

Review

Sustaining World Food Security with Improved Cassava Processing Technology: The Nigeria Experience

Peter O. Kolawole ^{1,*}, Leo Agbetoye ² and Simeon A. Ogunlowo ²

¹ Crop Processing Laboratory, Agricultural Engineering Department, Federal University of Technology Akure (FUTA), Ilesha road, Akure, Nigeria

² Agricultural Engineering Department, Federal University of Technology Akure (FUTA), Ilesha road, Akure, Nigeria; E-Mails: lasagbetoye@yahoo.com (L.A.); a_ogunlowo@yahoo.com (S.A.O.)

* Author to whom correspondence should be addressed; E-Mail: p.kolawole@cgiar.org; Tel.: +234-803-719-2399.

Received: 24 October 2010 / Accepted: 24 November 2010 / Published: 26 November 2010

Abstract: Cassava is a very important food crop that is capable of providing food security. However, a lot of problems prevent the development and use of modern equipment for its production. Most of the cassava produced still comes from peasant farmers who depend on manual tools for their field operations and these farmers have made Nigeria the world's largest producer of the crop. An increase in production of cassava to sustain the world food security needs improved machinery to allow its continuous cultivation and processing. Reasons for the low success recorded in the mechanization of cassava harvesting and processing were traced, and the attempts that have been made in the recent past by various engineers in Nigeria researching towards achieving mechanized harvesting and processing of cassava are well explained. The machinery required for cassava production in Africa, the development of new machines, and the need for more research and development in harvesting and processing machineries, which can reduce poverty worldwide and make food available and accessible for all, are also discussed. Research efforts made and the challenges facing the engineers, farmers, scientists and food processors towards achieving mechanical harvesting and processing of cassava are presented. Breeding a cassava variety with a regular shape for easy mechanization is one solution that could help the engineers worldwide.

Keywords: cassava; mechanization; food security

1 Introduction

Sustainable food security means enough food for everyone at present plus the ability to provide enough in the future. The global food security is in question today, with ever increasing food prices resulting from adverse climatic effects on agricultural production, rises in oil prices leading to increased running costs for farm tractors, increasing use of food items for other products and reduction of government spending on agriculture. The environmental sustainability has also become more elusive due to rapid industrialization, urbanization and population growth, without public realization about the effects of environmental pollution on agriculture. The economies of many countries of the world depends on agriculture that demands technological breakthroughs to lead to the required significant increase in the level of food production. Large stocks of food materials are stored up to meet exigencies. Importantly, some of the large stocks of food products might be infested; the prevention of these infestations could increase the cost of storage, though preventing the deterioration in the quality of the materials. The use of food materials for manufacturing of biofuel to meet the world energy need for industries and the transportation sector has resulted in diversion of food crops like guinea-corn, rice, maize and beans. With this, the question of food security for the increasing population has emerged. The problems of dwindling food availability and environmental sustainability will continue to aggravate because the total food production has remained constant over the last years with growing environmental and socio-economic challenges [1]. The use of biofuel may encourage a war between food and fuel. Production of biofuel may lead to a decrease in the land available for food production, thereby creating scarcity of food. There is a greater need for farmers to have access to other crops with modern and eco-friendly technologies that will ensure food security and environmental sustainability.

In the past, maize was Africa's most important food crop, however, maize production in Africa is risky due to unpredictable rainfall, and it is not financially feasible to depend on irrigation. For this reason and perceived others, Cassava (*Manihot esculenta*, Crantz) became the most important food crop in Africa. Cassava as a food crop could play a vital role in the food security of the world because of its capacity to yield under marginal soil conditions and its tolerance to drought. The crop originated in South America, where its tubers have been used throughout the ages as a basic food; from there it spread to regions of the world. It is now the most widely cultivated crop in Africa and is grown by smallholder farmers, who depend on seasonal rainfall. Cassava as a food crop might help in sustaining food security: "It is Africa's best kept secret", but efficient mechanical handling, storage and processing technologies need experts' attention.

