularly Tanzania, and to present how industrial use of domestic cassava starch can help tackle problems of unemployment and food security.

Key words: Cassava, food security, commercialization, Tanzania, Africa

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Introduction

Cassava (Manihot esculenta Crantz) is perennial woody shrub with a starchy edible root. It grows in tropic and sub-tropic regions of the world. The most commonly used part of cassava is the starchy root, which is rich in carbohydrates, about 20-30% dry matter. Cassava leaves can also be consumed and are rich in protein (14 - 40% dry matter), minerals, Vitamin B1, B2, C and carotenes (Fasuyi, 2005; Nassar and Marques, 2006). Cassava's growth characteristics make it a suitable food security crop, particularly due to its resilience growing in conditions that become unfavorable for other crops, such as periods of erratic rainfall. Due to this resilience to adverse environmental conditions, cassava has been named as an ideal climate change crop (Howeler, 2013; Mtunguja *et al*., 2016a).

Cassava is adapted to growing on poor degraded soils and can tolerate low pH, high levels of exchangeable aluminum and low concentrations of phosphorus (Howeler, 2002), conditions that typically limit crop growth. Sandy soils have been also found to be suitable for cassava production because of easy root penetration and expansion of the growing root during carbohydrates partitioning. Sandy clay loam soils are also appropriate due to the high-water retention capacity which provides a good distribution of soil water for long periods even after the onset of dry season (Mtunguja *et al*., 2016b). Nevertheless, adequate soil nutrient availability important for increasing cassava production and dramatic differences in cassava yield has been reported, with changes in soil nutrient supply (El-Sharkawy, 2006; Mtunguja *et al*., 2016b).

Cassava requires annual rainfall between 1000 and 3000mm, but can tolerate low rainfall if the rainfall is well distributed throughout the growth period (Lebot, 2009). Significant water supply is required during the period of root and shoot initiation, 3-5 months after planting. Water deficit during this period severely affects cassava yield (Vandegee r*et al*., 2012; Santisopasri *et al*., 2001). Several studies have demonstrated that if cassava experiences water deficit later than 5 months after planting, there is no significant yield reduction (Alves, 2001; Vandegeer *et al*., 2012).

In addition to being a widely consumed food for people in sub Saharan Africa and Latin America, cassava is also becoming an important raw material for industries around the world (Mtunguja *et al*., 2014; Nassar and Ortiz, 2007). Thailand and China are the world's largest cassava producers followed by Indonesia, Brazil and India, which primarily use cassava to produce starch for industry and export. Within sub-Saharan African, Nigeria is the largest producer of cassava, followed by Ghana, Democratic Republic of the Congo, Tanzania, Mozambique and Malawi. Cassava is becoming an important crop for economic development in these African countries (Olukunie, 2013). While corn starch has dominated world starch production, accounting for 80%, cassava accounts for 10%, wheat 7% and potato 3% (Waterschoot *et al*., 2014). Cassava starch production formerly done by small-scale farmers has now been transformed to be a large scale agro-industry with improved processing technology. For example, average production capacity of one cassava processing factory in China is about 200 tonnes starch per day (Sriroth *et al*., 2000). This transition from small to large-scale production was further complemented by breeding of high-

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starch cassava varieties and technological improvement of starch processing to enhance quality.

Cassava sub-sector

The cassava subsector is underdeveloped in Tanzania, and opportunities exist to expand cassava production and processing to make a considerable contribution to Tanzania economic development. The Government of Tanzania has emphasized the opportunity to work toward food security goals through expansion of agricultural productivity in the Tanzania Development Vision 2015 (TDV 2025), Agricultural Sector Development Program II (ASDP II 2017- 2027), and the National Five-Year Development Plan (2017-2022). Specifically, these documents focus on the transformation of subsistence agriculture to commercial operations, thus making agriculture a more profitable enterprise. To achieve industrialization, availability of raw material within the country is necessary. Government efforts also need to align with Sustainable Development Goals 1 and 2, which are to end poverty in all its forms, and to end hunger, achieving food security and improved nutrition by 2030. Cassava production in Tanzania is estimated to support 37% of rural farmers, many of whom are the poorest in the country. Cassava production is also constrained by a variety of biotic and abiotic factors which have hindered further development of the cassava subsector (Abbas *et al*., 2013).

Cassava is a highly efficient nutrient absorber, hence, adapts well to poor degraded soils with low pH, high levels of exchangeable Aluminum and low concentrations of phosphorus (Howeler, 2002). Sandy soils have also been found to be suitable for cassava production because of easy root penetration and expansion of the growing root during carbohydrates partitioning. But also, sand clay loamy soils are appropriate because of their water retention capacity and, thus, provide a good distribution of soil water for long periods even after the onset of the dry season (Mtunguja *et al*., 2016b). Nevertheless, nutrient availability in the soil is important to cassava production and differences in cassava yield have been reported with changes in soil nutrients supply (El-Sharkawy, 2006; Mtunguja *et al*., 2016b).

