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Can food technology innovation change the status of a food security crop? A review of cassava transformation into "bread" in Africa

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ABSTRACT
Reducing both hunger and high expenditure on food imports is a priority for most developing African countries. Countries that hitherto have relied heavily on food imports are seeking new approaches to increase the utilization of locally grown crops. This review uses the case of cassava to propose that scientific and technological innovations, supported by public investment and appropriate policies, offer opportunities for better utilizing locally grown crops, encouraging agro-industrial development, reducing import expenditure, and providing much-needed income (bread) to smallholders. This review highlights areas that require further research in order to achieve sustainable development in the processing of raw cassava root into cassava flour for bread production.

KEYWORDS
Bread; cassava; high-quality cassava flour; import substitution; income; investment; technology

Introduction

The Millennium Development Goals (MDGs) were established in 2001 by the UN member states as a collective action to eradicate world hunger by 2015.[(1)] A multifaceted strategy involving the application of science and technology has been proposed for resolving the challenges of global food insecurity.[(2)] Although the proportion of people living in extreme poverty was halved at the global level by 2015, 80% of the world population lacks a basic food intake.[(3)] The highest proportion of the chronically undernourished is found in developing countries. The capacity to preserve food is directly related to the level of technological development of a nation. The low capacity of people in many African countries to process and preserve foods contributes to food and nutrition insecurity, slow growth of rural-based small-scale food processing enterprises, limited capacity to generate employment in the rural areas, and failure to reduce rural–urban migration.[(4)] One of the challenges the developing countries are facing is the huge expenditure on food imports, which is a drain on foreign exchange. A massive

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importation of food reduces public investment in food production and, in some cases, causes an increase in public debt. In 1964, the Food and Agricultural Organization (FAO) of the United Nations championed a reduction in developing nation dependency on food imports by promoting the use of indigenous crops as a partial substitution for wheat flour.[5,6] The FAO objective was not fully achieved, as no technology was available to provide a suitable alternative to wheat flour for baking bread from the target crops.

Following the adoption of a structural adjustment program in many African countries, various governments focused on reducing expenditure on food imports by developing markets for locally produced foods and raw materials and seeking suitable technologies for using locally grown crops to replace imported ones such as wheat.[7] New technology is needed because some of these crops, such as cassava, are very high in dietary fiber (4.92–5.6% insoluble fiber and 3.40–3.78% soluble fiber)[8,9] and starch content (64–72%), which differs from that of cereal starch in its granular structure, amylose content, and branch chain length distribution.[10] Furthermore, cassava starch is highly digestible and shows no signs of significant α-1-2 and α-1-3 bonds as evidenced by its hydrolysis to glucose by the industrial enzyme α-amylase.[11] These properties are very important in the functionality of flour produced from cassava. Cassava, moreover, is low in protein content, especially in the sulfur-containing amino acids (methionine and cysteine),[12] and is not able to form a network that retains gas during the development of bread dough, as wheat flour does. Wheat flour, on the other hand, contains large amount of the protein known as gluten. Gluten is made up of glutenins, which provide strength and elasticity to dough, and gliadins, which are responsible for the viscous properties of the dough.[13,14] Starch is also the largest fraction of the wheat flour, making up about 65%, and influences dough elasticity.[14] Goesaert et al.[15] reported that the importance of starch in bread-making is related to its water-absorption capacity, gelatinization, and retrogradation. Cassava flour was reported to exhibit early gelatinization, high peak viscosity, large paste breakdown, and low retrogradation tendency compared with wheat flour.[16] Consequently, these researchers concluded that the physicochemical and functional performance of cassava flour can successfully replace portions of wheat flour in the bakery industry. To this end, research institutions were mandated to investigate the suitability of locally sourced cassava roots for use in bread baking, the aim being to reduce expenditure on wheat imports.[17] This led to research on improved processing methods for the crops, and blending these crops with wheat flour to bake bread in various African countries.[18–20] However, progress in this area has not been uniform across the continent.

This review is meant to help researchers and policy-makers by providing an overview of ongoing research activities on cassava-related science and engineering innovations in Africa. It also pinpoints the essential policies that boost adoption of the innovations that were developed, the emerging potential impacts on private sector investment, a reduction in national import expenditure, and the potential food security implications at the household level.

