Chapter

Breeding Cassava for End-User Needs

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Abstract

A lot of research initiatives have gone into the breeding of cassava which has led to the development and release of over 30 cassava varieties in Ghana, of which adoption rate is 40%. This low adoption is due to inadequate promotion of improved varieties and the fact that some of the varieties do not meet end-user needs. With cassava becoming an important cash crop, it is important that breeding programmes refocus to define the market segments and objectives to facilitate the improvement of target traits such as poundability, dry matter content, starch and carotenoids that will lead to the development of varieties tailored towards end-user needs. This will in the long run promote food and nutritional security especially in low- and middle-income countries where the crop is a major staple. In addition, there should be more investment in high-throughput phenotyping to enhance the assessment and evaluation for the development of varieties with end-user traits. Subsequently, the cassava seed system should be formalized to enhance the production and dissemination of high-quality improved cassava varieties with end-user traits.

Keywords: end-user, value chain, market segments, seed system, food security

1. Introduction

Cassava (*Manihot esculenta*) is the fourth most important crop after rice, wheat and maize [1]. It is an important root crop serving as food for approximately 500 million people worldwide [2]. The crop's attributes including carbohydrate richness, availability throughout the year, tolerance to low soil fertility, and resistance to drought, pest and disease make it an attractive crop, especially to small holder farmers [3]. In addition, it is used as source of carbohydrate in animal feed. It also serves as a raw material in the manufacture of processed food and industrial products.

The world's production of cassava was reported as 278 million metric tonnes, of which Africa's contribution was about 61%, followed by Asia with 29.5%, and the Americas with 8.9% [4]. The largest producer of cassava is Nigeria (60 MT), followed by DR Congo (41.01 MT), Ghana (21.81 MT), Angola (8.78 MT) and Mozambique (5.4 MT) [4].

Cassava improvement and production are faced with many challenges. These challenges include high incidence of pests and diseases, scarcity of quality planting materials, lack of adequate technical knowledge in the use of improved technologies, inadequate modern processing equipment for end-user needs and marketing [5]. In developing countries, agricultural productivity is also constrained by limited access to improved varieties as well as biotic and abiotic stresses [6]. In addition to these constraints, seed systems for root and tuber crops including cassava have received less attention. This is usually manifested in seed multiplication and distribution which leads to challenges of low multiplication ratios from one generation to the next, bulkiness, perishability, and pest/pathogen accumulation in planting material. These issues create impediments in the establishment of commercially sustainable seed systems for the distribution of certified clean planting materials of varieties with end-user preference [7].

Many breeders have ignored the importance of breeding to meet the needs of the end-user. A lot of efforts have gone into cassava breeding in terms of agronomic traits at the neglect of breeding for the enhancement of crop palatability. Palatability of cassava (sensory characteristics) relates to end-user acceptance to ensure that improved cassava varieties are adopted and consumed by the local population in relation to the purpose for which it was released [8]. Factors such as cooking quality, size of root, appearance, odour, texture, and taste of cassava products relates to end-user consumer acceptance or preference. To meet end-user needs, breeders should take into consideration the aforementioned traits in their breeding objectives. This will facilitate breeding for varieties tailored towards end-user needs.

The success and failures of farmers to adopt newly released varieties inform breeders on their breeding objectives taking into consideration socioeconomic, gender and marketing issues. In determining where the resource investment in cassava breeding should be channelled, there is the need to pay more attention to breeding for varieties that meet the needs of different market segments. To facilitate this, the cassava breeding program in Ghana must be restructured emphasizing on target product profiles that will enhance the palatability of cassava.