Cultural Significance and Uses of Cassava

In most cassava producing communities, the root has long been used as a food reserve crop, especially during periods of food shortage or near harvest time, when reserves of other staple crops are running out. Cassava plants have a large harvest window from between 7 to 15 months after planting, with some variation between varieties. This ability to "store" cassava before harvest can help to suffice food supply across a longer season than many other crops which require immediate harvest. In rural areas where cassava is important staple, farmers often grow a mix of varieties to accommodate differences during the harvesting window. Famers grow both short duration (6-9 months) and long duration (9-15 months) varieties to ensure food supply for a long period (Mtunguja *et al*., 2014). Bitter varieties have a harvest window up to 24 months, preferred by farmers who want to harvest their cassava piece meal, rather than all at once (Mkumbira *et al*., 2003; Chiwona-Karltun *et al*., 2004). Bitter varieties offer protection against predators and theft, making them the variety of choice as a food reserve. Unlike other storage root crops, cassava has a very short shelf-life after

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harvest. Due to a complex process called post-harvest physiological deterioration (PPD), fresh cassava has a shelf-life of only 2-3 days after harvest. Therefore, farmers will wait to harvest the roots until ready for consumption or marketing. Post-harvest losses due to PPD are estimated to be as high as 30% in sub-Saharan Africa (Djabou *et al*., 2017).

During the rainy season, farmers usually plant cassava after they have finished planting staple and cash crops which are considered to be a higher priority for household food and income (Mtunguja *et al*., 2014). Subsequently, cassava is typically planted in marginal or infertile areas and may receive poor management practices. This, in part, explains the low productivity of cassava reported in most sub- Saharan Africa as compared with countries like Thailand and India.

In West, Central and East Africa the root is most commonly boiled, particularly the sweet cassava varieties. Cassava is also processed into traditional foods in Tanzania (*bada*, *kivunde, shinyaya*), Uganda (*busye, atap),* Mozambique (*rale*), Brazil (*farinha*), and West Africa (gari) (Mtunguja *et al*., 2014; Guira *et al*., 2016; Abbas *et al*., 2013; Cardoso *et al*., 2005). As a raw material for industrial processing, cassava is used for food processing (tapioca), textiles and animal feed (Mtunguja *et al*., 2016a). Industrial uses of cassava could catalyze production at farm level as opportunities to increase on-farm income from cassava sale become available. Cassava can also stimulate opportunities for smallholder-scale production of cassava flour and starch for local sale. Locally produced cassava starch could be a good alternative to imported corn starch, maximizing profit by local industries and reducing the cost of starch by avoiding importation costs (Bennesi *et al*., 2006; Mufumbo *et al*., 2011; Olunkunle, 2013; Mtunguja *et al*., 2015).

Contribution of cassava to household food security especially during drought periods cannot be ignored, but also cassava sales can generate income for the households (Guira *et al*., 2016). Cassava processing can create jobs at the commercial level. Numerous researchers have strongly urged that productivity enhancing technologies alone, without access to profitable markets, cannot get poor farmers out of poverty (Tonukari, 2004; Abbass *et al*., 2013). Strengthening marketing, promotion and value chain improvement will make cassava production a very profitable enterprise and could attract investment to the sector.

Cassava Productivity

Farmers in most African countries, including Tanzania, typically have yields between 8-12 t/ha (Mkamilo and Jeremiah, 2005), as compared with the worldwide average of 25-30 t/ha (Lebot, 2009). The lower recorded yields in Tanzania and other sub-Saharan countries is attributable to the fact that cassava is grown on marginal lands with poor management practices. Input use in cassava production is also limited or absent. While cassava's ability to tolerate low nutrient, availability makes it a good staple crop for resource-poor farmers, it keeps yields low as compared with the global average and genetic potential. Productivity improvements will only occur if reliable markets are introduced (Lazaro *et al*, 2007), which could incentivize increased attention and resource allocation to cassava. Development of the cassava market is anticipated to

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contribute to improved food security and contribute sustainably to poverty reduction in poor households (James *et al*., 2013).

In a study conducted in the Coastal region of Tanzania, cassava production in two villages increased from 168.5 acres to 375.5 acres between 2000 and 2003 following the development of cassava flour and animal feed processing in the region (Lazaro *et al*., 2007). When market opportunities exist, farmers may prefer to grow cassava, as it has been shown to have higher returns to production than other staple crops such as rice and maize (Lazaro *et al*., 2007; Abbas *et al*., 2013; James *et al*., 2013). It is suggested here that the ability to capitalize on increased cassava production depends primarily on improvements in processing outlets and access to viable markets (Abbas *et al*., 2013).

