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Trends at Mechanizing Cassava Postharvest Processing Operations

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ABSTRACT

The recent transfiguration of cassava from a low profile into an industrial raw material, coupled with the new cassava revolutionary policies of the Federal Government of Nigeria have resulted in a serious surge in the demand for cassava and cassava-based products locally and the world over. However, cassava processors are currently finding it extremely difficult to respond positively to this increase in demand due to the prevalence of the traditional processing methods employed in the processing operations. This has made the review of the current processing technologies imperative in order to address the areas requiring technical improvement and further research efforts towards the evolution of cost effective technologies with improved efficiencies which would enhance the capacity to exploit the cassava market potential the world over. Therefore, this paper reviews the presents status of knowledge as regards cassava processing technology and a critical appraisal of the existing cassava processing technologies available to cassava processors and highlights the research need towards the evolution of better and improved cassava processing equipment.

Keywords: *Cassava, processing, engineering properties, tuber age, postharvest*

1. INTRODUCTION

Cassava, (*Manihot esculenta,crantz)* is a tuberous starchy root crop of the family *Euphorbiaceae* (Kochlar, 1981). It is a popular crop worldwide. It is known for drought tolerance and for thriving well on marginal soils, a cheap source of calories intake in human diet and a source of carbohydrate in animal feed (Kordylas, 2002). It is believed to be originally native of South America. It grows well in areas with annual rainfall of 500-5000mm and full sun, but it is susceptible to cold weather and frost (Agodzo and Owusu, 2002). Thus, it is commonly grown in all the tropical countries of the world, mostly in Brazil, Indonesia, Nigeria, Zaire, Congo, Uganda, Ghana, and the Democratic Republic of Congo etc. A very wide range of cassava varieties are grown worldwide depending on the locality, but they are broadly classified into the sweet and the bitter varieties based on the level of the poisonous hydrogen cyanide (HCN) present in the tuber. They are also classified based on time to maturity. Most of the traditional varieties mature in eighteen months and beyond but, some new improved cassava varieties have been developed by the International Institute for Tropical Agriculture which matures as early as six months after planting. They are high yielding, more resistant to pest and diseases, with cyanide contents as low as 3.1mg/100g, (Ikuomenisan, 2001).

Nigeria is by far the highest producer of the crop in the world with production level estimated at 49 million tons per year (Uthman, 2011). This is a third more than the production in Brazil (The world's second largest cassava producer). And almost double the production of Indonesia and Thailand.

Until recently, cassava was primarily produced for food as it is consumed on daily basis in different forms and often times more than once a day. Its importance as a major cheap source of calorie intake for both human and livestock in many tropical countries has been widely acknowledged. It is mostly processed, traditionally, into *gari, lafun, fufu, abacha and akpu* in Nigeria, and, *kokonte* and *agbelima* in Ghana (Quaye *et al.*, 2009) while the sweet varieties are boiled and pounded into dough and consumed with vegetable soup.

It is presently the most important food crop in Nigeria from the point of view of both the area under cultivation and the tonnage produced due to the fact that it has transformed greatly into high yielding cash crop, a foreign exchange earner, as well as a crop for world food security and industrialization. As a result of this there has been an unprecedented rise in the demand for cassava and its numerous products worldwide for both domestic and industrial applications (Adetunji and Quadri, 2011). The world import demand for cassava in 2004 stood at 25 million tons while the local demand by poultry farmers alone was 400,000 tons. The 180 million litres yearly domestic demand for ethanol in Nigeria was met through importation in 2005 (Nigeriafirst, 2011). The Federal Government recent directive that flour millers must substitute 10% of the wheat flour with cassava flour (Olukunle, 2005), has also led to a surge in demand to the tune of 600,000 tons of processed cassava per day, apart from orders from abroad for semi-finished cassava products in the form of chips and pellets. All these facts are pointers to the fact that opportunities abound in the area of cassava processing, but, these opportunities cannot be fully exploited using the traditional processing methods currently in use in the country which is generally adjudged as arduous in nature, labour intensive, time consuming and unsuitable for large scale production (Adetan *et al.,* 2003; Quaye *et al.,* 2009; Agbetoye, 2005). The present situation in the country whereby limited quantities of cassava-based product are exported is due largely to the inability of such products to meet the international standards for healthy foods (Adetunji and Quadri, 2011), which could be attributed to the unwholesome and unhygienic features of the traditional processing methods being used. Thus, a review of existing technologies for processing cassava into its various semi and finished products is pertinent. Therefore the objective of this paper is to review the efforts made, and currently being made towards an efficient and cost effective mechanization of cassava postharvest processing operations so as to address the challenges being faced in the quest to fully exploit the numerous benefits of cassava crop.

2. THE PROBLEM STATEMENT

Freshly harvested cassava roots starts deteriorating almost immediately after harvest and can only last for three days. This is due to its high moisture content of about seventy percent (Ngoddy, 1989). The best form of preservation and reduction of post harvest losses is therefore immediate processing into various shelf stable products such as gari, chips, pellets etc. Alternatively, farmers prefer to delay harvest of the tubers until it is actually needed, thereby leaving it in the ground for up to two years and beyond since it stores well in-ground and effort at developing modern storage technologies to store cassava tubers beyond few days is still on-going. Processing cassava into finished or semi-finished products often involves all or some of the following operations, depending on the desired end-products; peeling, washing, grating/chipping, dewatering/fermentation, pulverizing, sieving, pelletizing, and drying/frying. Up till now, most of these operations are still being done manually, and they are generally labour intensive, arduous in nature, time consuming and unsuitable for large scale production (Adetan *et al.*, 2003; Quaye *et al.*, 2009), due to their low output capacity among other negative attributes, although some levels of success have been recorded in the areas of grating and dewatering (Davies *et al.*, 2008; Adetunji and Quadri, 2011).