2. Cassava as food security crop

Food security is when food exists for all people, at all times, and there is physical and economic access to sufficient, safe, and nutritious food. This food should meet dietary needs and food preferences for an active and healthy life [9]. Population growth and consequent increase in global consumption has called for rising demand for food globally. Additionally, the effects of climate change have enormous potential of disrupting food security [10]. These developments have generated a lot of discussions among scientists and policy makers on the adoption of approaches to ensure food security [11]. In sub-Saharan Africa (SSA), cassava is a very important food security crop for millions of people. There is therefore the need to increase breeding activities for production and improvement of its quality attributes [12]. In relation to the significant contribution of cassava to the livelihoods of African farmers and its potential of transforming the economies of Africa, cassava is reported to be amongst the six commodities defined by African Heads of State as a strategic crop for the continent [13]. Its numerous attributes make it a food security crop. Some of these attributes include tolerance to poor soils, ability to grow on marginal soils, and harvesting all year round [10].

3. Cassava breeding progress and activities

In the 1970s, most cassava breeding programs started [14], however, in the case of Ghana it started in the 1980s. In recent times, cassava has migrated from being a basic foodstuff to a cash crop serving as source of income and employment for rural populations in Africa. This is due to its potential for processing into many different products such as ethanol, starch, and high-quality cassava flour (HQCF). Crop improvement has the potential of contributing significantly to cassava transformation through the development of varieties responsive to changing needs. This could be achieved using improved technologies to support demand and supply. There is also the need for sustainable development as increases in production area expansion alone are not sustainable [15].

Cassava mosaic disease (CMD) is very devastating and was first reported in Ghana in the 1930's and government of Ghana (GoG) at that time intervened [16, 17]. Government's initiative targeted developing improved varieties tolerant to CMD to salvage cassava production in Ghana. This GoG initiative was highly welcomed since CMD is highly devastative severely affecting all existing local accessions at early stages and therefore meriting a lot of attention [18]. Superior varieties were introduced from sister countries in Africa and the Caribbean. This was followed by making several crosses between local accessions and the introduced superior clones followed by selection of desirable traits including CMD tolerance. The varieties were named as Queen, Gari, Williams and Ankrah and these were subsequently released in 1935 [17]. From 1993 to date, many improved cassava varieties which are tolerant to CMD and are high yielding have been released by the Council for Scientific and Industrial Research Institute (CSIR), the universities and other research institutes [19]. Aside these progress, use of molecular markers were introduced for the selection of desirable traits with emphasis on CMD tolerance. Approximately all the varieties released in Ghana are white pulp. To meet demands of malnutrition and malnourished populace, cassava breeding programmes targeted developing yellow-fleshed varieties in the last decade. In addition to the 25 released cassava varieties in Ghana, nine yellow-fleshed varieties have been released to meet consumer needs for gari production and other products.

3.1 Conventional breeding

Conventional planting breeding methods have enormous benefits such as high rates of return among the investments in agricultural research. In this regard, cassava breeding has achieved enormous benefit from technological input. New varieties released in Africa, Asia and Latin America with conventional breeding efforts have to some extent met the needs of farmers, processors, and consumers for income generation. Using participatory breeding approach, plant breeding is advantageous for subsistence farming where many subtle criteria define the success of a given variety and subsequent chance of adoption by farmers [20].

The same conventional cassava breeding method are used by many breeding programs, with few variations. This entails producing full- or half-sib families in crossing blocks. Cassava is highly heterozygous, hence progenitors generated from crosses are genetically diverse. F_1 seedlings are genetically distinct therefore production of enough cuttings for multilocation trials takes several years. In addition, the multiplication rate is usually low (1:10) [21]. Due to its long breeding cycle, which is approximately 12 months, the development of improved varieties is time consuming [12].

3.2 Biotechnological interventions for cassava improvement

For a constantly changing world, plant biotechnology provides a wide range of opportunities that can facilitate cassava production [22]. Great advances have been made in cassava using biotechnology in the past 30 years [22]. This section will focus on transgenics, gene editing and marker-assisted techniques.