Cassava is typically grown by small-scale farmers using traditional methods, and often on land that is not suitable for other crops. Cassava is propagated by cutting a mature stem into sections of approximately 15 centimeters and planting these prior to the wet season. These plantings require adequate moisture during the first two to three months, but are subsequently drought resistant. The roots are harvestable after six to 12 months and can be harvested any time in the following two years,

thus providing farmers with a remarkable amount of flexibility. World production of cassava root was estimated to be 184 million metric tons in 2002. The majority of production was in Africa, where 99.1 million metric tons were grown, while 51.5 million metric tons were grown in Asia, and 33.2 million metric tons in Latin America and the Caribbean. Nigeria has doubled the production of other major producers of cassava such as Thailand and Indonesia since 1990, and the country has surpassed Brazil as the world's leading producer of cassava. The total area of cassava crop harvested in 2001 was 3.1 million hectare with an average yield of about 11 t/ha. The rapid adoption of Tropical Manioc Selection (TMS) improved cassava varieties and the presence of the International Institute of Tropical Agriculture (IITA) in Ibadan has assisted Nigerian's position as a leader in cassava production. However, based on the statistics from the FAO of the United Nations, Thailand is the largest exporting country of dried Cassava, providing 77% of world export in 2005. The second largest exporting country is Vietnam, with 13.6%, followed by Indonesia with 5.8% and Costa Rica with 2.1% [2].

Cassava food items have not been paid proper attention worldwide; however, a difficulty faced in their consumption is that the process for making them edible depends on the variety. Cassava varieties are often categorized as either "sweet" or "bitter", signifying the absence or presence of toxic levels of cyanogenic glucosides. Cassava provides the livelihood for farmers and countless processors and traders as a famine reserve crop, cash crop for urban consumption, industrial raw material, foreign exchange earner, and livestock feed. Cassava production exhibits high levels of variability and cyclical gluts, due mainly to the inability of markets to absorb supplies in some countries, resulting in a decline in the price of harvested and processed roots and subsequently reduced production levels in succeeding years before picking up again. Such factors identified by IITA-Ibadan have caused price instability in Nigeria over the years, which significantly increases the income risk to producers.

The processed flour from cassava is used throughout the Caribbean. The traditional method used in West Africa is to peel the roots and put them into water for three days to ferment. The roots are then dried or cooked. In several West African countries, including Nigeria, Ghana, Benin, Togo, Cote d'Ivoire, and Burkina Faso, the roots are usually grated and lightly fried in palm oil to preserve them. The result is a foodstuff called 'Gari'. Fermentation is also used in other places such as Indonesia. South American Amerindians relied on cassava and generally understand the processing methods.

Cassava roots are very rich in starch, and contain significant amounts of calcium (50 mg/100g), phosphorus (40 mg/100g), and vitamin C (25 mg/100g). The quality of protein is relatively good [2]. According to Katz and Weaver in 2003, cassava roots are cooked in various ways in order to turn them to food. The soft-boiled root has a delicate flavor and can replace boiled potatoes in many uses: as an accompaniment for meat dishes, or made into purées, dumplings, soups, stews, gravies, *etc.* Deep frying (after boiling or steaming) can replace fried potatoes, with a distinctive flavor. Cassava flour, can also replace wheat flour. It is also used in cereals; several tribes in South America have used cassava extensively in this way. Cassava can also be used to make alcoholic beverages. In many countries, significant research has begun to evaluate the use of cassava as an ethanol. Among other industrial applications, dried tapioca are used in China as a raw material for the production of consumable alcohol and emerging non-grain feedstock of ethanol fuel, which is a form of renewable energy to substitute petrol (gasoline). In South America, cassava is used as bread, as a roasted, granular meal (*farinha*, *fariña*), as a beer (*chicha*), a drink (*manicuera*), as a vegetable (boiled or boiled

and fried). Farinha is part of a number of traditional dishes. Chicha is a mildly alcoholic beer made from both sweet and bitter cassava. Cassava is very popular in Bolivia, with the name of *yuca*, and is consumed in a variety of dishes. The capacity of cassava to be stored for a long time makes it an ideal and cheap reserve of nutrients. Recently, more restaurants, hotels, and also the general population are including cassava into their original recipes and everyday meals as a substitute for potato and bread.

Cassava is heavily featured in the cuisine of Brazil, In the Colombian northern coastal region; it is used mainly in the preparation of soups. In the Caribbean region of Colombia, it is also eaten roasted, fried, or boiled with soft homemade cheese or cream cheese and mainly to accompany fish dishes. Cassava is widely used by the Creole, Indian, Javanese, and indigenous population.

The Chinese name for cassava is *Mushu*, literally meaning “tree potato”. In the subtropical region of southern China, cassava is the fifth largest crop in terms of production. In sub-Saharan Africa, cassava is the most important food crop. In the humid and sub-humid areas of tropical Africa, cassava is either a primary staple food or a secondary co-staple.