Mechanization of cassava processing operations will no doubt play a pivotal role in removing the negative attributes of the traditional processing techniques and promote timely large scale processing of the tubers in hygienic environment. Mechanizing cassava processing operations requires the design and development of equipment such as cassava peelers, graters, chippers, dewatering machines, pelletizers, dryer etc. Several attempts have been made at solving these problems which resulted in the development of various types of cassava peeling machines (Odigboh, 1976; Ezekwe, 1976, 1979; Nwokedi, 1984; Ejovo *et al*., 1988; Itodo, 1999; Sheriff *et al.*, 1995, Ariavie and Ejovo, 2002; Olukunle *et al.*, 2005; and Olukunle and Ademosun 2006); various types of cassava grating machines (Akinyemi and Akinlua, 1999; Akande *et al.*, 2005); various types of cassava chipping machines (Raji and Igbeka, 1994; Bamgboye and Adebayo, 2009) etc. However, most of these machines have been widely acknowledged as being inefficient (Adetan *et al*., 2006; Davies *et al*., 2008; Kolawole *et al.*, 2010). A major constraint is the poor quality of the products from these machines and poor efficiencies of the technologies. Some of the problems with these machines include peeling off of unacceptable percentage of useful flesh during mechanical peeling, reduction in peeling efficiency with increased time of operation, production of grated cassava mash or cassava chips with uneven (particle) sizes resulting in varying and low product qualities between processors and even from the same processor. The dewatering mechanism (hydraulic jack) only increases the processing (dewatering) capacity per batch but still takes the usual longer time to dewater to acceptable moisture content thereby allowing fermentation. Imported dryers as an alternative to sun-drying is too costly while locally fabricated flash dryers are yet to be efficient (IITA, 2006).

3. PRESENT STATUS OF CASSAVA POSTHARVEST TECHNOLOGIES

Cassava processing operations are often preceded by peeling which makes a very important operation. However, no efficient cassava peeler is presently in the market (Ejovo *et al*., 1988; Adetan *et al*., 2003; Agbetoye, 2005). Attempts at mechanizing the peeling operation was acknowledged not to be fully developed yet (Kolawole *et al.*, 2010) and this is attributed to the irregularity in the shape of the tubers as well as the wide variations in the thickness of the peel, tuber size and weight across the different varieties of the crop (Adetan *et al.*, 2006; Kamal and Oyelade, 2010). Odigboh (1976) also listed the period of the year that the tuber is harvested and the time that lapsed before peeling is carried out after harvesting as some of the factors causing wide variations in the peel characteristics of the tubers.

Most of the research efforts at developing a suitable peeler have concentrated on the use of abrasive drum to achieve the peeling (; Ezekwe, 1979; ; Nwokedi, 1984; Odigboh, 1988). However, a common problem with these set of machines is the fact that a tuber may be reduced to a uniform cylinder with considerable wastage of useful flesh before satisfactory peeling could be achieved. Nwokedi (1984) even reported a peeling efficiency as low as 45% but was able to achieve a better performance with sized root lots.

Ejovo *et al.*, (1988) developed a rotary batched cassava peeler that worked based on a novel peeling concept involving compression of the unpeeled tuber against a sharp-edged rig and rolling off the peels without disturbing the tuber flesh (peel-flesh separation through compression). Although, a peeling efficiency of 92% was reported with zero flesh loss, the tubers had to be sliced into straight segments before being fed into the machine. They, however, pointed out that the stage of maturity of the roots greatly affected the performance of the machine. Adetan *et al.* (2005) also designed and fabricated an experimental mechanical cassava peeler using this concept following the characterization of some properties of the root which they earlier reported (Adetan *et al.*, 2003). In 2006, the authors developed and validated a model with data from the peeling machine. The model was able to predict the peel removal efficiency of the machine with a certainty level of 95.46%.

Odigboh (1976) had however earlier attempted the development of a continuous flow peeler consisting of a solid cylinder mounted parallel to another 'cylinder' of knives which peeled the tubers as they traverse the length of the cylinders in-between a 20mm space. The results showed that much of the useful flesh of the large roots was wasted where the tubers were completely peeled while the smaller roots were incompletely peeled. Better results were obtained only when the roots were cut into slices. Although the author pointed out wide variations in the physical properties of the roots with age, he did not report putting this into consideration in the process of designing the peeler. This also did not reflect in the performance evaluation of the machine.

Akintunde *et al.* (2005) also designed a cassava peeling machine that worked based on abrasive drum principle. The machine was designed such that the tubers were soaked in water prior to the peeling operation. During the peeling operation the tubers were held in-between two rotating drums with abrasive surfaces. Peeling was achieved when the two drums were rotated in opposite directions. They reported a peeling efficiency of 83.0% and an average percentage flesh loss of 5.4% but the peeling efficiency of the machine reduced with increase in the speed of rotation of the drums while the percentage flesh loss increased with the speed of drums as well as peeling time, hence, the machine had to be operated at a slow speed which consequently affected its throughput capacity adversely (as low as 35kg/hr). The poor performance of the machine may due to the force required to bring about peeling which was not actually used in the design calculation instead the report appear to have based the calculation on the torque needed to peel cassava and an arbitrary values seemed to have been used.

A collaborative work between IITA and FUTA in 2005 was reported by Agbetoye (2005) to have resulted in the development of a single and double gang hand-fed peeling machine which peels by using a rotary brush. It gave an efficiency that was less than 80% and useful flesh waste of more than 8% with unsatisfactory output capacity which the authors describe as unacceptable. The machines' output per day was reported to be dependent, among other things, on the variety and stage of maturity (age) of the tubers (Olukunle *et al.*, 2010). This also underscores the need for an in-depth study of the properties of the tubers with emphasis on the influence of age and variety. A self-fed version of the machine reported by Olukunle *et al.* (2010) also required that the tubers were trimmed into slices longer than 10cm otherwise they were poorly handled. A peel retention as high as 16% was also reported for the self-fed peeler which makes it unsuitable for end products like *gari* and high quality cassava flour.