3.2.1 Transgenics

Genetic engineering advances can significantly speed up the development of improved varieties with enhanced yield, nutritional quality, increased disease and pest resistance, as well as improved starch yield and quality [23]. Improvement of cassava using transgenics help in overcoming crossability barriers and facilitates the development of improved varieties with end-user traits. It however has some challenges such as low level of awareness, lack of appropriate facilities and infrastructure [24].

Cassava genetic transformation efforts have been used in improving traits such as CMD resistance, increase in protein content from 40 to 130% and improved starch content and quality [25]. For the development of transgenic cultivars, desirable genes are cloned, vectors are constructed, crops are transformed, and subsequently, screening and identification of transformed lines are conducted [23, 26]. Through a concerted effort of several laboratories for about 25 years, transformation of cassava and the use of *Agrobacterium tumefaciens* or particle bombardment as gene delivery system became a reality. It has been possible to obtain transgenic plants of cassava that expresses marker and selectable genes of agronomic traits.

3.2.2 Gene editing

Improvement of cassava is of utmost importance since it is the fourth most important crop and uniquely occupies an important position. Technologies of gene editing based on zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENS), and clustered regularly interspaced short palindromic repeats (CRISPR) using engineered nucleases induces double strand breaks (DSB) at known DNA sequence within the genome. Repair at the target site subsequently, introduces variation via error prone non-homologous end joining (NHEJ) [27]. CRISPR-associated protein 9 (Cas9) have been shown to improve target traits to meet end-user needs [28]. This technology has been used for the modification of phytoene desaturase [27], increment in carotenoid content and production of waxy starch [29] in cassava.

Gene editing enables precision breeding, reduces time of breeding cycle with fewer plant generations and help in the development of varieties with enhanced nutrition [30]. In crops where there is little to no information on genome sequence, it will be impossible to identify potential targets of interest for editing [31, 32] and subsequently impossible to develop new improved varieties using this technology.

3.2.3 Marker-assisted breeding

Genetic diversity is of paramount importance in crop improvement. Different molecular markers have been used to assess the genetic diversity among crop varieties. Genetic variation from some African countries have been assessed using molecular markers such as simple sequence repeats (SSRs) and single nucleotide polymorphism markers (SNPs) [33, 34]. Advanced technologies such as genotyping-by-sequencing (GBS) have also been used for the identification of varieties in Nigeria [35] and Ghana [6]. For enhancement of conventional plant breeding, high density genome-wide markers, combined with statistical tools have been used for the identification and validation of trait markers for marker-assisted selection (MAS) and implementation of genomic selection. In addition, whole genome sequencing has also been used for the discovery of markers in cassava breeding populations. Identification of quantitative trait loci (QTLs) in breeding populations have been achieved using high-density markers in association and linkage mapping. These detected QTLs provide detailed information for designing diagnostic markers for MAS.

The use of molecular markers greatly increases the efficiency and effectiveness of breeding. It can be carried out in the seedling stage and reduces the breeding cycle. Some limitations of the technique are high startup expenses, recombination between the marker and the gene of interest may occur leading to false positives, non-transferability of markers from one population to other populations and imprecise estimates of QTL may result in slower progress than expected [36].

4. Released cassava varieties, markets, and adoption

Different cassava varieties have been developed and released by CSIR-Crops Research Institute (CRI), Universities in Ghana and other institutes targeting different market segments. These varieties have been adopted for use and processed into different products to meet end-user needs.

4.1 Released cassava varieties

Over 30 cassava varieties with varying uses have been released in Ghana (**Figure 1**). **Table 1** shows released varieties, quality attributes and their uses.

Figure 1.
Vegetative phase (a) and fresh roots (b) of some released cassava varieties in Ghana.

