PERFORMANCE EVALUATION OF A DOUBLE ACTION SELF-FED (DASF) CASSAVA PEELING MACHINE

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CERTIFICATION

We certify that this work was carried out by Ayoade Oladele ATERE in the Department of Agricultural Engineering, Federal University of Technology, Akure, and that it has not been submitted elsewhere.

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DEDICATION

I will like to dedicate this project to my mother, my father, Phillips Ademola Abiodun Atere (deceased) and also to God Almighty, my maker.

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There are many people who invested in the success of this project who must be, and should be, acknowledged. Without them I would not have been able to meet the stringent demands of my life and still provide the quality information that was essential to this kind of project.

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ABSTRACT

The performance evaluation of a Double Action Self-Fed (DASF) cassava peeling machine was carried out at the Federal University of Technology, Akure. The aim was to investigate the effects of size of tuber (Φ) and speeds of rotary auger and peeling brush (V) on the performance of the machine.

Machine and crop parameters such as size of tubers and speeds of operation were varied in order to determine their effect on the peeling process. A 10 kg weight of cassava was fed into the inlet hopper. The speeds of the auger and the rotary brush, and time taken for peeling were recorded. The weight of peeled tubers and the peel weight (plus tuber portion which was removed together with peel). Each experiment was replicated five times.

Result showed that minimum peeling efficiency of 20% was observed in class I tubers of length between 15-20 cm, whereas a maximum of 90% was observed in class III tubers of length between 31-40 cm at the auger:brush speed ratio 1000:1400. Tuber size significantly influence peeling efficiency and peel retention at probability levels of 0.001 and 0.003, respectively. The Least Significant Difference (LSD) test revealed that peel retention was significantly different between classes I and III, and classes II of length between 21-30 cm and III. Models fitted, to explore the individual and combined effects of tuber size and speed on the machine performance, showed that tuber size alone explained about 75%, 8% and 67% of the variations in the efficiency, tuber loss and peel retention, respectively.

Furthermore, the multiple linear regression models combining both variables (tuber size and speed) significantly influence machine performance with R^2 of 0.945 for efficiency and 0.941 for peel retention. The economic analysis of DASF revealed that about ₦ 1900 could be saved per ton of cassava over manual peeling. This study provides useful information for design modifications, which would improve the performance of automated peelers.

NOMENCLATURE

M_s = weight of sample, kg

M_{pc} = weight of peel collected through careful peeling, kg

p = proportion of peel by weight in the root

M_b = weight of cassava before machine peeled, kg

M_{pt} = weight of tuber after machine peeled, kg

M_{pr} = weight of peel remaining on the tuber after machine peeled, kg

M_c = weight of completely peeled tuber, kg

M_{pf} = weights of peel plus tuber removed by the machine, kg

M_{pa} = weight of peel collected through the peel outlet of the machine, kg

M_p = weight of peel only, kg

M_f = weight of tuber portion removed by machine along side with peels, kg

η = peeling efficiency

ℓ = tuber loss

μ = peel retention

S_1, S_2, S_3 = speeds ratio of operation, rpm

Φ = tuber size, cm

V = brush speed, rpm

β_0 = model constant

β_n = coefficient of the variables

x_n = explanatory variates (n = 1-3)

LSD = Least Significant difference, SD = Standard deviation

ANOVA = Analysis of variance

CHAPTER ONE

1.0 INTRODUCTION

Cassava (***Manihot esculenta Crantz***) is a perennial shrub grown by planting a cutting from the mature stem. It is a crop tolerant of drought and infertile soils and can produce tubers as from 5 months, depending on the variety. Its processing is becoming a daily affair in Nigeria where the crop has been adopted as a major staple. Several unit operations have been mechanized successfully. However, peeling remains a global challenge to design engineers. This is due to variations in physicomechanical properties of cassava, which are borne out of the existence of many cultivars of cassava, and variation in climate as well as the cultural practices employed in the production of the crop. To this end IITA in conjunction with the Federal University of Technology, Akure initiated the search for an effective cassava peeler in 2005.

Peeling which is defined as "to strip off the skin" is an important operation in the processing of any tuber or root crop. Cassava peeling mechanization has come a long way from the conventional knife to modified knifes; to the more recent automated cassava peeling machines. However, the challenges of cassava peeling are still scaring.