Promoting cassava worldwide as food for both man and animal would not be difficult, but the modern harvesting and processing has some engineering constraints, causing technical, resource, socioeconomic and organizational challenges [3]. These constraints are presented here for the attention of researchers and other experts around the world. The objective of this review is to present cassava production problems that have been encountered and to show some efforts being made in Nigeria toward its mechanization. Other countries of the world have equally tried to solve their own cassava production problems, but the IITA discovered that High Quality Cassava Flour (HQCF) comes with so much challenges that donors and scientists need to assist. HQCF has the potential to solve the world food crisis, but better harvesting and processing equipment solutions are needed to solve the production problems. From cassava, there is potential to generate one crop with multiple economic benefits, capable of providing a sustainable world food security with improved post harvest handling and processing technology.

2. Current Cassava Harvest—Processing Practice in Nigeria and Its Constraints

There is a wide range of cassava products produced in Nigeria, mostly for direct human consumption after harvesting. This is because the emphasis of the promotion of cassava has been on its use as a food. The use of the crop as a basic raw material for industrial purposes would improve industry in Nigeria. The new focus of market diversification, such as the use of cassava in livestock feed, means that more maize and other feed materials used in the past can now be available for other uses. Diverse uses of cassava flour food products such as its glucose for pharmaceuticals products as well as food supplements, and to make alcohol and other beverages, would make farmers smile all the way to the bank.

There is a weak link between industrial processors and producers of cassava products that must be strengthened. The Federal government of Nigeria’s mandate to include 10% HQCF flour in all products of wheat flour for bread-making has led to farmers and food processors demanding equipment and machinery to increase production. The Raw Materials and Research Development Council (RMRDC) of the Federal Ministry of Science and Technology has organized stakeholders’ workshop on cassava research and development with discussions centered on increasing technology

for cassava production, processing and export. The need to develop adaptable machinery for cassava production and processing has become increasingly important [4].

2.1. Harvesting

The most difficult operation in cassava production is cassava harvesting [5]. Cassava is harvested by hand by raising the lower part of stem and pulling the roots out of the ground, then removing them from the base of the plant. The upper parts of the stems with the leaves are plucked off before harvest. Cassava harvesting processes include cutting of the stem about 0.3 m above the soil surface and collecting the stems as planting material. The loosening of the soil at the cassava root zone is followed by lifting the cassava root system out of the soil. Separating the root system from adhering soil could be done with special tools, before collecting tubers, loading them on to transport vehicles and transporting them as required. Existing manual harvesting techniques leads to drudgery, wastage, and also consumes a lot of time and farm labor, which is scarce and costly. Cassava harvesting is still done manually in Nigeria. Manual harvesting of cassava does not fit well with the modern processing factories; which could lead to under-utilization of the operational capacities. Freshly harvested cassava roots are bulky and the shelf life rarely exceeds two days after harvesting due to enzymatic reactions.

The problems militating against the development of a mechanical harvester for cassava are:

- 1 The indeterminate shape and geometry of the tubers in the soil at the time of harvesting makes the design of digging blades difficult.
- 2 The depth of growth of the tubers in the soil. At the time of harvesting, there is need to dig the soil to depths of between 0.25 and 0.30 m and handling about 500 kg of soil to harvest one plant of cassava, at a planting density of 10,000 plants per hectare. At least 75 kW of tractor power per row is required to achieve this. The woody nature of the stem thereby impairs the movement of workers and machinery. The tubers perish easily, especially when bruised or cut by harvesting blades. Desiccation of the soil during the dry season is detrimental to efficient harvesting of tubers. Yet tubers are harvested at any time of the year. The nature of the soil, especially in the forest areas, includes the presence of tree roots, stumps and rock outcrops. Small farm holdings and fragmentation of farmlands may not be able to afford the high power requirement of a harvester. Presently, there is no commercially available cassava harvester in Nigeria.

2.2. Processing

Roots deteriorate within three to four days after harvesting and thus are either consumed immediately or processed into a form with better storage qualities. The bulkiness and high perishability of harvested roots make immediate processing of the roots necessary. The simple processing methods available, including pounding, grating or chipping, to convert the cassava roots to acceptable products are too slow. The operations involved in cassava processing depend on the end product desired. In general, the processing stages in cassava include peeling, washing, grating, chipping, drying, dewatering/fermentation, pulverization and sieving/sifting and frying. Five distinct operations are involved in producing *gari*, and these include peeling, grating, fermentation/dewatering

