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Chapter

Advances in Cassava Trait Improvement and Processing Technologies for Food and Feed

Kariuki Samwel Muiruri and Anwar Aliya Fathima

Abstract

Cassava is an important staple crop globally; its roots and leaves are directly consumed as food or undergo secondary processing in food industries or as animal feed. Inherent biological challenges in cassava affect the quality and quantity of food and feed. Although trait consolidation has been explored, the diversity in cassava food products has led to stratification of target crop characteristics. Among the traits targeted, crop improvement for food includes: yield and starch quality for different applications such as pounding, resistant starch, waxy starch, and even post-harvest deterioration. The presence of the antinutritional compound cyanide reduces the quality of food and feed, and efforts to reduce cyanide levels are continuously explored. In this Chapter, we review biological and technological research efforts in cassava geared toward improving the quality/quantity of cassava for food and feed. These efforts cut across target trait improvement efforts to new bioprocessing technologies.

Keywords: food, feed, traits, cassava, agro-processing, improvement, starch, quality, quantity

1. Introduction

Cassava is a major staple food crop cultivated for its starchy roots and sometimes its leaves. It ranks among the top five crops as a food source and is consumed by over 700 million people globally [1]. Cassava not only plays a critical role in food security but also serves as a trading commodity in most rural areas where it is grown [2]. In most cassava growing regions, for example, cassava trade entails the sale of fresh or recently harvested roots. In the recent past, cassava has gained additional importance owing to its increased use in animal feeds, bio-energy, and processed food industry [3–5]. Cassava is increasingly being used to partially or fully replace grains in livestock [5] and chicken [6] feed without negative effects [7]. Cassava is better adapted to drought and reduced soil fertility compared to cereal crops (mostly maize) used in animal feeds [8]. Cassava, therefore, serves to a greater extent as an appropriate animal feed alternative during the unpredictable conditions being experienced with changes in climate. Cassava biomass is already being used for nonfood and nonfeed applications [9, 10] and the uses are still rising. The utility of cassava as food, feed, and agro-processing is challenged by intrinsic
and extrinsic threats. Among many challenges, low productivity impacts cassava use, resulting from a wide range of factors including cultivar type [11], agricultural management practices [12], pests and diseases [13], and environmental conditions [14]. Post-harvest physiological deterioration (PPD), a loss in quality of harvested cassava roots due to physiological and biochemical processes, is another major challenge in cassava use as food and feed [15]. The PPD results in the darkening of harvested roots rendering them unusable as food and feed. Another major drawback in cassava utility is the presence of cyanide in the roots, which have antinutritional properties. Consumption of cyanide-laden cassava or constant exposure in a cassava processing industry can cause neurological disorders and even immediate death [16, 17]. Poor nutritive value of cassava roots is yet another challenge, particularly in areas where cassava is consumed regularly as a staple. Cassava roots are generally low in proteins [18] and minerals like iron and zinc [19]. These among other challenges compromise the quantity and quality of cassava produce and approach to overcome them have been extensively explored.

Cassava roots contain up to 80% starch on a dry-weight basis [20]. Starch polymers contain amylose and amylopectin, which are interconnected α-1,4 linear chains and β-1,6 branched chains of glucose monomers. Amylose is insoluble in water at low temperatures whereas amylopectin dissolves easily in water. The heating and cooling of native starch cause retrogradation, a condition in which the amylose and amylopectin chains realign to form a more crystalline structure. High amylose content in native starch can promote retrogradation [21] and subsequently, the starch polymer expels water, a process called syneresis, and becomes unfavorable for food applications [22]. Other constraints include water absorption and swelling behavior that influences the consistency of the product in certain baking applications and this is dependent on the amylose content, size, and structural integrity of starch granules [23].

Approaches aimed at overcoming challenges affecting cassava use as food and feed can be broadly grouped into two: 1) those that modify the biology of the plant with the ultimate goal of improving its performance in quality and quantity [24, 25]. These methods include conventional breeding and biotechnologies such as genetic engineering and genome editing. 2) Processing and bioprocessing methods that modify cassava product profiles [26, 27]. These include addition of missing but critical compounds that enhance cassava product quality or removal of unwanted and harmful metabolites. In addition, methods that change cassava products’ profiles to fit intended use are grouped into this second category. This chapter reviews these different approaches used in addressing challenges affecting use of cassava and its products in food and feed industries.