Apart from the peelers, various types of cassava grating machines have been developed (Akinyemi and Akinlua, 1999; Akande *et al.*, 2005), likewise cassava chippers (Kodylas, 1990; Ajibola *et al.* 1991; ; Balasubramanian *et al.*, 1993; Kurup *et al.*, 1995; Bamgboye and Adebayo, 2009; Igbudu, 2009). While a modest success have been recorded in the development of cassava graters and chippers, including (pressers) other postharvest operations such as washing, slicing, drying and frying are still predominantly undertaken manually (Davies *et al.*,2008). One of the shortcomings of the existing graters is that the grating mechanism gets blunt easily and does not give smooth products (Quaye *et al.*, 2009). The modest success may not be unconnected with the fact that almost all the publications on the design and fabrication of cassava processing equipment rely solely on previously published data on the engineering properties of the root which may have been haphazardly determined while trying to develop the machine since data from in-depth studies are scarce. For instance, Bamgboye and Adebayo (2009), while designing their cassava chipper used a value of 0.68 for the coefficient of friction of cassava on mild steel as previously used by Ashaolu (1989) in the design of a cassava chipping machine. This value is almost double the 0.363 value reported by Ejovo *et al*. (1988) for cassava flesh on mild steel. They also used a shear strength value from the work of Igbeka (1985) which has been found to be in wide variation from all other values published on the same subject matter. The influence of tuber moisture content was also not considered during the design and performance evaluation. This probably accounted for the 60% efficiency of the machine so designed using these data. Worst still, Akande *et al.* (2008) did not even use any mechanical property data in the design of their manually operated cassava chipping machine. They only design for the size of the shaft carrying the chipping plate. Even, most of the existing machines were merely fabricated without adequate engineering research (Kolawole *et al*., 2010). This manifest in the frequent need to replace the bearings, belts and grating mesh, which is compounded by serious vibration, as revealed by Davies *et al.* (2008) while presenting the results of a survey on the availability and level of adoption of cassava processing machines in Osun State. Another major problem is the different particle sizes obtained from the various types of graters (Igbeka *et al.*, 1992; Onyekwere *et al*., 2006), and constant breakage and damage of the roots during these operations which sometimes exceed 10% (Odigboh and Ahmed 1982; Ajibola *et al.*, 1991). Fish and Trim (1993) have also identified wide variation of cassava chips' size, perhaps from various cassava chipping machines, as a major problem encountered with cassava chips' production and drying.

Other unit operations involved in cassava processing include dewatering of cassava pulp (mash), drying (of chips, *lafun*, mash for flour production, etc) and frying (for gari production) which are still majorly carried out manually with the attendant negative attributes (Ajibola, 1987; Igbeka, *et al.*1992; Nweke 1994; Kolawole *et al.* 2007a). Traditionally, grated cassava mash is dewatered by filling it into sacks and placing it under heavy materials like big stone, iron etc. This operation has, however, been improved upon by the hydraulic and the screw jack mechanism whereby piles of bagged cassava mash are slowly compressed with the jacks. The failure of the machine by frequent worn out of the screw (Davies *et al.*, 2008; Quaye *et al.*, 2009) or the deformation or complete breakage of the cross bar as a result of the high pressure experienced daily by the hydraulic press is an indication that necessary engineering properties of the crop, such as cassava cake resistance in the form of reaction to the action of the jack, was not factored into the design. This problem may not be unconnected with the fact that most of these machines were developed using engineering property data that were reported by others which may either be unsuitable or haphazardly determined and insufficient to form a reliable data-base for the scientific design and development of these machines (Adetan *et al.*, 2003). Research publications are scanty on the study of relevant engineering parameters for the dewatering of cassava pulp.

Ajibola (1987) studied the important parameters in the dewatering of grated cassava mash by applying heavy weights on the grated mash and concluded that the equilibrium moisture content of the grated mash was only affected by the applied pressure. Kolawole *et al.* (2007a) in a similar study, however, concluded that the resistance of the filtering medium and that of the cake resulting from the pressing operation were those necessary to be overcome for a successful dewatering operation. They further established a relationship between the pressure applied, mash thickness and moisture recovery from pressing which showed that a close interaction of parameters such as area of dewatering container, porosity and permeability of the grated mash combined to formed the resistance.

Olusegun and Ajiboye (2010) also designed and tested a motorized double screw vertical compression cassava pulp dewatering machine with two power screws positioned a distance apart being the main feature of the machine. The top half portions of the power screws were made to be right-handed while the bottom half portions were made to be left-handed such that each portion of the screws carried a wooden platform that moves towards each other when the screws were powered by the 7.5hp motor connected to them through the use of bevel gears, thus compressing the bag of cassava pulp placed in-between the two platforms to press out the moisture in the cassava pulp. The machine was able to reduce the moisture content of cassava pulp to an average of 30% from 80% moisture content in less than 35 minutes, which translates into an average throughput capacity of 400kg/hr. The machine appear good but the 7.5hp electric motor used to power the machine suggested that it is not cost effective since affordability is critical to the adoption of any new technology (Quaye *et al.,* 2009) considering that most cassava processors are rural peasants. The local capacity for repair and maintenance of the machine as well as the cost implication on profit margin could definitely discourage its adoption apart from the fact that the machine was designed from the mechanical engineering view point which only concentrated on the machine factors without any consideration for the material (cassava pulp) the machine was meant to work on. The average final moisture content of 29.85% and 33.6%of the samples tested with machine may not give a good *gari* product as a moisture content range of 40-45% was recommended by Kolawole *et al.* (2007c).