or pressing, sieving (or sifting) and frying. Peeling is the first operation performed after the cassava tubers have been harvested. It involves peeling off the cassava tuber outer skin with a knife, mostly carried out by the women and children. The next stage is grating: this is done with graters, but in older times cassava tubers were grated on a piece of galvanized metal sheet, punched with about 3 mm diameter nails leaving a raised jagged flange on the underside. The grating surface was fixed on a flat wooden frame. This method is tedious and time consuming and endangers the operator's fingers. Dewatering of cassava mash is the second and most difficult operation and occurs after the peeling operation, fermentation and pressing (de-watering) are done in one operation. The grated mash is packed inside baskets, jute bags or perforated plastic sacks and left to ferment for one-to-four days. The duration of this fermentation affects the color, taste and texture of the *gari*. After fermentation is complete, the mash is pressed to reduce the water content. The traditional method of dewatering grated cassava mash involves tying and twisting the neck of a hessian sack over which heavy stones are placed for one or two days. The fermentation and pressing takes a long period to accomplish. At the village level, *gari* is fried in shallow cast-iron pans after sieving with raffia mat. The sieved cassava mash is spread thinly in the pan in 2–3 kg batches. A piece of calabash is often used in stirring the *gari* on the hot surface of the pan to prevent it burning until the frying is completed. *Gari* frying is a complex procedure, which depends on the skill of the operator. The inability to control the temperature of frying; exposure of the operator to heat and smoke from the fire; and steam from the wet cassava mash, have been major setbacks in the traditional frying of *gari*. The fried *gari* is finally spread onto mat or polythene to cool before packaging.

Since processing adds value to the cassava and also extends the shelf life, the present cassava processing methods are not good enough, and are highly labor-intensive and expensive. Manual processing requires a minimum of four person-days to peel and wash, and 23 person-days to chip one tonne of fresh cassava roots, translating to approximately US\$65 to prepare a tonne of flour. In contrast, the cost of processing cassava into flour could be approximately US\$16/t with mechanized processing [4].

Constraints

Constraints to cassava processing include the absence of efficient equipment; appropriate processing technologies, machines, and tools. These are not easily affordable and sometimes unavailable at the farm level. The currently available ones were merely fabricated without adequate engineering research. Presently, the equipment available is the grater, dryer, and dewatering machines. Some success was recorded with graters and some dewatering tools. The dewatering tools work in batches while factories need a continuously-working machine for better production. Almost all the processing of cassava requires the roots to be peeled at one stage or another, and no efficient peeler is on the market. One of the greatest constraints to cassava processing is drying, which takes up to four days to complete when using sunlight; the available dryers are expensive beyond the farmers' means. Drying is a key process for making virtually all cassava products, however, the major cassava producing zones are also those with relatively more rain and a longer rainfall period. Solar radiation is relatively low, clearly justifying the need to use modern dryers for cassava commercialization in Nigeria, which are expensive.

Making cassava production competitive—both at the domestic level and for export to world markets—requires wide research and investments into processing machine designs and development, among others. Improved processing, storage and packaging technologies to extend shelf life will go a long way toward helping the world to maintain food security; this would contribute to increasing cassava root availability and reliability, which can provide self sufficiency and also allow export to areas of the world where food is not available [5]

3. Technological Development for Cassava Harvesting and Processing in Nigeria

Engineers at home and abroad have made many attempts towards the development of cassava harvest and processing methods. These include manual and semi-mechanized/mechanized methods carried out in the farm and in laboratories.

3.1. Harvest

Manual harvesting tools such as cutlasses and hoes with some harvesting aids have been designed to assist manual harvesting of cassava. The aids include the hand-operated levers, wooden crowbars and manually operated fork-lifter. The development of mechanical harvesters for cassava started in 1932 when Cantamby tried unsuccessfully to harvest cassava using Prairie moldboard ploughs with different structural configurations. Many decades after, Makanjuola and Moldenhawer [6] experimented with four machines for harvesting cassava;

1. inverting the whole ridge and roots with a moldboard plough body;
2. pulling a moldboard share (with the board removed) below the soil level
3. using a moldboard plough to split the ridge along the crest; and
4. pulling specially designed blades (different shapes of diggers) to cut below the tubers.

Furthermore, Sharma [7] used animal- and tractor-drawn single disc ploughs and moldboard ploughs to harvest cassava. Further work on the machine led to the development of a single-row harvester with two gangs of reciprocating Power Take Off (P.T.O.) driven diggers, which digs on two opposite sides of the ridge from the furrow bottom in order to uproot the cassava root cluster [8]. Other types of machines that have been used to harvest cassava are the Ritcher harvester with wide share [9] and the Mark III harvester [10]. Peipp and Maehnert [11] reported the development of a cassava harvester utilizing the principle of combined digging of the soil and pulling of the cassava stem to harvest the plant. Harvesters have been reportedly used in large cassava plantations in Brazil, such as the CEEMAG Arm '81 harvester.

3.1.1. Soil dynamics to improve cassava harvesting

The lifting force and energy requirement are relevant criteria for the development of a cassava harvester. Based on an agro-physical parameter study of cassava roots at the time of maturity, and a review of soil disturbance systems, it was summarized that the lifting force and energy requirement for cassava harvesting can be reduced by a process of pre-lift soil loosening.