2. Improvement of cassava crop for food and feed

2.1 Targeting cassava for yield improvement

The quantity of cassava harvested is important in both food and feed industries. Yield in cassava is influenced by, among other factors, genetics, environment, and the corresponding interactions [28]. The selection of cassava cultivars for increased yield breeding using crop physiology as the basis entails simple yield parameters that include harvest index (HI), biomass, and root dry matter content (DMC) [29]. In cassava, HI is the ratio of root wet weight to the total plant biomass whereas dry matter content is the percentage of fresh root weight that is dry matter. The higher variability in the fresh weight of the harvested cassava necessitated the use of HI as a cassava yield indicator. High levels of HI heritability have been observed even early on in cassava growth.
making it a crucial yield prediction trait in cassava [30]. A positive correlation between fresh root eating qualities and DMC exists [31]. Majority of processing in the cassava food industry involves drying of the roots. The DMC and HI equally determine a key target trait in improving cassava yield and have consistently been used in breeding programs in Brazil [11, 32], Uganda [33], Nigeria [34], and Thailand [35] among others.

2.2 Early bulking for faster harvest

The increase in cases of drought occasioned by climate change makes predictability of harvest time a herculean task. This in turn makes predictable food and feed production from cassava difficult, especially for varieties that take long time to mature [36]. Planting of early maturing cassava varieties is a clear strategy for adapting to climate change and ensuring a quick return on investment in both cassava food and feed industries. Early bulking (thickening of storage roots due to starch accumulation) is a genotype-dependent trait that can be used in breeding for quicker harvesting and, consequently, faster food provision [37]. Bulking in cassava is thought to occur when vegetative requirements of photosynthates are less than the ones being generated [38]. Early bulking varieties are thought to be ready for harvest 6—8 months post-planting [39]. Early bulking varieties among pro-vitamin A cassava genotypes have been selected with the goal of ensuring early harvesting [40]. Early cassava bulking has also been achieved in efforts to breed drought-tolerant varieties [37, 41].

2.3 Crop improvement for increased levels of pro-vitamin A carotenoids

Vitamin A deficiency is common, particularly in areas where one type of food naturally low in pro-vitamin A is consumed as a staple. Most of the cassava varieties cultivated in regions where it is a staple food tend to be low in vitamin A [42]. Fortification of cassava is used as a strategy for enriching cassava produce, particularly flour with β-carotene [43, 44]. Fortification can be a costly option compared to biofortification, where cassava varieties naturally produce pro-vitamin A [45]. Cassava varieties able to accumulate pro-vitamin A carotenoids in the roots have been developed using biotechnology [45] and conventional approaches [46]. Overexpression of the deoxy-d-xylulose-5-phosphate synthase (DXS) and bacterial phytoene synthase (crtB) genes resulted in enhanced levels of β-carotene in the roots through biotechnology approaches. Breeding for improved β-carotene requires first screening for varieties with this trait and working upwards to enhance it [47]. Varieties with higher levels of β-carotene have been identified and bred into the major cassava lines [48–50]. In addition to β-carotene, varieties with increased pro-vitamin A have longer shelf life, albeit at the expense of low dry matter content [45].

2.4 Improvement of cassava against post-harvest physiological deterioration (PPD)

Post-harvest physiological deterioration results in cassava roots turning blue, black, or brown in color one to five days post-harvest. The discoloration is accompanied by a bitter taste rendering the roots unusable [51]. The PPD has been associated with both plant genetics as well as environment, particularly storage conditions. In Indonesia, different cassava genotypes were observed to have a range of 10 to more than 20% deterioration and were classified as having low, medium, and high susceptibility to PPD [51]. Similar variations have also been observed in cassava from Africa and South America [52–54]. The genes responsible for PPD and the associated quantitative trait loci (QTLs) have
Cassava - Recent Updates on Food, Feed and Industry

already been mapped in the cassava genome [55, 56]. In Nigeria, where extensive breeding for tolerance to PPD has been done, four major tolerance sources have been identified and include interspecific hybrids, gamma irradiated mutants where a gene involved in PPD is silenced, clones with high β-carotene, and an amylose-free waxy starch mutant [29, 57]. In addition to conventional breeding, genetic engineering strategies have also been applied in addressing the PPD challenge. Overexpression of reactive oxygen species (ROS) scavenging genes has shown promising results in reducing PPD [58]. One major challenge observed in silencing some of the genes associated with reduced PPD is loss in dry matter content and reduced starch storage [59]. Therefore, appropriate genes that minimize PPD while still retaining desirable traits like starch deposition and dry matter accumulation should be explored.