Cassava research

Cassava is a food security crop in many countries, but it is also one of the most suitable crops for processing into industrial raw materials such as starch.[21] Processing helps to reduce post-harvest loss of cassava and evens out fluctuation in seasonal supply. In many

of the cassava-growing African countries, diverse traditional techniques are used to process cassava into foods such as flour, starch, *fufu*, tapioca, *makopa, chingwage, baton de manioc, rali*, and *gari*.[22] However, there has been growing interest to use cassava as a substitute for imported food items such as wheat flour and to make new food products from cassava flour. Researchers have been investigating different methods to make intermediate, shelf-stable cassava products such as chips and pellets,[22] from which cassava flour could be made and marketed. This could generate demand for cassava roots and stimulate widespread adoption of more efficient production technologies.

While institutions have been implementing the research for development (R4D) approach, a larger number of actors were targeted as beneficiaries of this research for development approach: farmers, rural food processors, equipment manufacturers, consumers, input suppliers, unemployed youth, local investors, food industries, and others.

With the focus on processing cassava into suitable flour for baking bread, researchers have investigated alternative methods making cassava safe for consumption. Cassava contains potentially toxic compounds such as cyanogenic glycosides, primarily as linamarin and lotaustralin, which liberate hydrogen cyanide (HCN) upon hydrolysis.[23] As fermentation was understood to be the most efficient method of reducing cyanide from cassava, researchers have mostly focused on this method to make safe cassava flour.[23,24] However, fermentation produces discolored cassava flour having a repulsive odor and, in some cases, mycotoxin contamination.[25] The composite flour made from fermented cassava and wheat was not acceptable to bread bakers, due to its poor quality and fermented taste. This was the result of the research carried out at both the Federal Institute of Industrial Research Oshodi (FIIRO) and the International Institute of Tropical Agriculture (IITA), all in Nigeria.[26,27]

Further research into the mechanisms of cassava detoxification has resulted in new techniques to make safe food from cassava without fermentation.[28] Over time, knowledge has been gained in the microbiology and biochemistry of cassava fermentation in relation to detoxification.[29,30] Although the cyanogenic glycosides are found in all parts of the plant, the greatest concentration is in the root cortex. The spontaneous release of HCN from the plant depends upon the presence of a specific linamarase and water. The enzymes are extracellular and gain access to the glucoside after physical disruption of the plant cells. The enzymes are readily destroyed by heat, as the boiling point of HCN is 26 °C.[31] Hydrolysis occurs when the plant is macerated in water. Consequently, improving the processing methods used for conversion of cassava roots to different storable cassava products, such as peeling, slicing, soaking, retting, fermenting, boiling, drying, roasting, pounding, and milling, could potentially detoxify/reduce the toxins. For instance, Nebiyu and Getachew[32] reported an average of 81% reduction in total cyanide in cassava chips after 24 hours of soaking and sun-drying, in different cassava varieties. Furthermore, chopping the cassava tubers into small pieces (chips) may have improved contact between the enzyme and cyanogenic glycosides, resulting in higher hydrolysis. Similar results were also reported by other researchers such as Gomez et al.,[33] who obtained a reduction of 70–80% after 48 hours of sun-drying, and Tivana and Bvochora,[34] who obtained a 95.41% reduction by heap fermentation followed by sun-drying. Similar results on the detoxification of cassava roots during processing have been reported by other researchers.[35–37] Apart from the detoxification of cassava roots through processing, research has shown the potential of a biotechnological approach to optimize and regulate the

content and distribution of cyanogenic glucosides in cassava to increase food security.[38,39] In addition, transgenic approaches to reduce cyanogen in cassava root have focused on suppressing cyanogen synthesis or accelerating cyanogen breakdown.[40] One potential benefit of lowering cyanogen content is the facilitation of free cyanide assimilation into amino acids,[40] thereby improving the protein value of the roots.