Therefore, analytical models were developed to predict the force and energy required to lift flat plates embedded in a cohesive-frictional soil. Experiments were also conducted to determine the lifting

forces and energy required to lift flat plates and model cassava roots (simulated from polypropylene ropes and cultivated dahlia plants) over two seasons to test and verify the model [12].

3.1.2. The lifting forces for cassava harvesting

An analytical model was developed based on knowledge of soil dynamics, for predicting the lifting force requirement of a flat plate submerged in the soil. The input to the model includes soil mechanical properties, namely, cohesion, angle of shearing resistance and unit weight, and also the size of the plate and depth in the soil. Predictions of lifting force were in close agreement with those obtained from soil bin experiments. Furthermore, the model was modified to take into consideration the contribution of the roots to soil shear strength and then used to predict cassava-lifting forces. A comparison between the predicted lifting forces of cassava and those obtained from a separate experiment indicated that the predicted values were significantly higher than the observed values [13].

3.1.3. Evaluation of tools for soil loosening

Loosening the soil in the root zone before lifting the tubers out of the soil is a critical step in the efficient harvesting of cassava, both in terms of reducing the lifting force and to prevent tuber damage. Therefore, three soil-loosening devices were modified for pre-lift soil loosening in cassava harvesting, and evaluated for performance in terms of soil disturbance and soil forces acting on them in a laboratory soil bin and in the field under similar soil characteristics [14]. The devices include an L-tine, A-blade, and a combination of a curved chisel tine working at a depth of 0.1 m ahead of a L-tine. Results show that of the three devices, the A-blade resulted in the least soil forces and specific resistance followed by the L-tines. Furthermore, the results indicate that the L-tines are most suitable for pre-lift soil loosening in cassava harvesting due to their simplicity of fabrication, the reduced damage to cassava roots and adjustable width. The results show that a harvester incorporating L-tines as the pre-lift soil loosening device (requiring a draught force of 18.6 kN/m) is technically feasible.

3.1.4. Force requirement of cassava roots

For the design of a cassava harvester, knowing the force required to lift cassava roots at the time of harvesting is essential. Therefore, the force required to lift cassava roots (TMS) 30572 was measured in two soil types, namely, sandy loam and clay loam, and at three moisture contents of the soil ranging from 10.2 to 19.8% [15]. The experiment also incorporated three depths of pre-lift soil loosening and direct lifting. The lifting effectiveness and the amount of physical damage to the tubers were also evaluated. Results show that the force required to lift cassava depends on the depth of soil loosening, soil type, and moisture content. Direct lifting of matured bunches of cassava roots require an average force of 1.26 kN on sandy loam and 1.49 kN on clay loam soils at a moisture content of 19.8%. By loosening the soil to half, two-thirds and the full depth of the root bunch, these lifting force values were significantly reduced.

3.1.5. Strength of cassava tubers

Strength properties are important data required to predict the behavior or resistance to damage of crop materials during mechanized harvesting. Tubers are extremely susceptible to damage during mechanized harvesting of cassava due to the application of vertical and/or horizontal force on the root by the harvesting tool. The bending strength of mature cassava roots (TMS 30572) was determined experimentally using a simple and portable device [16]. Results show that the bending strength varies along the length of the root tuber and also depends on the moisture content of the tubers. While the lower portion has an average bending strength of 5.9 N/mm², the upper portion nearest the stalk has a value of 7.1 N/mm².

3.1.6. Evaluation of a device for cassava lifting force

Implementing the harvesting of cassava tubers by mechanized methods is one of the difficulties facing cassava production. The determination of the lifting force required to harvest cassava is essential for the design of a cassava harvester. Therefore, a portable device capable of lifting one stand of cassava at a time and to also measure the maximum lifting force was designed, fabricated and tested [17]. The device consists of a lever which when pressed down at one end exerts a magnified force at the other end in order to uproot the bunch of cassava tubers. A spring balance incorporated in the machine was used to measure the maximum lifting force. The machine performed satisfactorily in lifting the tubers from two soil types, sandy loam and clay loam, with a low percentage of damage to the tubers. The percentage of damaged tubers lifted was 23.3%.