Adzimah and Gbadam (2009) also modified existing grater and press into a single automated unit using two side crank mechanisms in combination with chain drives, gears and springs. The tubers were pressed against a rotating perforated plate by the side crank mechanism and caused the tubers to grate. The centrifugal force developed by the grating plate throws the grated mash into the pressing unit where it was pressed against a spring-loaded gate. When a set pressure level is attained in the pressing chamber the side crank mechanism in the forces the spring-loaded gate open to push out the pressed cake. The machine seems good but complex for the a typical local setting for prompt repair and maintenance in times of breakdown and this could adversely affect its adoption by the rural processors who are, according to Quaye *et al.* (2009) very sensitive to issues relating to repair and maintenance when taking decisions on the adoption of any new technologies.

Fish and Trim (1993) carried out a review of research into the drying of cassava chips. They reported that the bulk of cassava chips world-wide are sun dried with drying time of 2-3 days. No evidence was found of mechanical drying of cassava chips on a commercial scale. The few locally designed dryers were developed for specific food materials like grains, fish etc and are not available in the market (Akor and Zibokere 2002). Iwoha (2004) developed a solar cassava dryer with stone provided in it as a heat reservoir. It has the capacity of drying 50kg of chips on a clement-weather day.

Some moisture-dependent engineering properties of cassava mash during drying for *lafun* production were also studied by Faborode *et al*. (1992) and he reported a general non-linear decrease in bulk density, coefficient of friction and emptying angle of repose as drying progressed. Also, Igbeka (1980) studied the relationship between moisture content, temperature and diffusion coefficient of cassava during drying and he concluded that moisture diffusion followed an Arrhenius relationship with respect to temperature. He further developed an equation relating the diffusion coefficient to the moisture content and temperature of the chips and to the relative humidity of the drying air coupled with a model to describe the moisture gradient within the thickness of a cassava slab drying from only one surface, using a finite difference approach. It was however noted that most of the above results reported by Igbeka were experimented with the sweet variety of cassava, which may or may not be applicable to the bitter or the improved varieties since wide variation in features (or behaviour) have been widely reported across varietals divides.

Okpala *et al.* (2003) also studied the drying characteristics of cassava slices and concluded that the drying characteristics of cassava generally had no constant rate period, but two falling rate periods, the second being slower that the first and that drying is controlled by liquid diffusion. In a survey conducted by Davies *et al.* (2008) to assess the level of acceptability of cassava processing technologies in Iwo Local Government of Osun State, Nigeria, in terms of availability of the machines, cost of acquisition and cost of maintenance revealed that operations such as peeling, washing, chipping, slicing, drying and frying were still being done predominantly by manual methods. High cost of acquisition and cost of maintenance were cited as some of the reasons for the low level of adoption of the technologies. Rusting, tearing and wearing of the grating mesh as well as serious vibration and frequent need to change the bearings were also cited as common problems of the garters even though the spare parts were readily available with most of them adulterated. Thread of the screw type cassava dewatering presses easily got worn-out while the hydraulic jack type often spills it oil through the plunger casing. The few sifting machine found during the survey had low efficiencies as the sieves got clogged and rusty easily thereby requiring frequent replacement

A similar survey conducted by Quaye *et al.* (2009) in Ghana reported similar problems with the machines. The survey which set out to determine the adoption requirements for some cassava processing technologies vis a viz cassava graters, pressers, improved stoves for *gari* and High Quality cassava flour (HQCF) production, revealed the factors that end-users consider before adopting new technologies as affordability of the technologies in term of cost implication on the profit margin of the user, efficiency of the machine, number of labour required to operate the machine as well as simplicity or otherwise of the machine to enhance or impair local capacity for repair and maintenance of such technologies were listed as some of the considerations often made for adopting a new a new cassava processing technology which most of the existing machines currently lack.

4. RESEARCH NEEDS

4.1 Engineering Properties of Cassava Roots

The need to design and develop efficient and cost effective machines and equipment for cassava postharvest processing and handling operations cannot be over emphasized, given the present global status of the crop as a foreign exchange earner, crop for food security and an important industrial raw material. However, the design and development of equipment and processes for these purposes solely depends on thorough understanding of the engineering properties of the root, but cassava-based researches have focused more on its production than processing (Kolawole *et al.*, 2010). This, perhaps, accounts for the reason why advances in cassava processing technologies lag behind its production. A good knowledge of the engineering properties of the root is, however, germane to a successful mechanization of its postharvest handling and processing operations (Adetan *et al.*, 2003). This is pertinent as earlier reports by Odigboh (1976) revealed that over 200 different varieties of the crop are planted in all the cassava planting areas of the world, each with its unique features. More clones of cassava have recently been added by the IITA, Ibadan and the NRCRI, Umudike, which are high yielding, resistant to diseases and pests, and early maturing, among other positive traits. These desirable traits are being exploited by the farmers which probably accounted for the present position of Nigeria as the world leading cassava producing nation (Kolawole *et al.*, 2010). This, consequently, demands an expansion of the frontier of knowledge on the engineering properties of the tubers since no two varieties exhibit similar properties (Odigboh, 1976), hence a follow up study of the engineering properties of these new varieties is imperative for a successful effort at mechanizing cassava postharvest operations.

Several researchers have made attempts on the engineering properties of cassava while trying to develop cassava handling and processing equipment. Odigboh (1976) determined some physical properties of some cassava varieties whose particular identities were not declared while trying to develop a continuous flow cassava peeler. Properties such as the roundness, shape and tuber weight were determined. He reported that many varieties (over 200) are grown in the tropics with each of them yielding roots with wide variations in their physical properties including the shape, with cross sections having a mean roundness ranging from 0.65-1.00. The tuber weight reported ranged from 25g to 4,000g with conical shaped tubers predominating. All these properties were reportedly dependent on the age of the tubers at the time of harvest as well as the time of the year when the roots were harvested. This was only an observation because the experiment was actually carried without conscious effort at studying the effects of age on these properties.