Variety	Dry matter content (%)	Other quality attributes	Uses
Afisiafi	32	Not poundable	Starch, flour and gari
Abasafitaa	35	Not poundable	Starch, flour and gari
Tek-bankye	30	Poundable	Fufu, gari and "ampesi"
Nyeri-kogba	33	Not Poundable in the dry season	Starch, gari, flour and "tuo zaafi"
Eskamaye	33	Not poundable in the dry season	Starch, flour, gari and "tuo zaafi"
Fil-Ndiakong	36	Not poundable in the dry season	Starch, flour, gari and "tuo zaafi"
Nkabom	32	Poundable	Starch and fufu
IFAD	30	Poundable	Starch and fufu
CRI-Agbelefia	—	24% Starch, not poundable	Starch and gari
CRI-Essam Bankye	—	19.8% Starch, not poundable	Starch and flour
CRI-Bankye Hemaa	—	21% Starch, poundable	Fufu and bakery products
CRI-Doku Duade	—	24% Starch, not poundable	Starch
Capevars Bankye	—	Starch >25%, poundable	Starch, fufu, "ampesi", gari, flour, "agbelima"
Bankye Botan	—	Poundable in the dry season	Starch, gari, "agbelima", "konkonte"
CRI-Ampong	36	Poundable	Starch, flour and bakery products
CRI-Broni Bankye	33	Not poundable	Starch, flour and bakery products
CRI-Otuhia	39	Not poundable	Starch and flour
CRI-Duade Kpakpa	37	Poundable	Starch, flour, fufu and industrial alcohol
CRI-Amansan Bankye	38	Not poundable	Flour and bakery products
CRI-AGRA Bankye	32	Not poundable	Starch and flour
CRI-Dudzi	38	Not poundable	Starch and flour
CRI-Abrabopa	40	Not poundable	Starch
CRI-Lamesese	39	Poundable, pro-vitamin A	Flour and fufu
CRI-Bediako	33	Poundable	Starch, flour and fufu
CRI-Bankye	30	Poundable	Starch, flour and fufu
Nyonku Agbeli	26	CP: 36.75 μg/g, pro-vitamin A: 9.6 μg^{-1}	Flour and gari
Kpomu Agbeli	26	CP: 32.58 μg/g, pro-vitamin A: 7.97 μg^{-1}	Flour and gari
Tetteh Bankye	21	Poundable, CP: 31.91 μg/g, pro-vitamin A: 6.91 μg^{-1}	Flour, gari and fufu
Fufuohene Bankye	41	Poundable, CP: 32.80 μg/g	Starch, flour, gari and fufu
Ampesi Hemaa Bankye	40	Poundable, CP: 34.71 μg/g	Starch, flour, fufu and "ampesi"

Variety	Dry matter content (%)	Other quality attributes	Uses
CRI-Kent	30	CP: 48.15 mg/100 g, TCC: 7.8 μg/g	Gari, Chips
CRI-Kyerewaa	33	Poundable, CP: 42.03 mg/100 g, TCC: 4.12 μg/g	Gari, chips
CRI-Peprah	30	CP: 40.38 mg/100 g, TCC: 12.70 μg/g	Gari, chips
CRI-Manu	30	CP: 63.11 mg/100 g, TCC: 10.40 μg/g	Gari, chips

CP, cyanogenic potential; TCC, total carotenoid content [19].

Table 1.
Quality attributes and uses of released cassava varieties.

4.2 Potential markets

Cassava could be marketed fresh for cooking or could be processed into many different products of industrial and economic value. Some of these products include gari, starch, ethanol, high-quality cassava flour (HQCF), and other products. For example, in Nigeria, the cassava commercialization and market promotion programme were implemented between 2002 and 2008. Processed products such as HQCF, starch, glucose syrup and ethanol were produced. To replace some imported raw materials with the intermediate cassava products, this initiative was backed with policy. The programme increased production enormously by 10 million tonnes in the six years of implementation [37] and Nigeria is still reaping a lot of benefits from this initiative.