3.1.7. Status of cassava harvesting mechanization in southwestern Nigeria

A survey was conducted covering the cassava growing areas of southwestern Nigeria, namely, Ogun, Ondo, Ekiti, Oyo, Osun and Kwara, to establish the current status of the mechanization of cassava harvesting in southwestern Nigeria [18]. The information collected include farm size and distribution, farmland description, land preparation and planting methods, existing harvesting methods, destination of harvested tubers, sources and forms of tuber losses and damage during harvesting. The results indicate that farmlands are generally small (<2 hectares), and are often fragmented into units that are sometimes several meters apart. Most of the farm operations, especially harvesting, are done manually using tools such as cutlasses and hoes. Furthermore, farmers require improved practices for cassava production, especially harvesting. Such a machine developed for harvesting must be cheap and suitable for a group of cooperative farmers.

3.1.8. Some rheological properties of cassava

Experiments have been performed to determine some rheological properties of cassava [19]. The variety of cassava investigated was TMS 4(2) 1425. The properties studied include the tensile, compressive and shear strengths, elasticity and hardness. These properties were investigated under five tuber moisture content levels of 70, 65, 60, 55 and 50%. Results that were obtained show that the higher the moisture content of the tuber, the lower the tensile, and compressive and shear strength. However, the lower the moisture content, the lower the degree of elasticity. Average moduli of

elasticity of 0.50, 0.70, 0.84, 1.02 and 2.50 N/mm² were obtained at moisture contents of 70, 65, 60, 55 and 50% (wet basis), respectively. Furthermore, it has been shown that the higher the tuber moisture content, the lower the resistance of cassava to cutting and the lower the penetrometer resistance. This study has provided information that is relevant for the design of machines for cassava harvesting, processing and handling.

The development of a cassava harvester that will be suitable for use in small and large farms was under consideration with the Centre for Research and Development Centre (CERAD) of the Federal University of Technology, Akure Nigeria [20].

3.2. Processing

Processing adds value to the cassava and also extends the shelf life. The present cassava processing methods involve peeling, grating, dewatering and roasting.

3.2.1. Peeling

Peeling is the first operation performed after the cassava tubers have been harvested and mechanized. The peeling method is yet to be fully developed due to factors that include the irregularity in the shape of the cassava tuber. Attempts have been made by engineers, including the National Centre for Agricultural Mechanizations (NCAM), whom developed the abrasive peeler machine [21]. Perhaps the most successful motorized cassava peeler was exhibited and demonstrated by the Federal University of Technology, Akure, (FUTA), Nigeria. The peeler was awarded a prize for outstanding innovative design. With the development of a functional peeling machine, the mechanization of cassava processing will be further enhanced. Other contributions have also been reported [22].

3.2.2. Grating

The next operation after cassava tubers peeling is grating. Mechanized cassava graters have been designed and are replacing manual grating in many locations in West Africa, where *gari* is produced. A typical cassava grater consists of a wooden drum rotor of about 250–300 mm in diameter, covered with a perforated tin sheet. These are usually powered by electric motors or diesel/petrol engines, which save time and are less injurious than manual grating methods.

3.2.3. Dewatering

Presently, the common practice of mash dewatering with a mechanical press is by using either hydraulic jacks or a bolt screw and plate ram to apply pressure to woven polythene sacks that contain the grated cassava mash. Such a device was designed by Babatunde [23]. It reduces the time needed for dewatering and reduces the likelihood of accident. However, a lot of improvements are still required. To this end a study was conducted [24] to evaluate the parameters affecting the dewatering of cassava mash during processing. The IITA TMS 4(2) 1425 variety of cassava at three levels of maturity (age of 9, 12 and 15 months) was utilized in the study. The dewatering pressure from a hydraulic jack was used to press the grated mash. The dewatering parameters investigated were pressure drop, face area of the filter medium and mash resistance. The results showed that mash

resistance varied with the cassava tuber harvesting age. The medium resistance also varied with the cassava age. The Kozemy constant value for the TMS 4(2) 1425 variety of cassava was found to be 11,400,000 and Porosity 0.0181; the result presents the distribution and values of identified parameters numerically for equipment designers' use. This result has led to further research in developing equipment for cassava mash handling by the same authors.

3.2.4. Sieving

After pressing, the de-watered cassava mash is a solid cake, which has to be broken up and sieved to remove the large lumps and fiber and to obtain homogenous product. Uniform particle size is important because it makes for a more uniform roasting of individual particles during the frying operation. Indeed, smaller particles take less time and energy to roast; sieving the final product of *gari* ensures uniformity of the product. *Gari* is first sifted after de-watering in order to remove the fiber (ungrated cassava pieces). In the final re-sieving, the *gari* product is separated into chaffy, fine, coarse and medium size fractions. This is done after the frying operation. The texture and consistency of processed cassava food products is an important consideration throughout sub-saharan Africa [25].