In 1981, Asoegwu determined the stress relaxation modulus and creep compliance of cassava tubers he thought necessary in the design of cassava harvesting technologies, and these parameters may not be completely relevant in the design of processing equipment. Ejovo *et al*. (1988) also determined some physical and mechanical properties of cassava such as the tuber length, weight diameter, peel thickness, Poisson ratio and, coefficients of friction and rolling resistance. Others were shear stress, peeling stress, cutting force and rupture stress. They reported that the coefficient of friction of cassava on wood ranged from 0.404-0.663, the values of this property on mild steel ranged from 0.364-0.577 while the values ranged from 0.213-0.404 on aluminum surface. They also reported some values of coefficient rolling resistance of cassava root on wood, mild steel and aluminum surfaces as 5.57-8.73; 5.27-9.38 and 4.71-7.80 respectively. However, like the earlier researchers, limited number of specimens was used to study most of these parameters. For instance, these authors used only three specimens each to determine the five mechanical properties studied. Also, the study did not take into account the influence of moisture contents, tuber age and cassava specie, but they later concluded that their results might have been influenced by the stage of maturity of the tubers used in testing the machine produced with the data so generated. In addition to age (as pointed out by the authors) the influence of moisture content may be very significant. The authors, while comparing results, reported that their values of shear stress ($3.22 N/mm^2$ and $0.28\ N/mm^2$ for unpeeled and peeled tubers respectively) were closer to the 0.676 - $9.6 N/mm^2$ reported by Odigboh (1983) but in wide variation to the 21.8 – $87 N/mm^2$ reported by Igbeka (1984) which they claimed were yet to be corroborated by any research results. It is however, noteworthy that the frictional properties reported by Ejovo *et al*., (1988), though limited as they were in terms of number of samples used and scope, they are yet to be refuted or corroborated by any other research publications.

Adetan *et al.* (2003) also published an extensive work on the physical properties of cassava where they reported that the percentage by weight of peel ranged from 10.6-21.5%, peel thickness ranged from 1.20-4.15mm, root diameter ranged from 18.8-88.5mm while the peel penetration force per unit length ranged from 0.54- 2.30N/mm. The values of the peel proportion by weight were reported to be in reasonable agreement with, but slightly higher than the range of 0.085-0.17 reported by Ezekwe (1979). However, an improvised tool (soil penetrometer) which was manually loaded was used to measure the peel penetration force of the tubers. This casts aspersion on the reliability of the reported values. Better and more reliable results could be obtained with more sensitive equipment.

Furthermore, Kolawole *et al.* (2007b) studied some strength and elastic properties of cassava root using TMS 4(2) 1425 cassava clone and reported that the tubers were stronger under tension than compression at higher moisture contents than at lower ones. The values ranged from 0.235 to $0.116 N/mm^2$ and 0.065 to $0.095 N/mm^2$ for tensile stress and strain respectively in the moisture content range of 50-70% (wb) while values ranging from

0.080 to 0.047N/mm^2 and 0.032 to 0.093N/mm^2 were reported for compressive stress and strain respectively. Values ranging from 0.187 to 0.112 and 0.140N/mm^2 to 0.048N/mm^2 were also reported for shear stress and strain respectively. They observed a positive relationship between the strength properties (tensile and compressive) of cassava and its moisture contents, whereas, Nwagugu and Okonkwo (2009), after determining the compressive strength of a sweet type of cassava reported a negative relationship between compressive strength and moisture content. Maximum compressive force values of 499N and 274N were reported for compression along and across the cassava fibre directions respectively. In both separate studies, only one cassava variety was used and they were not the same.

Njie *et al*. (1998) studied the thermal properties of cassava, yam, and plantain as a function of moisture content at temperatures near 30^{o}C and moisture contents between 18 and 70% wet basis. They reported thermal conductivity values ranging from 0.16 to 0.57 Wm^{-1} ^{o}C and a positive relationship between thermal conductivity and moisture content of samples of cassava. A similar trend was observed for specific heat capacity and moisture content with values ranging between 1.636 and 3.275kJ Kg^{-1} ^{o}C^{-1}. The specific heat also increased with increase in temperature. The thermal diffusivity of cassava, however, initially increased but later decreased with decrease in moisture content. The average values ranged from 0.79 to 1.66 x 10^{-7}m^{2}s^{-1}.

In all the reported works on the engineering properties of cassava to date it is observed that in most cases, the studies were not conducted with respect to the influence of moisture and age on the studied properties while in some, only one cassava specie was used. More importantly, most of the reported data were unsuitable and insufficient to form a data base for the engineering properties of cassava as exemplified in the work of Igbudu (2009) where only one sample was used to determine the force required to make chips from cassava tubers. This may evidently be part of the reasons for the modest breakthroughs recorded so far in the development of appropriate technologies for the postharvest handling, processing, and transporting of cassava.

4.2. Effects of Age on Engineering Properties of Cassava Tubers

Cassava roots are considered ripe as from the age of 12 months after planting, but are often left in the ground beyond a year ((Odigboh, 1976; Ngendahayo and Dixon, 1998; Sriroth *et al*., 1999). At times they are left in the ground up to two years because it can continue to grow for years due to its perennial nature. The main reason for this practice is the problem of poor storability of cassava roots after harvesting, (Ngeve, 1995) whereas, its quality is sustained when left in-ground up to 24 months and beyond. Even though this common practice among cassava farmers has some advantages such as easy and flexible harvesting time, year round availability of the crop etc., one of its greatest shortcomings is that the roots become more fibrous and woody with time. Besides, many previous studies have reported the influence of age on tuber yield, dry matter and starch accumulation, culinary quality of cooked roots, as well as the quality and physico-chemical properties of the starch and flour produced from them (Moorthy and Ramanujam 1986; Ntawuruhunga *et al*., 1995; Ngeve, 1995; Ngendahayo and Dixon 1998; Defloor *et al*., 1998; Sriroth *et al*., 1999; Chatakanonda *et al*., 2003; Chotineeranat *et al*., 2006; Apea-Bah *et al*., 2011;).