2.5 Improvement of cassava for specific starch profile

Cassava is prepared for food in different ways including boiling and pounding to make foods like “fufu” common in west Africa, and even in drinks, the most famous being bubble tea. The physicochemical qualities of cassava starch determine the culinary uses of the roots and associated products [60]. Cassava starch contains amylpectin and amylose, the former being longer and more branched and the latter linear. The levels of complexity in branching differentiate amylpectin’s physical and chemical characteristics [61].

The variations in physical and chemical properties of starch in cassava are dependent on the genotype. There are four cassava genotype classes categorized on the basis of amylose levels: The waxy type contains a maximum of 2% amylose, semi-waxy with a maximum of 15%, normal-regular with a maximum of 35%, and high category with more than 35% amylose cumulative root starch yield [61]. Most varieties are grown for food fall within the normal-regular category. However, waxy varieties that completely lack amylose have been observed to exist as natural variants [62–64]. Naturally, waxy scratch variants have been observed to carry a mutation in the granule-bound starch synthase (GBSS) gene that renders it non-functionally [65]. Silencing of the GBSS gene through transgenic approaches has also resulted in waxy starch genotypes [66]. Cassava waxy starch is extensively used as a stabilizer in food storage because it does not have syneresis making it first among other starches in food stabilization.

Other than waxy starch, resistant starch, which is starch less amenable to enzymatic breakdown in the human stomach and reduced absorption in the small intestine, has been considered for a product profile [67]. The difficulty in breakdown of the RS bears resemblance to dietary fiber in being indigestible. The indigestibility of RS in the small intestine lowers the pH in the large intestine consequently increasing the fecal bulk, and consequently reducing the risks associated with cancer of the colon [68].

2.6 Developing cassava with reduced cyanide levels

The presence of cyanogenic glycosides in cassava roots risks its use for food and feed in both humans and animals. Development of cassava varieties with reduced cyanide levels is considered a viable approach to safe use of cassava root [69, 70]. To reduce the levels of cyanide in cassava a combination of both biotechnological and conventional approaches is being implemented. Through biotechnology, targeting cassava CYP79D1 and CYP79D2 genes resulted in a cyanogenic cassava, especially in the leaves [69, 70]. Low cyanogenic glucoside cassava varieties have been identified and selected for use in food production [71]. Combined, biotechnological, and
conventional approaches to cyanide reduction can be used to enhance usability of both the raw and processed products from cassava roots for both food and feed (Table 1).