In Ghana, the industrial starch production was promoted by GoG in 2001. This was spearheaded by the Cooperative Village Enterprise (COVE) program. The initiative resulted in the establishment of a starch processing plant. The presence of this processing plant facilitated the buying of roots from villages in that vicinity leading to job creation for most of the citizenry. Though some challenges were encountered, there was increase in cassava production and processing at that time [37]. Currently, there are new business opportunities for cassava processing where private entrepreneurs have shown a lot of interest in products such as ethanol, starch, HQCF, chips for animal feed. To meet the needs of these different markets, the cassava breeding programme must redefine and confirm the country's cassava market segments and develop target product profiles.

4.3 Adoption of released varieties

A lot of research has gone into the development and release of new varieties due to the potential of cassava as a food security and industrial crop, as well as other benefits such as its multiple opportunities for poverty reduction and nourishment for vulnerable population. The adoption rate of improved cassava varieties in Ghana have been reported to be 40% [17]. This low adoption of improved varieties could be attributed to inadequate promotion and the fact that some varieties do not meet end-user needs, hence most farmers still rely on landraces [38]. Consequently, there is the need to change this trend through a lot of promotion of the good attributes of improved varieties for the attraction of both local and international markets. In addition, the breeding programmes in Ghana need to change their breeding strategy to develop new varieties to meet end-user needs.

5. Target traits for cassava improvement to meet end-user needs

Cassava has a lot of potentials to tackle malnutrition in addition to generation of income especially in parts of the world where food and nutrition security is a major challenge. A lot of breeding work has concentrated on agronomic traits with relatively less emphasis on nutritional quality and end-user traits. To make more progress to breed for varieties that will meet end-user needs, it is important to pay more attention to some added traits such as improvement in starch content and quality, dry matter content, mealiness/poundability in addition to the usual agronomic traits. Other traits such as early bulking is also important especially in this era of climate change.

For the acceptance of cassava for value chain actors, dry matter content (DMC) is an important character for variety acceptance. DMC is referred to as true biological yield or economic yield which is controlled by many genes [39, 40]. Majority of cassava accessions have DMC between 20 and 40% [39]. DMC accumulation is influenced by genetic and environmental factors. These factors include age of the crop, efficiency of canopy to trap sunlight, season, and location effects [41]. Therefore, in breeding for high DMC, there is the need to consider these factors.

Cassava starch is the cheapest and the most preferred because of its many positive characteristics such as high paste clarity, relatively good stability to retrogradation and swelling capacity. Other qualities include low protein complex, and good texture [41]. Most cassava varieties released in Ghana have starch content between 20 and 30%. As Ghana become more industrialized with the one district one factory and planting for food and jobs initiatives, there will be the need to breed for new varieties with higher starch content than existing varieties currently available. In addition, the breeding program should have replacement strategies to replace cultivated varieties that have declined in starch content. This will result in the release of superior varieties with high starch content to meet the demands of the starch growing industry in Ghana and beyond.

Cassava is boiled and eaten as "ampesi" or pounded together with plantain to make fufu, a delicacy for most people in Ghana. About 70% of cassava produced is used for fufu, making poundability a major end-user trait. Out of over 30 improved varieties released, about 60% are poundable, however most of them are not poundable all year round. It is imperative for breeders to pay more attention to poundability as a major target trait in the breeding programme. Another important organoleptic attribute of poundability in recent times is the texture of boiled cassava [42]. This is crucial for the release of end-user preferred varieties as these are principal quality attributes of boiled cassava roots [43].

The process of increasing micronutrient amount in crops through plant breeding, transgenic techniques, or agronomic practices is termed biofortification. This is a feasible means of reaching rural populations with limited access to diverse diets or other micronutrient intervention [44]. More than two billion individuals are affected by micronutrient deficiencies [45]. There should therefore be the need to breed for more biofortified cassava varieties to feed the vulnerable populace. In addition, there should be a balance between the potential benefit of increasing market demand for biofortified cassava, thereby making it more attractive for farmers to grow [44]. Most cassava varieties have white to cream root pulp. The colour of the pulp is closely linked to carotenoid content. Development of high carotenoid biofortified cassava varieties have been initiated by HarvestPlus [46] and through the project, nine yellow-fleshed varieties with good carotenoid content have been released in Ghana to help meet the needs of the vulnerable population with vitamin A deficiency.