Findings from UPoCA (Unleashing Potential of Cassava) project, IITA-CFC project and Lazaro *et al*. (2007) show that farmers increased cassava production areas in response to increased demand. Therefore, breeding programs should ensuring increased productivity and profit for cassava farmers. Farmers need also to be sensitized on the benefit using improved varieties, use of fertilizer and other agro-inputs for increased productivity for maximum income generation.

Different studies have demonstrated that productivity for local cassava varieties can be achieved through good agronomic practices (Table 1). Also, development of high starch yielding varieties is important to maximize returns to investment. Studies in Nigeria have demonstrated that adoption of new varieties can result in yields as high as 32t/ha when coupled with better management practices. This has also revealed the potential for new cassava varieties to maximize starch production and reduce the cost of production, increasing profits for farmers and cassava processors.

Table 1: Yield potential of some local cassava varieties from Tanzania attained under improved agronomic practices

Variety	Geographical area	Yield (t/ha)
Kizimbani	Coastal low lands (Zanzibar, Pemba)	25
Mahanda		20
Mkombozi	Mild altitude (Lake zone)	25
Mumba		29
Hombolo	Central zone (Dodoma and Singida)	15-17
Naliendele	Coastal plains (Coastal region, Mtwara, Lindi	19
Kiroba		16-17
Kalolo		19
Msenene	Eastern plateau and mountain (Morogoro)	14-19

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Cassava genetic diversity and farmers' preference for cassava varieties

Biotic and abiotic stresses have been reported to affect cassava productivity. Improved productivity is possible through development and adoption of improved varieties that tolerate stress and have high yields (Mtunguja *et al*., 2017). Cassava can be vegetatively propagated through stem cuttings. Farmers also generate new landraces through preferential selection or add to morphologically identical landraces (Elias *et al*., 2001; Pujol *et al*., 2007). Cassava farmers in sub-Saharan Africa prefer to grow many different cassava varieties to suit various household needs (Mtunda, 2005; Mtunguja *et al*., 2014; Mtunguja *et al*., 2017) (Table 2). Some cassava varieties are used for flour, some are boiled and others are grown because of their long harvest window (Mtunguja *et al*., 2014; Mtunda, 2005). This practice has led to increased cassava diversity, a benefit for cassava-specific breeding programs.

Table 2: Different utilization option for cassava landraces grown by farmers in East and Southern Africa

Country	**Cultivar preferred for boiling and snacks** 7-9 MAP*(Short duration)	**Cultivar preferred for flour** 9-12 MAP*	**Cultivar preferred for storage and flour** 12-36 MAP*(Long duration)
Tanzania	Sufi Kibandameno Mahiza Msenene Kiroba	Kiroba Nyamkagile Kibandameno	Dide Kalolo Gago Kilusungu
Malawi	Mbundamali Nyasunguru	Sauti Chitembwere	Maunjili Silira Gomani
Zambia	Kompolombo Manyokola Mweule	Mweule Manyokola Nalumino Bangweulu Chila	Kompolombo Nalumino

* Months After Planting, (Mtunguja *et al*., 2014; Rusike *et al*.; 2010, Kizito *et al*., 2007; Chiwona-Karltun *et al*., 2015).

Farmers use morphological descriptors to distinguish cassava varieties that grow within their locality. Several studies have confirmed that farmers are knowledgeable in distinguishing varieties found in their fields (Mtunguja *et al*., 2014; Bennesi *et al*., 2010; Mkumbira *et al*., 2004). A study using 52 landraces collected from Eastern zone of Tanzania characterized the varieties using morphological descriptors (Figure 1) and molecular techniques using Next Generation Sequencing (NGS) (Figure 2).