Research on modernizing traditional cassava food products has demonstrated the potential for using mechanized processing techniques to increase the quality and safety of processed cassava products.[41,42] It was understood that mechanical grating or blending of fresh cassava roots releases the toxin-containing linamarin from the cassava roots, increases its contact with the inherent linamarase enzyme, thereby releasing the volatile toxic cyanide gas and an intermediate water-soluble cyanide-containing compound, cyanohydrin, which can immediately be removed almost entirely by mechanically squeezing out the water from the grated cassava.[28,43] This new knowledge improved the understanding of biochemical, chemical, and engineering properties of fresh cassava roots in relation to a mechanical method for processing cassava roots into safe high-quality cassava flour, without a fermentation step. The process was developed and first described by the International Institute of Tropical Agriculture.[24] The processing steps were thereafter standardized, so as to integrate a rapid peeling of cassava roots, washing, grating, water removal, and complete drying of cassava roots into dry grits within 24 hours of harvesting. The dried grits were then milled into fine flour and packed, avoiding fermentation and contamination throughout the process of producing the cassava flour, which was found to be suitable for baking bread.[44] Hence, the concept of composite flour technology proposed by the FAO became achievable, with this high-quality cassava flour and it was possible to test the replacement of wheat flour with cassava flour in bread baking.

Suitability of cassava flour for bread

Research into the use of cassava as a replacement for wheat has yielded promising results. Recipes were developed for making bread and a wide range of new food products; from either the 100% unfermented cassava flour or in combination with wheat flour. The new recipes included wheat–cassava composite bread (20% cassava flour and 80% wheat flour), meat pies, sausage rolls, cakes, biscuits, doughnuts, and *chin-chin*.[16,45–47] Further research from collaborating researchers revealed that cassava flour made from pro-vitamin A cassava (yellow-fleshed cassava) is in compliance with national standard specifications for cassava flour in Nigeria, in terms of proximate composition. Moreover, it has a low tendency to undergo retrogradation due to low setback viscosities, and the relatively high peak viscosity exhibited by most of the yellow cassava varieties shows that the flour may be suitable for products requiring high gel strength and elasticity.[45] Shittu et al.[47] found that baking temperatures had a significant impact on loaf volumes and crumb moisture-content levels, whereas baking times influenced loaf weights, dried crumb hardness, and density levels. These researchers added that higher loaf weight and volume have a positive economic effect on bread at the retail end, as consumers are attracted to a bread loaf having a higher weight and volume, believing that it has more substance for the same price. The variation in loaf volume in this study[47] could be attributed mainly to varying rates of gas evolution and the extent of starch gelatinization, due to differences in baking temperatures and times. In addition, dough rheology studies showed that dough development times for cassava and wheat flour blends were shorter than for the 100% wheat flour, and decreased as the extent of

substitution with cassava flour increased.[19] An overall weakening of the dough with increased substitution of cassava flour was also observed by Eggleston et al.[19] However, these studies suggested that further work was required on the sensory and storage properties of bread made from composite cassava–wheat flour.

A study by Eriksson et al.[16] found that increasing the proportion of cassava flour above 20% reduced the specific volume of bread and increased its density and hardness, compared with 100% wheat bread. This was attributed to the fact that cassava flour lacks gluten and is therefore unable to form the cohesive visco-elastic, open foam structure that is typical of wheat bread.[48–50] Pasqualone et al.[51] reported that nutritious and palatable gluten-free cassava breads, suitable for the diet of celiac patients, can be produced by using egg white and extra-virgin olive oil to achieve a significant improvement of loaf-specific volume and crumb firmness even in the absence of hydrocolloids and industrial improvers. Shittu et al.[52] reported that adding up to 2% xanthan gum resulted in a major hindrance of gluten–starch interaction in the presence of hydrocolloid molecules, thus conferring a significantly higher softness to fresh, composite cassava–wheat bread. They also reported that crumb hardening and moisture loss followed a linear sequence up to the 1% xanthan gum level, which, therefore, was proposed as the optimum concentration to reduce both phenomena, even if the 2% xanthan gum level best estimated the crumb firming rate. Khalil et al.[46] also added that partial substitution of wheat flour by cassava flour at levels of 20% and 30% and the addition of 1% malt resulted in good-quality bread, similar to that obtained from wheat flour at an 82% extraction ratio. This was because dough stability, flour strength, and weakening of dough made of composite flours were improved by the α-amylase activity of malt. Defloor et al.,[53] on the other hand, reported that the use of glyceryl monostearate (GMS) in wheat–cassava composite dough resulted in better air uptake at the mixing stage. This can be interpreted in terms of reduction of the interfacial tension in the dough, which results in smaller air bubbles and retention of gas during the fermentation phase. This influences the pasting properties of the starch and has a positive impact on the volume and crumb structure of the bread, consequently leading to good taste and keeping qualities of the product.