<table>
<thead>
<tr>
<th>Target trait/ starch property</th>
<th>Biotechnologies/bioprocessing methods</th>
<th>Outcome</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch content</td>
<td>ADP-glucose pyrophosphorylase overexpression</td>
<td>Increase in root tuber mass and enhanced starch content</td>
<td>[71]</td>
</tr>
<tr>
<td>Waxy starch</td>
<td>Conventional breeding</td>
<td>Low amylose, improved physico-chemical characteristics of starch</td>
<td>[64]</td>
</tr>
<tr>
<td></td>
<td>CRISPR-Cas9 targeted mutagenesis of GBSSI</td>
<td>Low amylose</td>
<td>[66]</td>
</tr>
<tr>
<td></td>
<td>Enzymatic modification of cassava starch using alpha-amylase/dry heat</td>
<td>Reduced amylose content</td>
<td>[73, 74]</td>
</tr>
<tr>
<td>Resistant starch</td>
<td>RNAi silencing of branching enzymes</td>
<td>High amylose</td>
<td>[75]</td>
</tr>
<tr>
<td></td>
<td>Cross-linking with citric acid</td>
<td>Increased amylose content, altered crystallinity</td>
<td>[76]</td>
</tr>
<tr>
<td>Protein content</td>
<td>Expression of storage protein ASP1</td>
<td>Root tuber enhanced with amino acids</td>
<td>[77]</td>
</tr>
<tr>
<td></td>
<td>Solid state fermentation (SSF) using Rhizopus sp., and soy protein fortification</td>
<td>Replacement for wheat flour</td>
<td>[78]</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>Expression of deoxy-d-xylulose-5-phosphate synthase (DXS) and bacterial phytoene synthase (crtB)</td>
<td>Provitamin A production in roots</td>
<td>[45]</td>
</tr>
<tr>
<td></td>
<td>Fermentation of cassava flour using Lactobacillus plantarum</td>
<td>Improved protein and Pro-vitamin A in cassava flour</td>
<td>[79]</td>
</tr>
<tr>
<td>Cyanide content</td>
<td>CRISPR-Cas9 mutagenesis of CYP79D1 and CYP79D2 genes</td>
<td>Reduction in cyanogenic glycosides</td>
<td>[70]</td>
</tr>
<tr>
<td></td>
<td>Fermentation and wetting</td>
<td>Reduction in cyanide content in fermented leaves and roots</td>
<td>[80, 81]</td>
</tr>
<tr>
<td>Physicochemical properties of starch amylose, granular integrity</td>
<td>Expression of starch-phosphorylating enzyme glucan water dikinase (GWD) and silencing endogenous phosphatase and phosphogucan genes</td>
<td>Altered swelling and paste clarity, starch granule size</td>
<td>[82]</td>
</tr>
<tr>
<td></td>
<td>Acid hydrolysis/enzymatic/high voltage electric treatment and phosphorylation</td>
<td>Decrease in amylose and starch content, low enthalpy of gelatinisation and damaged starch granule</td>
<td>[83, 84]</td>
</tr>
<tr>
<td>Retrogradation/ syneresis</td>
<td>Addition of hydrocolloids</td>
<td>Low syneresis, improved pasting viscosity</td>
<td>[85]</td>
</tr>
<tr>
<td>Post-harvest physiological deterioration (PPD)</td>
<td>RNAi mediated silencing of Feruloyl CoA 6′-hydroxylase gene</td>
<td>Reduction in PPD symptoms during storage</td>
<td>[86]</td>
</tr>
</tbody>
</table>

Table 1. Summary of research on trait and bioprocessing approaches aimed at enhancing cassava quality and quantity for food and feed.
3. Cassava bioprocessing for improved food and feed quality

Cassava is a source of commonly used ingredients in the food industry, which, when processed, result in functionally unique value-added products [87]. Owing to the high carbohydrate content and gluten-free status of cassava products, their demand has increased. The increase in demand has necessitated the development of economically viable processing methods [19, 88]. The quality of processed cassava products is largely determined by the quality of starch. The starch quality is dependent on factors such as (i) method of extraction (ii) physicochemical characteristics and (iii) nutritive quality. Bioprocessing methods have been widely used to alter the properties of native cassava starch to be made suitable for the food and feed industry.

3.1 Improving cassava starch content

Conventionally, cassava starch is extracted from root tubers using maceration at optimum temperatures to produce pulp. To recover starch, the pulp containing 50–60% w/w of starch [89] is resuspended in 10 fold w/v of water followed by filtration, settling, decanting, and drying [90]. This method results in starch recovery ranging from 18–25% per fresh cassava tuber weight. This makes the method laborious and time-consuming with minimal returns. Several modifications in the extraction methods have shown enhanced starch yield. The maceration of cassava tissues to produce pulp, for example, was improved by addition of microbial enzymes such as pectinases and polygalacturonase [91]. Recently, ultrasound-assisted extraction (UAE) was used to extract starch trapped inside cellulose fibers in cassava. The method produced the highest yield of 56.57% with a starch purity of 88.36% [92]. The limitations with starch losses in commercial-scale production units have been notably challenging and can be minimized by optimizing operation, design, and feed variables [93]. These processes have been further improved by addition of sulfur for improved starch granular stability and separation of the native starch from bound proteins and other impurities during the extraction process [94, 95].