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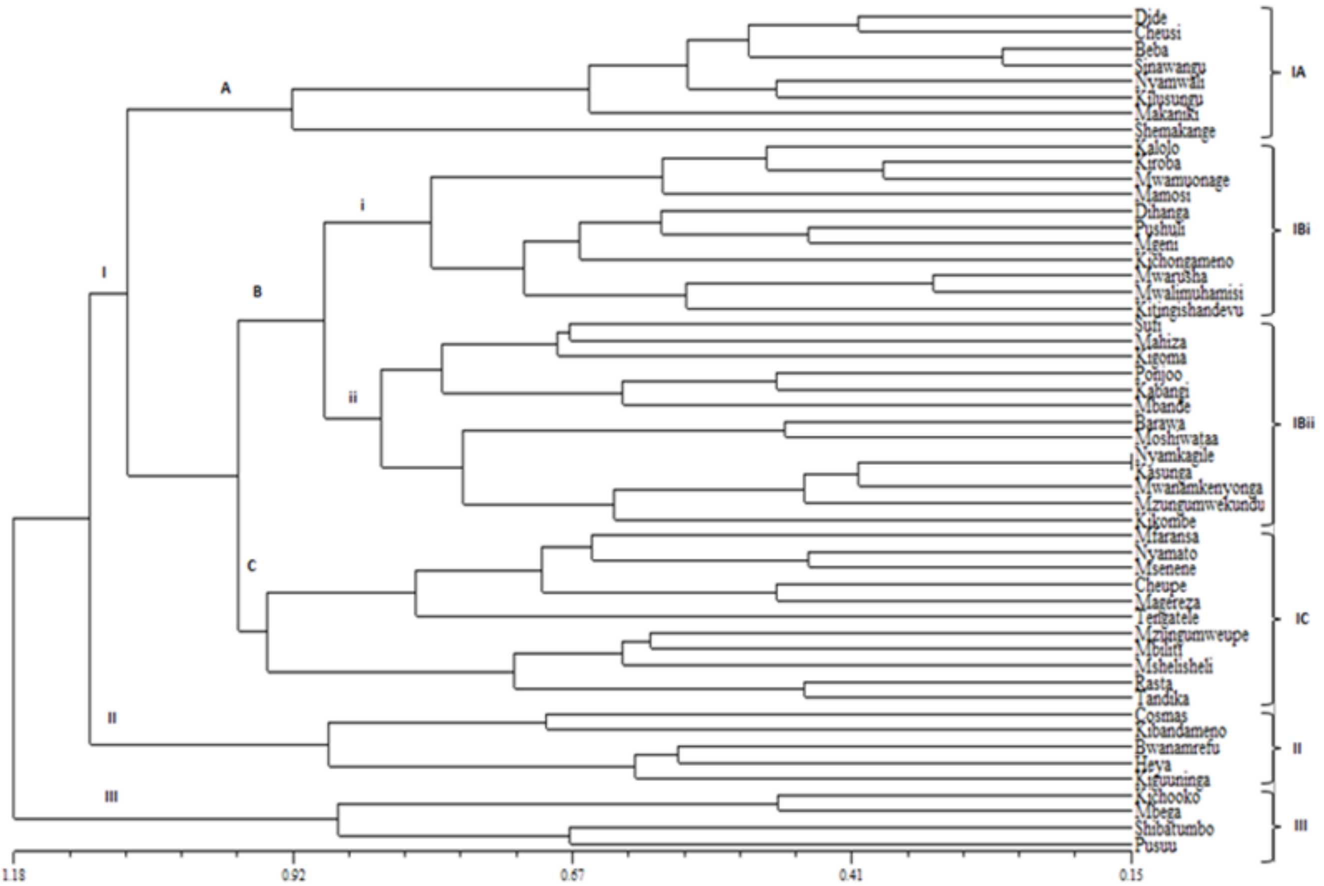

Figure 1: Dendogram obtained using Unweighted Pair Group Arithmetic Method (UPGMA) showing genetic diversity of 52 cassava landraces **showing diversity of 52 cassava landraces c**ollected from Eastern zone of Tanzania and generated from 24 morphological descriptors using genetic distance coefficient by Jaccard coefficient, (Mtunguja *et al*., 2017)

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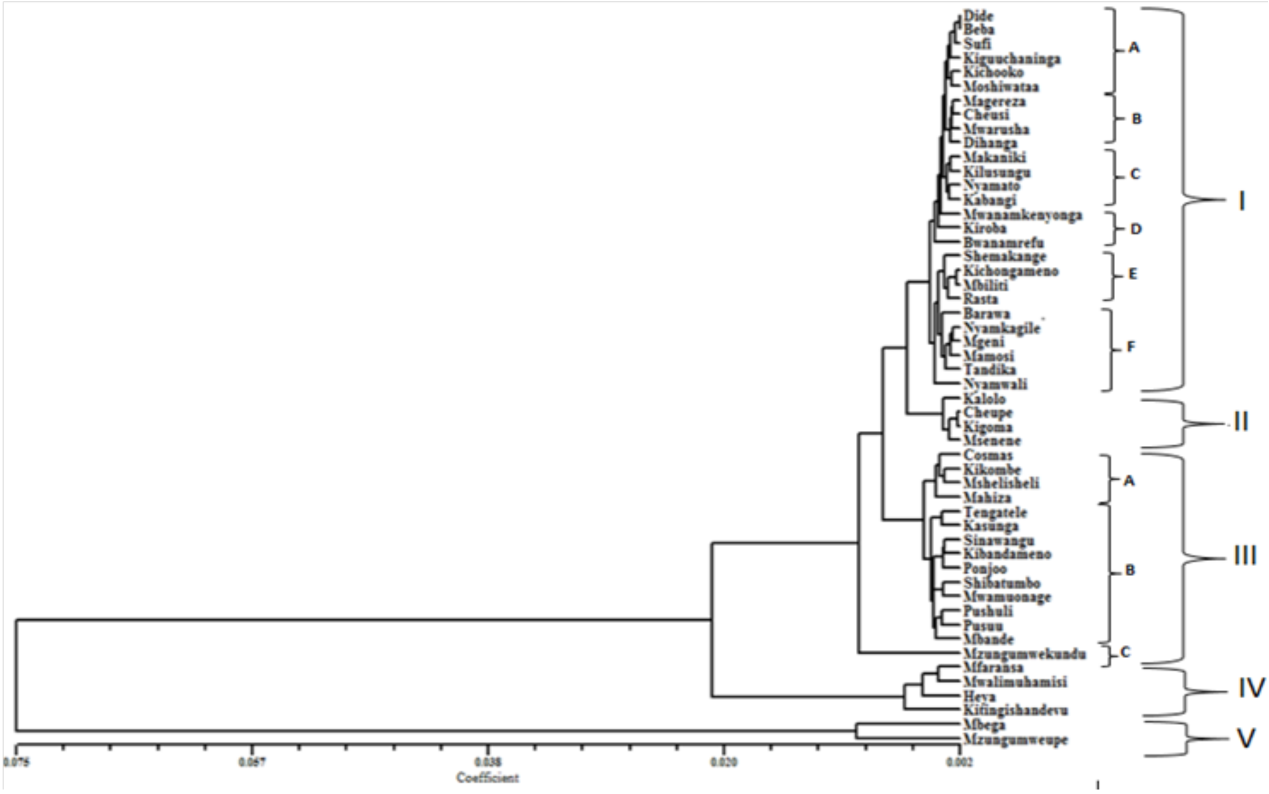