3.2.5. Roasting/drying

Frying and bagging are the final operations in *gari* processing. The sifting is done by rotary sifter and toasting operations can be done with an automated *gari* fryer. These newly developed machines can save *gari* producers from the hassles and drudgery that comes with the final phases of the production of this popular staple in Nigeria. This innovation was done in the agricultural engineering department of the Obafemi Awolowo University (OAU), Ile Ife.

Processing of cassava into its products such as chips and pellets requires machines such as peeling and washing machines, chipping machines, dryers and packaging equipment. Many of the machines are not available in commercial quantities on the market. The development of these machines—including their commercial manufacture to feed the rapidly expanding processing factories—is essential.

4. Recommendations (Cassava Mechanization Improvement Plan)

All research findings and available data from our laboratory can still not solve the farmer's problems, unless these results are converted to physical solutions. Most of the developed prototypes are rotting away in schools without investors' knowledge. The development of indigenous harvesting and processing machines for cassava is critical for the efficient mechanization of cassava production. Even though numerous efforts have been made to develop a suitable harvester for cassava, the fact that there is no commercially available harvester on the market implies that the mechanization problem of cassava harvesting remains unresolved. Furthermore, there is no existing complete process line for any of the cassava products in the market. These problems can only be solved through a collaborative work among all the stakeholders in cassava production including the farmers, the agronomists/scientists, the design engineers and tuber processors, research institutes, the Universities and the government.

The ways out should include the following:

- a. The farmers should improve on their current cultivation practices to enhance mechanization of production operations including harvesting.
- b. The agronomists should come out with improved varieties suitable for mechanized harvesting such as varieties with predictable shape, geometry, depth and spread of growth in the soil.
- c. The design engineers and processors should start again from fundamental principles such as studies in soil dynamics, soil disturbance mechanisms, engineering properties of roots relevant to tuber damage, development of adequate blade shape for digging, *etc.*, in order to generate design data for the development of harvesting and processing machines.
- d. Research institutes, educational institutions and government establishments should be empowered by international donors to develop machines for cassava harvesting and processing.
- e. A complete process line for each cassava product should be developed (in this regard, the National Agency for Research and Engineering Infrastructures (NARSENI) has begun collaborative work with our university Federal University of Technology Akure (FUTA) for the development of a complete package for cassava processing).
- f. In developing machines for cassava harvesting and processing, special attention should be directed at the small-scale farmers who still produce the greatest amount of cassava in Nigeria. For example, a cassava harvester that is powered by a small tractor suitable for small farms and affordable by individuals may be a good starting point for the mechanization of cassava harvesting.
- g. The government should provide funds for research into cassava harvesting and processing mechanization.
- h. Private sectors of the economy should show more interest and commitment in the development of not only cassava harvesting and processing machines, but also machines for harvesting and processing other tropical root crops.

5. Conclusions

Agricultural equipment innovations are relevant in transforming livelihoods in Africa. Cassava is a food security crop and a major provider of employment and income [26]. The crop is choice to farmers because of its affordability, ease of cultivation, and high return on investment. Apart from the stems, cassava roots and leaves are now offering additional income streams to farmers. More attention by way of support to research will go a long way in sustaining farmers' interest. More importantly, cutting down postharvest losses through investment into processing technologies and the creation of an appropriate policy framework are necessary to sustain cassava's role in ensuring food security. Cassava deteriorates in quality when the tubers are bruised; hence the development of mechanized harvesting system should be complemented by an adequate farm-processing factory-market transportation system. Even when the tubers are to be processed, adequate measures need to be considered to ensure preservation of their quality. Cassava processors can then respond to the growing urban demand for foods that are more convenient such as bread made with cassava flour; a better method of cassava flour production, using machines, will translate to reduced human effort, reduced time and improved quality.

This paper is an effort towards sustaining world food security; authors from other cassava producing nation are encouraged to present their efforts on cassava to serve in development of appropriate technology required for cassava processing. Global economic changes, in particular the downswing in the world economy with its accompanying effects on developing countries, call for interest in improving cassava processing technology to save other grains and other forms of food from disappearing. Cassava is a good hunger fighter that should be given the needed attention worldwide.