3.2 Improving functional properties of cassava starch

The native starch can be processed to improve the physicochemical properties that maximize the use of cassava in the food and feed industry. The cassava processing methods involve either physical, chemical, enzymatic, or biological pre-treatments that modify starch content, nutrient content, texture, swelling power, solubility, pasting property, viscosity, gelatinization, crystallinity, and anti-nutrient content of the modified starch [96].

Physical modification of starch includes thermal or nonthermal methods. Thermal modifications such as pre-gelatinization, heat and moist treatment, dry heating, annealing, and microwaving involve the treatment of starch at various temperatures and pressures [97]. These methods have been very effective in deformation of granular structure of starch and in reducing crystallinity. Nonthermal modifications such as ball milling, cold plasma technology, hydrostatic pressure, microfluidization, pulse electric field, and ultrasound require no heat treatment, and, therefore, reduce energy consumption [98]. These modifications have shown the ability to maintain the granular integrity and increase surface activity of starch consequently improving pasting and swelling properties of cassava starch [98]. Recently, a combination of methods utilizing dry heat and ozone treatment has been shown to affect starch molecule size, structural properties, and gelatinization [99].
The commonly used chemical treatments include acid hydrolysis, cross-linking, and oxidation [100]. The functional groups in chemicals react with hydroxyl groups in native starch to produce modified starch. The modification of cassava starch at various concentrations of hydrochloric acid and temperatures has been shown to alter the fraction of amylose and amyllopectin and crystallinity of native starch [101]. Acid hydrolysis improves water holding capacity and water absorption, which can alter pasting properties of starch [102]. The treatment of native starch with weak organic acids such as citric acid is advantageous in culinary applications because it reportedly improves granular starch yield and avoids depolymerization. Citric acid has also been used for cross-linking of native starch [103]. Cross-linking introduces covalent interactions and reinforces the hydrogen bonds between starch molecules and prevents movement of polymer chains thereby reducing retrogradation and providing resistance to shearing and thermal decomposition during storage [104]. Moreover, natural organic acids such as lactic acid, malic acid, and citric acid are safe for consumption and generally have applications in the food industry as acidity regulators, flavoring agents, etc. Some of the studies highlighted here have highlighted a combination of modifications that improve properties of native starch [105]. Post-acid treatment of lactic acid hydrolyzed native starch by drying under UV irradiation resulted in the depolymerization of native starch and improved its baking expansion [96]. Lactic acid hydrolysis combined with microwave heating or fermentation and esterification in the presence of ethanol have shown better properties of modified starch for use in food coatings [106]. Other cross-linking agents that are commonly used are adipic and acetic acid mixed anhydrides, phosphorus oxychloride, sodium trimetaphosphate, sodium hydroxide, and ethylene glycol diacrylate epichlorohydrin (EPI) [107–109]. Acetylation and esterification improved water retention and reduced retrogradation tendency in cassava starch compared to sorghum and potato starch [110, 111].

The starch processing approaches discussed have their pros and cons. Chemical processes, for example, can be high starch-yielding but are prone to residual by-products of the chemical reactions. Physical processes are considered clean and sustainable in comparison with chemical starch processing/modifying approaches. However, physical modification techniques involving prolonged heating may reduce starch viscosity and stability and are moderately effective in reducing the amylose content making the starch less suitable for baking [112]. Alternative enzymatic treatments and fermentation methods of starch modification alter amylose content by addition of hydrolyzing enzymes or treatment with microorganisms that can break down amylose [113]. Retting is a traditional process that allows microbial activity on plant materials to dissolve cell wall polysaccharides such as cellulose and pectin by immersion in water [114]. The pasting properties can be influenced by the combination of microbes used for retting [115]. Starch modifying and starch converting enzymes mainly perform hydrolysis, transglycosylation, or cleavage of α-1, 4 linked glucan and α-1, 6 linked branches, extensively reviewed for their use in baking applications by Mikolo et al. [116].