Figure 2: Dendogram obtained using Unweighted Pair Group Arithmetic Method (UPGMA) showing genetic diversity of 52 cassava landraces based on genetic distance matrix derived from SNPs markers. The analysis group the landraces into 5 main groups (Mtunguja *et al*., 2017)

The cluster analysis from the study revealed that the landraces did not segregate according geographical location, which implies that within each geographic area, there is a diversity of landraces. The collection of landraces revealed a wide range of genetic diversity, which represents a valuable resource for trait improvement and which is sufficient to capturing traits preferred by farmers. Desirable traits can be selected through breeding programmes, thus improving productivity of cassava and acceptability by farmers.

Income Generation and Opportunities for Commercialization

As we have seen in the previous section, cassava productivity can be increased if both suitable varieties and good management practices are adopted. The cassava industry can be used to produce native and modified starch, sweeteners, ethanol and high-quality cassava flour for baking industries. In addition to facilitating product development, having an end use for cassava will spur increased market demand and industry attention to the problem of post-harvest loss. Increased demand for cassava can also facilitate a transition out of subsistence-level production for market-oriented farmers who are able to create a business enterprise out of their agricultural production. Studies have also shown the potential for use of cassava in textile and paper industries.

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Demand from these industries is huge and may also stimulate increased cassava production at farm level (Abbas *et al*., 2013; Mufumbo *et al*., 2011).

FAO argues that developing countries in Africa could start utilizing cassava starch for different industrial applications. There is growing industrial demand for starch and cassava can help to meet demand and reduce supply pressure for other staple crops (FAO report, 2006). The demand for starch and other starch based products such as glucose and dextrin, is increasing in Tanzania. For example, in 2014, about 7,667 metric tons of starch and starch-based products were imported (5.2 milion USD CIF value), which is nearly double that reported in 2008 (TRA report, 2016). Establishing and strengthening starch industries in Tanzania to replace imported starch will help to improve farmers' livelihoods. Cassava farmers will increase production to feed starch industries. Thus, their income can increase when they sell fresh cassava to cassava processing industries. Developing starch industry will also help to tackle unemployment in Tanzania, which is estimated to be 10.3% (TNBS, 2016). Youth are not attracted to take agriculture as business because of low returns to labor and investments; which is mainly caused by market uncertainty. The market demand created by starch industries will likely attract youth to engage in agriculture. There is high labor availability and unused land; therefore, there is an opportunity for increased cassava production and processing which can lead to better income for farmers and employment for youth. Cassava is a priority crop which can be used to reduce the rate of unemployment and thus attract youth to participate in agriculture. Abbas *et al.* (2013) and James *et al*. (2013) estimate employment in the cassava flour industry to be around 53,124 people. Further development of this sector would lead to additional employment opportunities. This will reduce youth migration to urban areas and engagement in illegal activities. Policies should encourage the establishment of starch-based industries such as that produced cassava.

Cassava can play a big role in supporting development of the starch industry and reduce competition with other starch sources such as maize and potato. Efforts to increase productivity through dissemination of good agronomic practices should be emphasized and already established cassava improvement programs should continue to be supported (Cassava Diagnostic BMGF project, UPoCA, IITA CFC projects). Cassava farmers would benefit from selling their cassava to processing industries. Another benefit of establishing cassava starch factories will be increased employment through the entire supply chain from breeding of new improved varieties, to seed marketing, processing and trade (Olukunle, 2013). Cassava value chain analyses have revealed that increased employment could be generated at the stages of production, processing and trade. Therefore, increased local demand for cassava-based products, especially starch, can foster the growth of cassava industry and subsequently generate employment opportunities (Olukunle, 2013).