In a study conducted by Obigbesan and Agboola (1973) it was reported that root size continued to increase with age even when left in the soil beyond 24 months. Kolawole *et al*., (2007a) actually studied the influence of tuber age on the dewatering parameters of grated cassava mash and concluded that the 15 months old samples compressed more than the 12 and 9 months old samples. However, other researchers (Odigboh, 1976; Ejovo *et al*., 1988; Adetan *et al*., 2005) only observed that the tuber age might have influenced their results but they never made conscious efforts at studying the effects that the age could actually have on the engineering properties of the tubers.

Also, in their study, Sriroth *et al*., 1999 reported that the age of root considerably influenced the starch granule size, granule structure, granule size distribution and hydration properties. The granule size distribution changed from normal to bimodal distribution with increase in tuber age, implying that the structural and functional properties of cassava tubers could be influenced by the age of the root.

Apea-Bar *et al*., (2011) also reported a significant influence of tuber age on cassava flour yield, crude protein and ash content of the resulting flour reducing with time while Chotineeranat *et al*.(2006) reported that roots with different ages exhibited different levels of chemical compositions and cyanide content and thus resulted in the production of flour exhibiting different levels of cyanide contents depending on the age of the tuber used.

Ngeve (1995) while presenting the results of the investigation into the cooking properties/quality of some cassava clones in Cameroon reported that all the clones investigated would cook when harvested at the age of 8 months after planting beyond which some of them, classified as ‘non-cookable’, would not cook while the cooking time of the ‘cookable’ clones increased with increase in age of the roots. This corroborated the findings of Moorthy and Ramanujam, (1986) who had earlier reported a similar observation.

5. CONCLUSION

From the foregoing, a serious death of research publications on the studies of the influence of age on the engineering properties of cassava tuber is apparent even though a lot has been reported on the effects of age on many of the properties of the starch and other by-products produced from its roots and in spite of the acknowledgement of some of the earlier researchers of a possible influence of tuber age on the engineering properties of the root. This implies that little is presently known about cassava in relation to the influence of tuber age on its engineering properties. Most of the earlier works on the engineering properties of cassava were either conducted using one cassava variety most of which were not of the same clone, or they were determined using crude methods or insufficient number of samples that cannot be said to be representative of the characteristics of the crop, hence the need for an in-depth study of the influence of age and variety in addition to the engineering properties of the roots.

REFERENCES

[1] Adetan, D. A, Adekoya L. O and Aluko, O. L. (2003), Characterization of some properties of cassava root tubers. Journal of Food Engineering. 59: 349-353.

[2] Adetan, D. A., Adekoya, L. O., Aluko, O. L and Makanjuola, G. A. (2005), An experimental mechanical cassava tuber peeling machine. Journal of Agricultural Engineering and Technology,l 13: 27-34.

[3] Adetan, D. A, Adekoya L. O and Aluko, O. L. (2006), Theory of a mechanical method of peeling cassava tubers with knives. International Agrophysics, 20: 269-276.

[4] Adetunji, O. R. and Quadri, A. H. (2011), Design and fabrication of an improved cassava grater. Pacific Journal of Science and Technology, Vol.12, No.2, pp. 120-129.

[5] Adzimah, S. K and Gbadam, E. K. (2009), Modification of the designs of cassava grating and cassava dough pressing machines into a single automated unit. European Journal of Scientific Research, 38 (2): 306-314.

[6] Agbetoye L. A. S. (2005), Improving the technology of cassava harvesting and processing mechanization for food security in Nigeria. Paper presented at the International Conference on Science and Technology, Held at the Federal University of Technology, Akure, Ondo State, Nigeria, August 14-19, 2005. Pp 196 – 204.

[7] Agodzo, S. K and Owusu, F. A. (2002), Crop coefficient determination of a six-month variety cassava. Journal of Agricultural Engineering and Technology. 10: 1- 6.

[8] Ajibola O.O. (1987), Mechanical dewatering of cassava mash; Transactions of American Society of Agricultural Engineers, 30 (2): 539-542.

[9] Ajibola O. O., Faborode, M. O., Salami, T. K and Okpe, B. S. (1991), Development of a cassava chipping machine. Proceedings of the 9th Symposium of Tropical Root Crops in a Developing Economy. Accra, Ghana, 20-26.

[10] Akande, F. B., Adebayo, A. O and Busari, R. A. (2008,. Design, fabrication and testing of manually operated cassava chipping machine. Proceedings of the Nigerian Institution of Agricultural Engineers, Adamawa. Pp1-14.

[11] Akintunde, B. O., Oyawale, F. A and Tunde-Akintunde, T. Y. (2005), Design and fabrication of a cassava peeling machine. Nigerian Food Journal. Vol. 23, pp 1-8

[12] Akinyemi J. O., Akinlua O. and Okunaya, A. O. (1999), Design and testing of a cassava grater. International Journal of Tropical Agricuture, 17 (14): 103-108.

[13] Akor, A. J and Zibokere, D. S. (2002), Design and development of a universal dryer. Agricultural Mechanization in Asia, Africa and Latin America (AMA). Vol. 33 (4): 65-69.

[14] Anonymous, (2005), Cassava initiatives in Nigeria. http//www.nigeriafirst.org. Accessed in March, 2007.

[15] Apea-Bah, F. B., Oduro, I., Ellis, W. O. and Safo-Kantanka, O. (2011), Factor analysis and age at harvest effect on the quality of flour from four cassava varieties. world journal of dairy and food sciences, 6 (1): 43-54.

[16] Aravie, G. O. and Ejovo, O. N. (2002), Improved Ohwovoriole's rotary cassava tuber peeling machine. Nigerian Journal Engineering Research and Development, vol. 1(2): 61-63.

[17] Ashaolu, M. O. (1989), Design and construction of cassava chipping machine. Unpublished MSc. Project Report, Dept. of Agric. Engineering, University of Ibadan, Ibadan.

[18] Aseogwu, N. S (1981), Determination of some mechanical properties of cassava root. (*manihot esculentar cranz*). Msc. Thesis, Unviersity of Ife, Ile-Ife.