Girma et al.[54] observed that water absorption levels, dough development times, the mixing tolerance index, and the farinograph quality level of cassava–wheat composite dough differs from 100% wheat dough when 20% substitution was exceeded. The increase in the values of water absorption level in the composite flour dough with an increase of cassava flour could be attributed to the higher fiber and carbohydrate contents in cassava flour. This is also because the ability of cassava flour to absorb water has a significant correlation with its carbohydrate content.[54] Contrary to the observation of Eggleston et al.,[19] Pomeranz et al.[55] reported that the increase in dough development time (the time from first addition of water to the time the dough reaches the point of greatest torque) with increased level of cassava flour substitution may be due to higher fiber content of cassava flour, which picks up water slowly. This also may be a result of the decrease in gluten content and weakening of the protein network due to proteolytic activity of composite flours.[54] It was also reported by these researchers[54] that the mixing tolerance index of cassava flour composite dough was significantly higher than that of the wheat flour dough. Owuamanam[56] found that the quality of bread from wheat–cassava composite flour could be improved by steeping the cassava in citric acid solution prior to processing. Furthermore, studies by Oladunmoye et al.[57–59] on the use of cassava, wheat, maize, and cowpea flour blends showed that less heat energy and lower baking times were needed to make wheat–

cassava composite bread, compared with wheat–maize composite bread. Nwosu et al.[60] reported that bread produced with up to 30% cassava flour and malted soybean as a bread improver was comparable to that using 100% wheat flour. This is because the sensory attributes and proximate compositions of this 30% composite bread could be compared with breads produced from 100% wheat flour. Results obtained in Benin showed that the use of cassava flour as a 15% substitute for wheat yielded bread loaves and French baguettes of the same quality as those produced using wheat flour only.[61] Another study by Shittu et al.[62] found that the use of fertilizer when growing cassava had a significant effect on the quality of bread made from composite flours of different cassava genotypes and wheat. Genotype had the most significant impact on crumb moisture content, while fertilizer use had an effect on the bread crumb texture, suggesting that it was necessary to breed for varieties that would be suitable for composite bread production. Other studies confirmed the results of Onabolu et al.[44] that substituting 20% of wheat flour with cassava flour yielded bread that was acceptable to both Nigerian and Ghanaian consumers.[63,64] In order to facilitate the production of cassava-flour-based products of consistent quality, a number of criteria for screening cassava flour prior to purchase were specified.[24, 65] These include pH (5.0–8.0), moisture content (10–12%), ash (<0.9), white color, cyanogenic potential (<10 ppm), and the absence of an unpleasant odor.

Design of cassava processing equipment

Research has been conducted on the engineering and mechanization aspects of the cassava flour–making process, especially on the design, scale-up potential, and functionality of processing equipment.[42,66–68] The efficiency of cassava grating has been improved; raising from a capacity of 0.30–0.50 t fresh root/h to 2.0–3.0 t fresh root/h. The efficiency of hammer milling has also been improved, from 0.25 to 0.40 metric ton (MT) flour/h to 5.0 MT flour/day.[69] Mechanical cassava peeling, which did not exist at all, was developed to ease the process of making cassava flour. Peelers were developed with 0.6–0.8 MT fresh root/h capacity (60–90% peel removal), as well as 8 MT fresh root/day capacity twin-basket hydraulic presses for removing water from grated cassava roots and 4 MT flour/day capacity pneumatic dryers. Although many early designs of locally produced pneumatic dryers were inefficient in terms of energy consumption and/or product quality, this newly designed dryer is well-suited for drying cassava flour.[70]