Potential Industrial Applications for Cassava Starches

About 73.7 to 84.9% of the dry root weight of cassava is starch and this variation depends on the variety and the environmental conditions under which the cassava is grown (Sanchez *et al*., 2009). The suitability of starch for different industrial applications primarily depends on the physicochemical, morphological and functional

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properties of starch (Waterschoot *et al*., 2014). These properties have been reported to vary considerably depending on the source (Yuan *et al*., 2007; Mufumbo *et al*., 2011). Cassava starch, when compared to corn starch, is more resistant to acid, and has unique pasting properties, which make it suitable for the production of paper, textiles, sweeteners, alcohol, and monosodium glutamate (Taylor *et al*., 2012). Cassava starch also has unique properties which make it suitable for making specialty food products such as tapioca, baby foods and non-allergenic ingredients (Bennesi *et al*., 2004)

A study done by Mufumbo *et al*. (2011), found that the Ugandan varieties Bamunanika and NASE10 had a low gelatinization temperature, making them suitable for the manufacture of hydrolysis products and syrup. In a similar study, it was found that maize starch (39.85%) had a high retrogradation percentage compared to cassava starches which ranged from 14.26 to 18.05%. Similar results were also reported by Jane *et al*. (1999). Retrogradation is a process by which disaggregated amylose and amylopectic chain is gelatinized to form a more ordered structure. The lower retrogradation percentage in cassava starch was attributed to the larger proportion of amylopectin short branch chains (Xie *et al*., 2009) and presence of lipids in maize starch resulting in high retrogradation percentage for maize (Jeong and Lim, 2003). The results also suggested that cassava starch pastes were more stable under storage than maize starch pastes, thus making cassava starches more suitable in making products stored for a long time and in which soft texture is necessary, such as dessert-like products and baked products like cakes to maintain a soft texture (Mufumbo *et al*., 2011).

Table 3: Physicochemical composition of cassava landraces and their purified starches*

Mtunguja *et al*. (2016) compared the physicochemical and functional properties (Table 3 and Table 4) of commonly grown landraces collected from Eastern zone of Tanzania. The results were compared with other published data, and the study showed that landraces had a lower dry matter and starch content compared with varieties from the International Center for Tropical Agriculture (CIAT) (Sanchez *et al*., 2009). The study further managed to identify appropriate uses of starch from each genotype. Although there was great similarity among cassava starch properties measured, the genotypes could be clearly distinguished from one other by Partial Least Square – Discriminatory Analysis (PLS-DA).

Table 4: **Swelling power, water solubility, syneresis and pasting properties of starches***

Differences in starch swelling power, solubility, syneresis, and digestibility were observed during the analysis, indicating the different food and non-food uses that were possible for each cultivar. Msenene and Kilusungu starches have high swelling power and are suitable for use as thickeners and binding agents. Starch from the Msenene cultivar had a relatively low setback viscosity after cooling, and low syneresis suitable for gelling agents and thickeners in refrigerated and frozen food products. Kibandameno starch had the highest enzyme digestibility and lowest particle size

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distribution (p≤0.05), making this cultivar suitable for glucose syrup, adjuncts in brewery fermentation stock, low fiber feed, and sweeteners. Nyamkagile (p≤0.05) had the lowest digestibility suitable for food applications where individuals wish to manage their glycemic index, such as diabetic or overweight patients.

The potential of cassava for industrial use depends on starch yield, which is a product of both root starch content and total fresh root yield (t/ha). Productivity itself cannot sustain profit but together with varieties with high starch content properties will bring about profitability to the starch industry. Various authors have reported enormous genetic variation in starch yield among cassava cultivars (Benesi *et al*., 2008; Mtunguja *et al*., 2016). High starch yield can be achieved by crossing suitable varieties with high dry matter content and high fresh root yield (Pérez *et al*., 2011). Apart from high yielding traits, several factors have been reported to influence starch yield, including environmental conditions for growing the crop such as soil pH, nutrient availability and amount of rainfall received during plant growth (Mtunguja *et al*., 2016b; Benesi *et al*., 2008). Good management practices such as weeding, proper spacing and application of suitable fertilizers also play a critical role in cassava productivity (Fermont *et al*., 2009). The optimal harvesting period is also important, because if cassava is harvested too early or too late, there will be a loss in starch yield. Therefore, to maximize starch yield, cassava should be harvested once optimal maturity has been reached.