3.3 Bioprocessing to improve nutritive quality of cassava starch

The consumption of starch containing high amounts of amylose (resistant starch) has several health benefits [117]. Like previously noted, resistant starch (RS) escapes digestion in the small intestine and is fermented by the gut microbiota in the large intestine [118]. The fermentation end-products such as short-chain fatty acids, acetic acid, and butyric acid have been found to reduce the effects of chronic inflammatory health
conditions and also improve growth of beneficiary gut microbes [119]. Chemical modification of cassava starch using octenyl succinic anhydride has been shown to improve resistant starch content in cassava [120]. The most common and highly resistant starch-yielding methods use enzymatic debranching of native starch using isoamylase or pullulanase followed by autoclaving and/or high-pressure annealing [121, 122].

Cassava has a high energy content and is widely regarded as a good source of dietary fiber, minerals, and vitamins. However, the protein content of cassava roots is significantly low compared to cassava leaves [123]. Pre-processing of cassava roots through drying and fermentation improved protein, fiber, and shelf-life of cassava products [124]. Co-fermentation with legumes has been shown to enrich protein content in cassava [125]. Alternatively, cassava-based industries have developed high-quality cassava flour (HQCF) from processed cassava roots without fermentation, no-off odor, and appealing taste [126]. HQCF can replace wheat flour by addition of protein-rich mushroom flour to HQCF, which makes it a suitable food commodity [127, 128].

Research has been focused on developing different processing methods to reduce cyanide content [129]. The use of cassava as food and feed is primarily limited by high cyanide content and antinutrients that reduce nutrient availability as discussed in the previous sections [130, 131]. The edible parts of cassava including root tubers and leaves have been found to contain toxic cyanogenic glycosides (CNGLcs) namely linamarin and lotaustralin [132]. Prolonged consumption of cassava can increase risk of cyanide poisoning in humans and animals [133]. During tissue damage, the released glycosides come in contact with enzymes (linamarase) and form acetone cyanohydrin, a less stable intermediate that is either spontaneously or enzymatically (hydroxynitrile lyase) converted to volatile and toxic hydrogen cyanides (HCN) [134]. Previously, processing techniques such as pounding cassava tubers and soaking the paste in cold water, wilting, drying, boiling, ensiling, and fermentation removed most of the cyanides [135, 136]. During cassava root retting, microbial strains have been found to naturally evolve with ability to produce enzymes that degrade CNGLCs and have been proven to reduce cyanides efficiently during the process of fermentation [137–139]. Alternatively, the application of enzymes that degrade plant cell wall polysaccharides such as cellulases and hemicellulases may indirectly trigger release of linamarin due to tissue damage caused by these enzymes [140]. In another study, cassava leaves were washed, dried, and treated with bicarbonate to efficiently reduce the cyanide contents [141]. Bicarbonate treatment was most efficient in reducing cyanide levels in cassava leaves in comparison to thermal, enzymatic, and ultrasonic methods but significantly reduced nutritive components such as ascorbic acid [142]. The other antinutrients present in cassava leaves including polyphenols, nitrates, and phytates significantly reduce absorption of proteins and essential minerals [143, 144]. Fermentation of cassava leaves has been the most promising method to reduce antinutrients and concomitantly retain the nutritive value of cassava and flavors [145, 146]. Other potential methods include boiling, steaming, dry-roasting, and microwaving [147].

4. Conclusion

Cassava has been identified as an exemplary crop for developing a sustainable food system due to its hardiness, relatively better adaptation to abiotic stress, particularly drought and higher productivity. Challenges inherent in the crop have necessitated crop improvement and bioprocessing efforts to improve its use for food, feed, and bioenergy sectors. Some of these methods as highlighted in this
Advances in Cassava Trait Improvement and Processing Technologies for Food and Feed
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Chapter have progressively been implemented to enhance the quality of cassava food products in terms of palatability and dietary benefits and ensure transformation of cassava as a potential raw material to produce economic and high-value livestock and poultry feed. Crop improvement approaches as summarized in this chapter have been employed to produce varieties with increased essential micro-nutrients and pro-vitamin A to address malnutrition and adopt cassava as a biofortified crop. Protein supplementation of cassava flour has promoted cassava as an ideal choice for high-quality diet that can replace conventional food crops. The utility of cassava has been undoubtedly increased through modern technologies making cassava versatile to serve nontraditional subsistence roles with enhanced market value.

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