[19] Balasubramanian, V. M., Sreenarayanan, V.V., Visvanathan, R., and Balasubramanian, D. (1993), Design, development and evaluation of a cassava chipper. AMA 24(1): 60-64.

[20] Bamgboye, A. I and Adebayo, A. O. (2009), Development of a motorized cassava chipping machine. Science Focus 14(2); 262-272.

[21] Chatakanondaa, P., Chinachotia, P., Sriroth K., Piyachomkwan K., Hotineeranat, S., Tang, H. and Hills, B. (2003), The influence of time and conditions of harvest on the functional behaviour of cassava starch—a proton NMR relaxation study. Carbohydrate Polymers, 53: 233- 240.

[22] Chijindu, E. N., Boateng, B. A. Ayertey, J. N., Cudjoe, A. R. and Okonkwo, N. J. (2008), The effects of processing methods of cassava chips on the development of *prostephanus truncates* (Horn). African Journal of Agricultural Research, 3(8): 537-541.

[23] Chotineeranat, S., Suwansichon, T., Chompreeda, P., Piyachomkwan, K., Vichukit, V., Sriroth, K., and Haruthalthanasan, V. (2006), Effect of root ages on the quality of low cyanide cassava flour from Kasetsart 50. Kasetsart J. (Nat. Sci.) 40:694-701.

[24] Davies, R. M., Olatunji, M. O and Burubai, W. (2008), Mechanization of cassava processing in Iwo Local Government Area of Osun State, Nigeria. World Journal of Agricultural Sciences, 4(3): 341-345.

[25] Defloor, I., Dehing, I. and Delcour, J. A. (1998), Physico-chemical properties of cassava starch. Starch/Starke 50: 58-64.

[26] Ejovo O. N, Oboli, S and Mgbeke, A. C. C. (1988), Studies and preliminary design for a cassava tuber peeling machine. Transactions of the American Society of Agric. Engineers,31(2): 380-385.

[27] Ezekwe G. O. (1976), A feature for achieving a constant depth of peel in the mechanical peeling of cassava. Nigerian J. Engrg. 1(3): 174 – 181.

[28] Ezekwe G. O (1979), Mechanizing cassava peeling. The Project Development Agency (PRODA) cassava nibbling machine. PRODA Technical Reports, No1, Sept. pp.1-20.

[29] Faborode, M . O., Gbadegesin, A. B., Olotu, O. M. and Eboreime, O. K. (1992), Steeping and drying characteristics of maize and cassava and their products. Nigerian Food Journal, 10: 51-60.

[30] Fish, D. M and Trim, D. S. (1993), A review of research into the drying of cassava chips. Tropical. Science. 33:191-208.

[31] Igbeka J. C (1980), Relationship of moisture diffusivity with moisture content and temperature in cassava (*manihot escutenta*) and potato (*solarium tuberosum*) during drying. Nig. Journal of Science.14:27-26.

[32] Igbeka J. C., Jory, M. and Griffon, D. (1992), Selective mechanization for cassava processing. Agricultural Mechanization in Asia, Africa and Latin America. Vol. 23 (1): 45-50.

[33] Igbeka, J. C (1984), Some mechanical and rhelogical properties of yam and cassava. African J. of Science and Technology 3(2): 45-60.

[34] Igbeka J.C. (1985), Mechanization of tuber (cassava) peeling. Proc. Int. Symp. Mechanization of Harvesting and Subsequent Processing of Agricultural Products in Tropical Africa and the Manufacturing of Relevant Agricultural Implements, 11-15 February, Younde, Cameroun.

[35] Igbudu, O. S. (2009), Design and construction of a cassava chipping machine. African Journal of Engineering Research and Development, Vol. 2(1): 24-29.

[36] IITA. (2006). IITA annual report.

[37] Ikuomenisan, O. E (2001), Design and Construction of Cassava Chip Dryer. Unpublished Project Report. Department of Agric. Engrg. University of Ilorin.

[38] Itodo, I. N. (1999), Peeling rate of a manually-operated cassava *(Manihot esculenta Crantz)* peeling machine. African Journal of Root and Tuber Crops, 3(2): 3-7

[39] Iwuoha S. I. (2004), The design and development of a three-glass solar flat plate collector dryer for cassava chips preservation. International Research Journal in Engineering Science and Tech (IREJEST) vol.1 (3): 1-6.

[40] Kamal A. R and Oyelade, O. A. (2010), Present status of cassava peeling in Nigeria. Journal of Agricultural Engineering and Technology, Vol. 18 (2): 7-13.

[41] Kochlar, S. L. (1981), Tropical crops: A textbook of economic botany. Macmillan Publishers Ltd, pp 467.

[42] Kolawole O. P and Agbetoye, L. A. S. (2007a), Engineering research to improve cassava processing technology. International Journal of Food Engineering. Volume 3 Issue 6. Article 9 Page 1 – 2.

[43] Kolawole O.P., Agbetoye, L. A. S and Ogunlowo, A. S. (2007b), Strength and elastic properties of cassava tuber. International Journal of Food Engineering, Volume 3, Issue 5, Article 17. Page 1 – 10.

[44] Kolawole O.P., Agbetoye, L. A. S. and Ogunlowo, A. S. (2007c), Cassava Mash Dewatering Parameters. International Journal of Food Engineering. Vol 3(1). Article 4.

[45] Kolawole O.P., Agbetoye, L. A. S. and Ogunlowo, A. S. (2010), Sustaining world food security with improved cassava processing technologies: The Nigerian experince. Sustainability, 2: 3681- 3694

[46] Kordylas, J.M. (2002), Processing and preservation of tropical and sub-tropical foods. Macmillan Education Ltd., London

[47] Kordylas, J. M (1990), Industrial processing of roots and tubers. In; Processing and preservation of Tropical and Sub-Tropical foods. Macmillan Publishers Ltd. pp. 91-108.