Research outputs

The technology for processing cassava roots into cassava flour has provided opportunities for smallholder farmers to experiment with new ways of accessing more profitable markets.[71] Cassava machinery and flour processing were adopted by development agencies, NGOs, and research centers as a way to increase household food security, reduce food and raw material imports, and extend market options for smallholder farmers.[72] The combined effects of the Presidential Initiatives on Cassava (PIC) in Nigeria, policy plans, and some IITA-led projects jump-started the establishment of several medium-scale cassava processing enterprises between 2005 and 2008. By 2009, the number of companies and entrepreneurs that had invested in flash dryers for high-quality cassava flour (HQCF) or starch production had increased to circa 140–150, from a mere 6 or so in the year 2000 (Fig. 1). Nearly 95% of the enterprises were for HQCF processing, with additional facilities for making traditional products such as *gari* and *fufu*.

These include the model processing plants established under the Cassava Mosaic Disease (CMD) and Cassava Enterprise Development (CEDP) projects of IITA. The capacity that existed for processing HQCF with mechanical flash dryers increased from near zero in 2003 to about 85,000 tons per year in 2009.[69] This then lead to the possibility of producing higher volumes of HQCF of a consistent quality, even during the rainy season. This was a major achievement compared with the situation during the pilot testing stage of HQCF in Nigeria, when groups of 14 small-scale processors dried HQCF in the sun.[65] Consequently, researchers engaged in a series of training exercises on cassava flour technology and established several pilot processing operations with the participation of farmers and processors (Fig. 1). Caterers, bread bakers, and biscuit manufacturers received classroom-based and practical instructions on how to use cassava flour as an ingredient. Extension officers and university scientists from more than 25 African countries were trained on cassava flour technology, with an aim to up-scaling the technology.[42,69,73]

Subsequently, the adoption of new cassava flour processing methods by smallholder farmers and the use of cassava flour by end-users were evident.[74] Recipes and baking techniques were adapted by the cassava flour end-users to the food tastes and preferences of

Figure 1. Cassava flour processors and end-users in the early stages of the technology development in Nigeria; 1999.[69] HQCF, high-quality cassava flour. Source: Food and Agriculture Organization of the United Nations 2011, Abass, A.B.; Bokanga, M.; Dixon, A.; Bramel, P., Transiting cassava into an urban food and industrial commodity through agro-processing and market driven approaches: lessons from Africa, www.fao.org/docrep/015/i2420e/i2420e00. Reproduced with permission. © Food and Agriculture Organization of the United Nations. Reproduced by permission of Food and Agriculture Organization of the United Nations. Permission to reuse must be obtained from the rightsholder.

consumers in different countries.[67,75,76] Bakers and caterers purchased cassava flour for the preparation of acceptable and appealing bread, biscuits, noodles, chin-chin, pies (meat and fish), buns, and cakes, for example, using cassava flour at between 10% and 100% to replace wheat flour.[25] Different levels of cassava inclusion in cassava–wheat flour blends for different products were established,[65] for example, cassava–wheat bread (5–25%), biscuits (10–25%), noodles (10%), cake (100%), cassava–maize *ugali* (18%), chin-chin (25–100%), fish/meat pies (10–100%), buns and fish rolls (10–12.5%), and puff-puff (10–25%).

Development outcomes

Investments

Commercial tests on the use of cassava flour by food manufacturing factories showed that this flour was suitable for various food and industrial applications such as bread, biscuits, animal feed, paperboard, brewing, and textiles.[77] These market opportunities precipitated investments in mechanized cassava flour processing in many countries, using both public and private funds.[72]

Private and public investment in small-to-medium-scale cassava processing plants increased in few countries in which pilot activities were carried out, especially in Nigeria, Ghana, and Tanzania (Fig. 2). For Nigeria and Ghana, the main factor that boosted private investment was the deliberate policy and public investments by these two countries to promote import substitution and cassava commercialization.