References

1. GursharanSinghKainth. *Food security and sustainability in India*, 2010. Available online: <http://www.merineews.com/article/food-security-and-sustainability-in-india/15787915.shtml> accessed on 12 July 2010)
2. Katz, S.H.; Weaver, W.W. *Encyclopedia of Food and Culture*; Schribner: New York, NY, USA, 2003.
3. Nweke, F.I.; Spencer, D.S.C.; Lynam. J.K. *The Cassava Transformation: Africa's Best Kept Secret*; Michigan State University: East Lansing, MI, USA, 2002; p. 273.
4. *Agricultural Statistics*; Food and Agricultural Organisation of the United Nations: Rome, Italy, 2002.
5. Agbetoye, L.A.S. Engineering challenges in developing indigenous machinery for cassava production and processing. In *Proceedings of the Annual Conference of the Nigerian Society of Engineers (Lagelu 2003)*, Ibadan, Nigeria, 8–12 December 2003; pp. 80-86.
6. Makanjuola, G.A.; Moldenhawer, A. Mechanised cassava production investigations in Nigeria. In *Proceedings of the ASAE Meeting*, Martin, TN, USA, 1984; pp. 24-27.
7. Sharma, A.P. Studies on mechanical harvesting of cassava in Fiji. *Agric. Mech. Asia Afr. Lat. Amer.* **1979**, *10*, 39-41.
8. Odigboh, E.U. A single-row model I Cassava harvester. *Agric. Mech. Asia Afr. Lat. Amer.* **1991**, *22*, 63-66.
9. Kemp, D.C. Harvesting: A demonstration of two machines—Cassava harvesting and processing. In *Proceedings of a Workshop Held in CIAT*, Cali, Colombia, 24–28 April 1978.
10. Johnson, I.M.; Kemp, D.C.; Payne, P.C. Mechanisation of cassava production. In *Proceedings of the International Workshop in Bangkok*, Bangkok, Thailand, 6–9 December 1989.
11. Peipp, L. The development of a technical solution to cassava harvesting problem. *Agric. Mech. Asia Afr. Lat. Amer.* **1992**, *23*, 33-36.
12. Agbetoye, L.A.S; Dyson, J.; Kilgour, J. Application of soil dynamics to the improvement of cassava harvesting. In *Proceedings of Second International Conference on Soil Dynamics*, USDA-ARS National Soil Dynamics Laboratory, Auburn, AL, USA, 23–27 August 1994.
13. Agbetoye, L.A.S. The lifting force requirement of cassava roots. *Proc. Nigerian Soc. Agric. Eng.* **1998**, *20*, 212-222.
14. Agbetoye, L.A.S.; Kilgour, J.; Dyson, J. Performance evaluation of three pre-lift soil loosening devices for cassava root harvesting. *Soil Till. Res.* **1998**, *48*, 297-302.
15. Agbetoye, L.A.S. The lifting force requirement of cassava roots. *Proc. Nigerian Soc. Agric. Eng.* **1998**, *20*, 212-222.

16. Agbetoye, L.A.S. The bending strength of cassava tubers. *J. Sci. Eng. Technol.* **1998**, *6*, 1800-1808
17. Agbetoye, L.A.S.; Onakoya, M.F. Performance evaluation of a device for measuring cassava lifting force. *Afr. J. Sci.* **2002**, *3*, 625-641.
18. Agbetoye, L.A.S. A survey of the status of cassava harvesting mechanization in Southwestern Nigeria. *Ann. Agric. Sci.* **2004**, *3*, 52-59.
19. Agbetoye, L.A.S.; Kolawole, O.P. A study of some rheological properties of cassava (*Manihot esculenta*, Crantz.). *J. Eng. Appl.* **2002**, *4*, 14-36.
20. Agbetoye, L.A.S.; Ademosun, O.C.; Ogunlowo, A.S. Olukunle, O.J.; Adesina, A. *The Development of Cassava Harvester for Use in Nigeria*; Research Proposal Submitted to CERAD for Alhaji (Dr.) Mala Kachal Research Grant in Agriculture: Abuja, Nigeria, 2005.
21. Agbetoye, L.A.S. Developments in Cassava harvesting mechanization. *West Indian J. Eng.* **1999**, *22*, 11-19.
22. Ogunlowo, A.S. *Appropriate Agricultural Mechanisation Technologies: Bedrock for Industrial Renaissance in Nigeria*; Inaugural Lecture Series Number 34; Federal University of Technology: Akure, Nigeria, 2003; p. 52.
23. *Research Highlights*; International of Tropical Agriculture: Ibadan, Nigeria, 1978.
24. Babatunde, O.O. Design of a model dewatering press for gated cassava mash. *J. Agric. Technol.* **1999**, *7*, 8.
25. Kolawole, O.P.; Agbetoye, L.A.S.; Ogunlowo A.S. Cassava Mash Dewatering Parameters. *Int. J. Food Eng.* **2007**, *3*, Article 4.
26. IITA. Bulletin Issue No. 2026 19–23 July 2010; Available online: <http://www.iita.org/cms/curBulletin/bulletin.pdf> (accessed on 19 July 2010).

© 2010 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/3.0/>).