[48] Kurup, G. T., Sheriff, J. T. and Nanda, S. K. (1995), Development and testing of a pedal operated cassava chipping machine. J. Root Crops. 21(1): 7-11.

[49] Moorthy, S. N. and Ramanujam, T. (1986), Variation in properties of starch in cassava varieties in relation to age of the crop. Starch/Stärke 38, 58-61.

[50] Ngendahayo, M. and Dixon, A. G. O. (1998), Effect of varying stages of harvest on tuber yield, dry matter, starch and harvest index of cassava in two ecological zones in Nigeria. In: root crops in 21st century. Proceedings of the 7th Triennial Symposium of the ISTRC-AB (M. O. Akoroda and J. M. Ngeve Eds). Cotonou, Benin, pp 661-667.

[51].Ngeve, J. M. (1995), Effects of location and age at harvest on yield and culinary qualities of cassava (Manihot esculenta Cranz). In: Root crops and poverty alleviation. Conference of the 6th Triennial Symposium of the ISTRC-AB. (M.O Akoroda and I.J. Ekanayake Eds). Lilongwe, Malawi. Pp 22-28.

[52] Nigeriafirst, (2011), www.nigeriafirst.org. Accessed in 2012.

[53] Njie, D. N., Rumsey, T. R. and Singh, R. P. (1998), Thermal properties of cassava, yam and plantain. Journal of Food Engineering, 37: 63-76.

[54] Ntawuruhunga, P., Ojulong, H. and Dixon, A. G. O. (1995), Genetic variability among cassava genotypes and its growth performance over time. In: root crops and poverty alleviation. Proceedings of the 6th Triennial Symposium of the ISTRC-AB (M. O. Akoroda and I. J. Ekanayake Eds.) Lilongwe Malawi. pp242-248.

[55] Nwagugu, N. I. and Okonkwo, W. I. (2009), Experimental determination of comprehensive strength of sweet cassava (*manihot esculanta*). International conference of West African Society of Agric. Engineers and Nigerian Institution Agric. Engineers, Page 191 – 197.

[56] Nweke, F. I (1994), Processing potentials for cassava production growth. Collaborative Study of Cassava in Africa (COSCA) Working Paper No. 3, IITA, Ibadan, Nigeria.

[57] Nwokedi, P. M (1984), Performance evaluation of cassava peeling machine. In: Tropical root crops: Production and uses in Africa, E.R Terry, E.U. Doku, O.B Arene and N.M Mahungu (eds) Int. Development Research Centre, pp. 108-110.

[58] Obigbesan, G. O. and Agboola, A. A. (1973), An evaluation of yield and quality of some Nigerian cassava varieties as affected by age. 3rd international Symposium. Tropical Root Crops, IITA, Ibadan, Nigeria.

[59] Odigboh, E. U. (1976), A cassava peeling machine: development, design and construction. Journal of Agric. Engineering Research, 21, 361-369.

[60] Odigboh, E. U. and Ahmed, S. F. (1982), Design of continuous process gari frying machine. Proceedings of the Nigeria Society of Engineers, 6 (2): 65-75.

[61] Odigboh, E.U. (1983), Cassava production, processing and utilisation. In: Handbook of Tropical Foods, New York: Mercel Decker Pub. Inc., pp. 145-200.

[62] Okpala, K. O., Orga, A. C. and Onyelucheya, O. E. (2003), Drying kinetics of cassava slices. Nigerian Drying Symposium Series, 1, pp 1-14.

[63] Olukunle, O. J, Ogunlowo, A. S. Agbetoye, L. A. S, and Adesina, A. (2005), Development of a self-fed cassava peeler (model A). Journal of Agricultural engineering and Environment Department of Agricultural Engineering, Federal University of Technology, Akure, pp.39-42.

[64] Olukunle, O. J. (2005), Development of a cassava peeling machine. Abstract Proceedings of the International Conference on Global Food and Product Chain. – Dynamics, Innovations, Conflicts and strategies. *'Tropentag 2005'*, University of Hohenheim Stuttgart, Germany, pp.54.

[65] Olukunle, O. J. and Ademosun, O. C. (2006), Development of a double action self-fed cassava peeling machine. Journal of Food, Agricultural and Environment (JFAE), vol. 4: 3-4.

[66] Olukunle, O. J., Ogunlowo, O. S. and Sanni, L. (2010), The search for effective cassava peeler. The West Indian Journal, vol. 32, Nos. 1 and 2, pp 42-47.

[67] Olusegun, H. D. and Ajiboye, T. K. (2010), The Design, construction and testing of a vertical squeeze cassava pulp dewatering machine. International Journal of Engineering and Applied Sciences. Vol. 2 Issue 1. Pp 27-43.

[68] Onyekwere, O. O., Oyewole, O. B and Ngoddy, P. O. (2006), Cassava processing and utilization in Nigeria. A Federal Institute of Industrial Research, Oshodi, (FIIRO) Publication

[69] Quaye, W., Gayin, J., Yawson, I. and Plahar, W. A. (2009), Characteristics of various cassava processing methods and the adoption requirements in Ghana. Journal of Root Crops, vol. 35 No.1, pp. 59-68.

[70] Raji, A. O. and Igbeka, J. C. (1994), Pedal operated chipping and slicing machine for tubers. Journal of Agric. Engineering and Technology, vol.2, pp 90-99.

[71] Sheriff, J. T., Kurup, G. T and Nanda, S. K. (1995), Performance evaluation of cassava peeling machine. J. Root Crops 21(1): 30-35.

[72] Sriroth, K., Santisopasri, V., Petchalanuwat, C., Kurotjanawong, K., Piyachomkwan, K., and Oates, C. G. (1999), Cassava starch granule structure - function properties: infuence of time and conditions at harvest on four cultivars of cassava starch. Carbohydrate Polymers, 38: 161-170

[73] Uthman, F. (2011), Design and fabrication of cassava lump breaking and sieving machine. Oasis Journal of Research and Development, 1(2): 42-50.