New designs and improved capacities of cassava processing machinery, including mechanical dryers, were produced by equipment manufacturers, thereby increasing the access of private investors to such machines to establish small–medium-scale processing plants. According to Marchant et al.,[78] there are currently about 150 mechanical dryers for cassava in Nigeria, with some having been manufactured about 6–12 years ago.[69] Flash dryers have been shown to be economical for the cassava drying process[79] and have several advantages for drying cassava over more complex gas-suspension dryers such as fluidized bed or rotary types. However, not all of the mechanical dryers for cassava flour processing in Nigeria are functional, due to low technical efficiency.[78] Similarly, a recent study of dryers being operated by cassava flour processors in Tanzania found that the energy efficiency of a tunnel dryer for cassava was only 29% and the only pneumatic dryer in the country had a 46% energy efficiency. It was suggested that improvements to the thermal insulation and decreasing the air flow rate could improve the energy performance of the dryers, without having a negative impact on the quality of cassava flour.[79]

Challenges and further research

The production of quality cassava flour on a commercial scale has been made possible through research in new cassava processing innovations, including the designs of mechanical dryers. The adoption of the new technology has created additional industrial potential for the cassava crop and has proved to have the potential to generate income for smallholders, drive domestic industrial growth that creates jobs, and reduce reliance on imported commodities such as wheat and starch among others.[80] The increased cassava processing and marketing activities witnessed within the private sector represent a shift

Figure 2. Wheat millers and cassava flour processors in Nigeria by 2010;[69] HQCF, high-quality cassava flour. Source: Food and Agriculture Organization of the United Nations 2011, Abass, A.B.; Bokanga, M.; Dixon, A.; Bramel, P., Transiting cassava into an urban food and industrial commodity through agro-processing and market driven approaches: lessons from Africa, www.fao.org/docrep/015/i2420e/i2420e00. Reproduced with permission. © Food and Agriculture Organization of the United Nations. Reproduced by permission of Food and Agriculture Organization of the United Nations. Permission to reuse must be obtained from the rightsholder.

toward commercialization, which is evolving into full industrialization, especially in Nigeria. However, the transition has led to new challenges that need to be addressed.

A considerable expansion in the cultivation of cassava roots will be required to sustain the increased demand for cassava flour among industrial users without threatening rural food security. Policy initiatives that aim to encourage the use of cassava in baking flour need to be continued in the countries in which this process has begun. Furthermore, they would need to be implemented in many other cassava growing but cash-strapped countries, to promote efficiency and competitiveness in the entire cassava value chain. Wheat flour millers and bread bakers, however, have generally been reluctant to invest in new machinery that would facilitate the use of cassava flour and produce composite flour for other uses. In Nigeria, producers are not fully satisfied with the legislation that has made cassava flour inclusion mandatory, given that the cassava flour supply is not yet adequate. There is no doubt that cassava flour processors do not yet have the capacity to supply the estimated 1.2 million tons required by the wheat flour millers in Nigeria, which themselves have up to 7 million tons of flour milling capacity per year.[80] Hence, compliance with the local content policy cannot be fully achieved.

Until recently, when monetary policy in Nigeria reversed the uncertainty in the price competitiveness of cassava flour compared with imported wheat, bakers and wheat flour mills were reluctant to make huge investments in refitting their machines for a higher quantity of cassava flour. In addition, small-scale bakers did not have the modern baking facilities in place to maintain the precise baking conditions required when using the wheat–cassava composite flour, so as to secure the quality and storability of the bread.

Furthermore, there is a perception among cassava flour processors and other value chain actors that wheat flour millers use substandard wheat grains, which lower the ability to incorporate higher quantities of cassava flour in the composite flour. On the other hand, the perception of the wheat millers is that cassava flour lowers the quality of the bread, so that the millers and bakers incur the additional cost of adding improvers such as enzymes, chemicals, hydrocolloids and gums, emulsifiers, lipids, and proteins to the composite flour. However, in addition to further research on the use of improvers, this challenge could be overcome if the local content policy also sets the minimum gluten content of wheat grain that can be imported. Compliance with this policy needs to be enforced by food regulatory agencies, as should compliance with the approved national standards for HQCF to be channeled to the wheat millers.