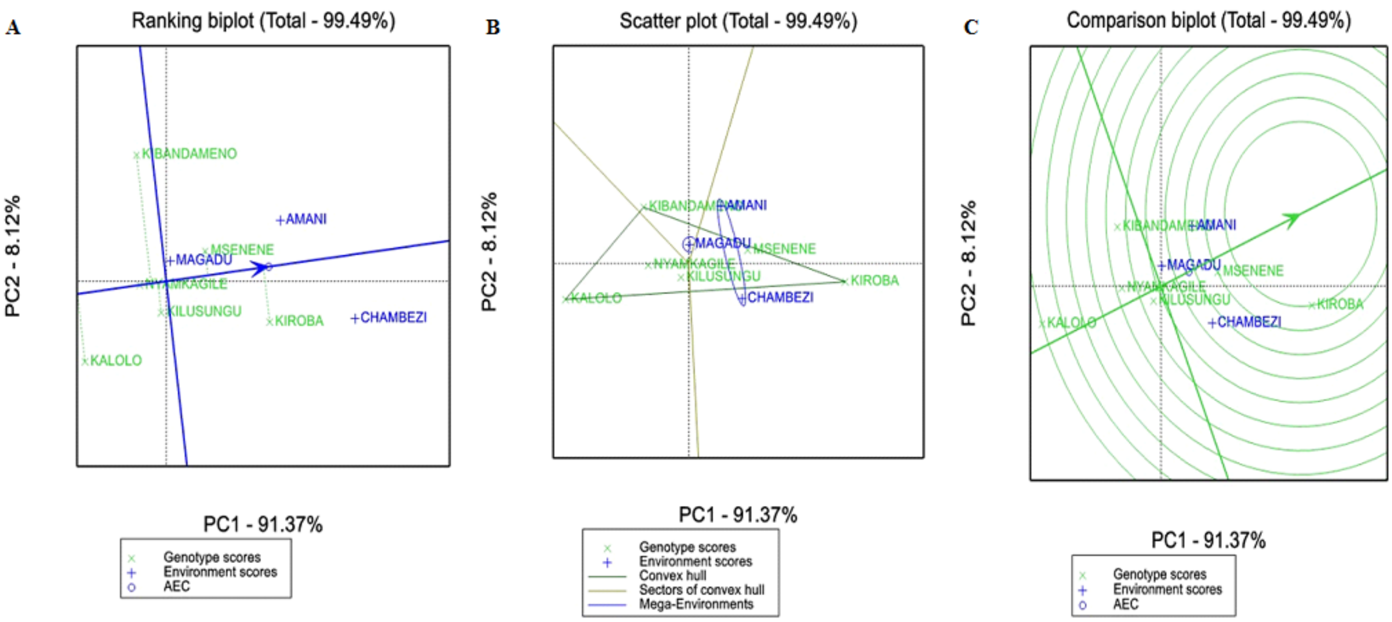

Figure 3: GGE Biplots; A), showing ranking of cassava landraces based on mean cassava starch yield and stability performance across three environments; B), scatter plot for which- won- where (superiority) showing the best landrace for each environment; C), the average environment coordination (AEC) view to rank landraces relative to an ideal genotype (center of the concentric circle) (Mtunguja *et al*., 2016b).

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A study conducted from 2012 to 2014 (Mtunguja *et al*., 2016[b]) evaluated starch yield potential for six commonly grown landraces in the Eastern zone of Tanzania. Analysis done using genotype and genotype by environment (GGE) biplots (Figure 3) revealed that the *Kiroba* and *Msenene* landraces had the greatest potential for high starch yield and should be targeted for commercialization and any future starch yield improvement breeding programs.

The results from the study showed significant interaction between genotypes and environment. This implies that genotypes should be specifically selected for adaption to the local environment. The researchers recommended that similar studies should be performed in other geographical zones to determine which high starch yielding varieties are best suited to commercialization in those areas (Mtunguja *et al*., 2016[b]). In this study, optimal harvest time was found to be a 12 MAP. The maximum starch partitioning is attained once physiological rest is reached, which is between 9-12 MAP for most cassava cultivars.

Sustainable Development of the Cassava Starch Industry

Concentrated effort geared to cassava commercialization can make a considerable contribution to Tanzania's economic development. Policies should be promoted that create a positive enabling environment for both cassava starch production and utilization within industry. There is also a need for policy makers to understand the importance of cassava as a food security crop that has the potential to alleviate poverty conditions for smallholder farmers. If cassava is to become a profitable enterprise, farmers need to be able to afford agricultural inputs such as improved seed, and fertilizer which can increase overall productivity. Linking cassava farmers to other actors in the starch supply chain will enable smallholder farmers to have improved market access, thereby increasing the likelihood that they will increase their returns. The policy changes proposed are focused on creating an enabling environment where farmers will be able to access market information and thoroughly understand the market requirements, and thus improve their ability to produce at sufficient levels to meet demand.

The efficiency and profitability of the cassava subsector must be increased. Studies have shown that a combination of institutional arrangements and improved agronomic practices is required to increase production efficiency. Studies have further shown that the adoption of high yielding varieties and better farm management practices could more than double the profitability of smallholder farmers' cassava crop. The government should strive to strengthen famer groups, develop links between traders, farmers and private agencies and enhance the value chain to make it profitable for all actors. Enabling policies should be enacted that create business opportunities for smallholder farmers and investors in starch industries. These policies should incorporate strategies that combat constraining factors to effective production and sustain the emerging cassava industry. Local industries should be given incentives to further develop the processing mechanisms.