6. Phenotyping tools for breeding for end-user preference

For conventional breeding, investment, and use of new tools for phenotyping should be taken seriously especially in SSA. This will enhance modernization of the breeding programme making it more attractive to the youth especially in this era of climate change. To facilitate genetic studies and improve genetic gains, accurate phenotyping is key. However, getting accurate phenotypic data for breeding to meet end-user needs remains a challenge [12]. Conventional use of colour intensity in the measurement of carotenoid content in cassava roots is sometimes very difficult [46]. Near-infrared spectroscopy (NIRS) has been applied in some countries for the prediction of nutritional constituents of cassava. This holds a lot of promise in exploiting carotenoid levels and other quality traits. In addition, the use of high-performance liquid chromatography (HPLC) would complement high-throughput phenotyping efforts in breeding for varieties tailored towards end-user needs. The breeding programme in Ghana must invest in high-throughput phenotyping equipment for assessing micronutrient levels and other quality traits.

7. Cassava seed systems for dissemination of end-user preferred varieties to stakeholders

Conventional system of propagation using stems has disadvantages such as low multiplication rate (7–10 new stakes/mature plant/cycle) and accumulation of pathogens with time. This system also takes long to get enough planting materials (8–14 months) [22]. Due to these challenges, complementing the efforts of conventional multiplication with innovative rapid propagation methods such as tissue culture and semi-autotrophic hydroponics (SAH) hold a lot of prospects [47], reported that a major challenge of cassava breeding programmes compared with private seed business is that the former lack efficient seed systems to produce and distribute planting materials of newly improved varieties with end-user needs. Putting in place a resilient and formal seed system starting from the tissue culture and molecular diagnostic laboratories, as well as screen house facility is key for increasing the production of varieties with end-user traits. In the case of Ghana, there are facilities for cleaning, indexing and mass production of improved cassava varieties. However, the cassava seed system is not well structured, hence this must be improved to enhance the dissemination of improved cassava varieties with end-user traits.

8. Linkage between breeding and market

Well targeted research initiatives are required for the initiation of commercial operation of cassava value chain. Value chain commercialization, linking breeding activities to the market, requires relevant technologies and market innovations to be tested at pilot scale. This will facilitate lessons learnt from technology adaptation, the challenges and other precondition for success. To link breeding and market, this calls for research and development initiatives with the primary objective of providing solutions to constraints militating against the efficient operation of the cassava value chain [37].

9. Future prospects and way forward

Cassava breeding activities keep on revolutionizing. To meet end-user needs and the growing demand for more cassava production, traits targeted should be chosen carefully. The Ghana cassava breeding programmes should redefine the country's cassava market segments, change the breeding strategy to develop new varieties with traits such as poundability, DMC, starch and carotenoids to meet end-user needs. They must also invest in high-throughput phenotyping equipment to enhance the development of varieties with end-user traits. The breeding programme should also look at formalizing the cassava seed system to enhance the production and dissemination of high-quality improved cassava varieties with end-user traits.

10. Conclusions

A lot of efforts have gone into cassava breeding in terms of agronomic traits. Consequently, most varieties do not meet end-user needs. This has resulted in relatively low adoption and most farmers still cultivate landraces. To overcome these challenges, the cassava breeding programmes in Ghana should identify the different market segments, develop target product profiles for the different market segments, develop improved varieties with end-user traits, outdoor and promote varieties, formalize the cassava seed system for the production and dissemination of clean planting materials. When all these are fulfilled, improved varieties released will be greatly adopted and utilized by farmers.

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Conflict of interest

The authors declare no conflict of interest.

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