Indeed, the inadequate access of the private sector to the capital required to make the necessary investments, a strong consumer preference for bread made from 100% wheat flour, and the poor and inconsistent cassava flour quality are major bottlenecks to the full commercialization of cassava flour in many countries.[81,82]

In order to tackle some of these challenges, a viable option would be to maintain the local content policy and at the same time, make efforts to improve the performance of the bread baking sector by providing access to capital to acquire improved but low-cost modern bread-baking facilities. It is also necessary to train cassava flour processors and bread bakers, and to foster the ability of wheat millers to adopt cassava flour. The local content policy for bread could be modified to allow a timed, gradual increase in the amount of cassava flour used in bread, for example, in Nigeria, rising from the current level of 3% to a figure of 20% over a 10-year period.

On the technical side, there is limited scientific understanding on the retrogradation phenomenon in wheat–cassava composite bread, with respect to bread staling, which is caused by starch transformation, starch–gluten interaction, and moisture redistribution processes.[83] Starch is the main component of bread and its reorganization during aging is known to contribute significantly to bread staling.[84] Cassava starch gelatinizes easily and retrogrades slowly due to its low amylose content,[16] therefore its combination with wheat flour for bread production could reduce the staling process. This is because in the stage of dough preparation, starch absorbs up to 46% water, and it mainly acts as inert filler in the protein matrix of the dough; however, its exact role has not been completely elucidated. During baking, the starch granules gelatinize and swell, while a small amount of amylose leaches out into the inter-granular phase. In this phase, amylose is located in the center of the large granules, while amylopectin is in the outer granule layers. Some of the solubilized amylose forms inclusion bodies with endogenous or added polar lipids.[15] Immediately upon cooling, the solubilized amylose molecules start to crystallize and interlink, forming a continuous network with embedded starch granules. Thus, amylose, due to its rapid retrogradation, is an important component in bread-making and may be crucial for the initial firmness of the bread.[15] In addition, the amylopectin fraction also contributes to the crumb firming, which affects

retrogradation. There is also a dearth of knowledge on the impact of cassava substitution for wheat flour on the nutritional and health benefits of the composite bread itself, from the perspectives of possible lower protein content and reduction in the incidence of diabetics from the addition of cassava. This is because the breakdown of the amylopectin in the cassava flour by the enzyme amylase happens slowly and there is a slow deposition of sugar in the blood. From a socio-economic perspective, further research is needed to generate additional empirical evidence on the social and economic benefits, on a national scale, of the use of cassava flour by local wheat flour mills as a replacement for imported wheat. There is also a need for a cost–benefit analysis of bread produced from wheat–cassava composite flour. This might add value economically to the commercialization of cassava flour for bread and other confectionaries.

Conclusion

Values added to perishable crops such as cassava, through processing, have great potential to spur industrialization, improve household food security, increase incomes, generate employment, and reduce poverty. The case study of cassava flour processing technology in Africa, especially in Ghana, Nigeria, Tanzania, and Uganda, provides evidence of how scientific innovation can transform African agriculture and change the status of a non-tradable subsistence crop to a commercial one. Collaborative research in food science, engineering, and economics can generate technologies and market innovations that may serve as a springboard for commercialization and agro-industrial development. However, the additional lesson from the case study is that merely generating a promising technology is not sufficient to transform African agriculture or the status of a crop. Researchers must continue to address emerging constraints that may be faced by the next generation of technology users, build capacity, and continuously provide technical support, until the technology is mature and can attract private sector investment.

Perhaps the most important lesson learned is the influence of policy innovations and other financial incentives as catalysts for agro-industrial development. This is well exemplified in the case of Nigeria, where innovative policies and strategic institutional arrangement were used to boost private sector investment, leading to a rapid increase in demand for cassava flour generated from the application of cassava processing innovations. This contrasts with the case of cassava flour in Uganda, Zambia, Mozambique, and Madagascar, where despite the introduction of the technology innovations, there were little or no policy innovations and other incentives directed to support the large-scale uptake of cassava flour.

Evidently, suitable policies are needed to link national agricultural research and extension systems with private-sector participants to support the commercialization of the technologies generated through research. Lastly, there could be a reduction in import expenditure on a national scale through the substitution of imported foods and raw materials with locally grown crops.

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