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Table 3: Table 3: Physicochemical composition of cassava landraces and their purified starches*

Cultivars	Dry Matter (%)	Starch content (%) dry weight	Total Reducing Sugars (%)	Amylose Content (%)	Mean Particle size (µm)	Granule size volume percent distribution (%)			Relative crystallinity (RC) (%)
						Small (<12 µm)	Medium (12-25 µm)	Large (25-48 µm)	
Nyamkagile	33.6±0.4[b]	80.3±0.4[b]	1.03±0.2[a]	19.4 ±0.4[c]	13.33[b]	46.19[a]	52.04 [a]	1.76 [a]	37.9 ± 1.1[a]
Kibandameno	39.5±0.6[d]	80.0±0.5[b]	1.43±0.1[ab]	11.9±0.5[a]	12.50[a]	49.87[a]	49.14[a]	0.96[a]	41.4 ± 0.8[b]
Kilusungu	30.6±0.5[a]	77.1±1.5[ab]	2.12±0.7[ab]	19.2±0.3[c]	13.21[b]	42.58[a]	57.37[a]	0.00[a]	37.0 ± 0.4[a]
Msenene	33.4±0.4[b]	78.4±1.5[ab]	1.75±0.4[ab]	17.1±0.3[b]	13.78[b]	42.02[a]	55.36[a]	2.62[a]	37.4 ± 0.4[a]
Kalolo	30.8±0.8[a]	74.3±1.5[a]	3.10±1.03[b]	16.9±0.3[b]	13.09[b]	44.05[a]	55.96[a]	0.02[a]	36.0 ± 0.3[a]
Kiroba	36.7±0.5[c]	80.2±0.8[b]	1.96±0.2[ab]	17.2±0.4[b]	13.43[b]	42.33[a]	57.32[a]	0.37[a]	36.1 ± 0.5[a]

Values with different letters in the column differ significantly (p value<0.05); *Mean ± SEM for three independent biological replicates (Source; Mtunguja *et al* 2016[a])

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Table 4: Swelling power, water solubility, syneresis and pasting properties of starches from cassava landraces collected from Eastern zone of Tanzania

Cultivars	Swelling power (g/g)		Water Solubility (%)		Syneresis (%)		Pasting properties				
	70°C	90°C	70°C	90°C	4°C	-20°C	Pasting temperature (°C)	Peak viscosity (m.PaS)	Peak temperature (°C)	Breakdown viscosity (Pas)	Setback viscosity (Pas)
Nyamkagile	8.9±0.8[a]	13.5±0.2[a]	3.0±0.3[a]	6.0±0.3[ab]	23.0±1.6[ab]	57.7±2.3[c]	69.6± 0.6[a]	0.64±0.10[a]	89.9±0.7[a]	0.30±0.05[a]	0.21±0.04[a]
Kibandameno	10.3±0.6[abc]	14.2±0.3[a]	3.0±0.5[a]	7.4±0.1[bc]	26.8±1.6[b]	38.3±3.3[ab]	67.5± 0.9[a]	0.72±0.10[a]	80.5±4.6[a]	0.46±0.09[a]	0.29±0.04[a]
Kilusungu	12.3±0.4[c]	16.3±0.8[b]	2.8±0.5[a]	5.0±0.3[a]	21.5±1.8[ab]	38.3±1.7[ab]	66.4± 0.3[a]	0.77±0.20[a]	76.6±2.6[ab]	0.57±0.09[a]	0.28±0.08[a]
Msenene	11.7±0.3[bc]	16.0±0.9[b]	2.1±0.4[a]	7.9±0.7[c]	16.7±1.7[a]	31.7±1.7[a]	66.7± 0.9[a]	0.54±0.10[a]	76.8±3.4[ab]	0.44±0.06[a]	0.11±0.01[ab]
Kalolo	9.5±0.3[ab]	15.7±0.3[b]	3.9±0.6[a]	8.5±0.3[c]	38.3±1.7[c]	48.3±2.8[bc]	67.7± 0.4[a]	0.64±0.10[a]	88.1±0.5[a]	0.36±0.02[a]	0.28±0.05[a]
Kiroba	11±0.3[abc]	14.5±0.5[ab]	3.3±0.03[a]	5.3±0.2[a]	28.7±0.7[b]	36.7±2.0[a]	67.5± 0.6[a]	0.68±0.04[a]	85.1±1.3[a]	0.31±0.06[a]	0.39±0.03[a]

Values with different letters in the column differ significantly (*p* value<0.05)
*Mean ± SEM for three independent biological replicates. (Mtunguja *et al* 2016[a]