1.2 Existing Peeling Machines

Different researchers and industries have come up with different prototype models of mechanical peelers. A continuous cassava peeler was developed by Odigboh (1976). It consists of a cylindrical knife assembly and a solid cylinder, mounted parallel and 20 cm apart on an inclined frame. The tubers are cut into slices and introduced through the feed channel. The two cylinders are rotated clockwise at different speeds with the knife assembly rotating at a higher speed. The tuber pieces rotate and the knives on the knife assembly progressively peel them as they move down the inclination. The throughput rate averages 18 kg/h but the rate depends on the size of roots. Odigboh (1985) further presented a modified version of a continuous cassava peeler, which operates only with cassava roots cut into 100mm long pieces and introduced lengthwise through a feed channel. He claimed a peeling efficiency of 95% at 135 kg/h.

Igbeka (1985) recommended the use of abrasive belt in a continuous cassava peeler. It operates with cut tuber slices and requires that the slices be near circular in shape. This same method was also reported by Ezekwe (1975).

In France, Bertin Limited has built a cassava-peeling machine (Martin, 1985). Its capacity is claimed to be 350 kg/h of tuber. The tuber is first sliced into four equal longitudinal quarters in a slicing machine and each slice is introduced, with the peel side up, into the peeling machine. CEEMAT is also working on this machine (Jory, 1989) and has a lower capacity (about 200 kg/h).

Another peeler, a batch process cassava peeling machine was developed by Odigboh (1979). A cylindrical drum with abrasive inner surfaces was eccentrically mounted on a shaft and the eccentric movement of the cylinder causes the tuber to rotate and tumble thus peeling the tubers. The modified model, that is the cylinder was replaced with an eccentrically mounted drum, which is rotated at a low speed of 40 rpm, and as it rotates, water is sprayed unto the tubers. This causes complete peeling of the tubers due to the abrasive action against the inner surfaces of the drum with negligible loss of useful tuber and hard trimming was virtually eliminated at about 180 kg/h throughput irrespective of the size and shape of tuber.

Makinde (1985) developed a peeler for yam, which can be adapted for cassava. The peeler consists of a hopper for the yams, a platform for feeding the yam, the peeler disc and a power transmission source (bicycle or pedal operation using chain and sprocket arrangement). The peeling mechanism consists of four peeling blades, peeler ring and peelers drum. The wooden hopper is loaded with yam tubers and some of these tubers are placed on the platform for easy reach of the operator during the operation of the machine. The operator selects yam tubers from the wooden platform and directs its pointed end towards the peeler. As the operator pedals, the peeler drum rotates and the yam tuber comes in contact with the abrasive surface of the blade and peeling commences. The yam tuber moves linearly due to pressure exerted by operator while rotation of the peeler drum and subsequently peeler ring causes the yam to rotate. The arrangement of the four blades of the peeler is such that 5 mm of the yam's skin is peeled in each revolution of the peeler ring.

Odesanmi (1988) designed a batch process abrasion cassava peeler. The peeler consists of a drum eccentrically mounted on a shaft rotating at 40 rpm. Two abrasives were used independently viz: - glass and expanded metal to determine the peeling effect on cassava roots.

Ohwovoriole *et al.* (1988) developed a preliminary design for a continuous process cassava tuber peeling machine based on the principle that if a cut is made on a tuber and the peel is held down or fixed, then the whole peel would "unwind" as the tuber is rolled especially when it is fresh. The machine consists of a fixed outer frustum of a cone, which is made up of a small circular end plate, a big circular end plate and a rotating inner cylinder.

Sherrif *et al.* (1995) evaluated a cassava peeler developed at Tamil Nadu Agricultural University (TNAU); Coinbatore has developed a nine-quintal per hour capacity cassava peeler. The TNAU model cassava peeler comprised of a rotor of 25 cm diameter and 30 cm length. The cutting blades, which scrape off the tuber surface during its operation, have been mounted along the circumference of the rotor with a blade angle of 50^0. However, the performance of the machine was in general, high peeling efficiency was associated with high tuber loss. The capacity, the peeling efficiency and peel retention were claimed to be 549 kg/h, 59.33% and 0.572 respectively.

Ayeni (2000) developed a rotary drum cassava peeler that consists of a drum eccentrically mounted on a shaft. Louver glass was used as an abrasive to achieve the peeling. The louver glass were held tightly to a galvanize plate with araldite and plates closely tightened to the drum by screws and nuts. A centrifugal pump with constant pressure and water flow rate is fitted to one end machine and connected to a series of jets arranged along skin and adherent dirt.

Akintunde (2002) designed and fabricated a machine to peel cassava tubers to a depth of 3 mm. It is electrically operated and the peeling operation is bath process. The machine is loaded before the electric motor is started and the machine is operated using the abrasive peeling mechanism while the power is transmitted through belt-pulley mechanism. The machine consists of two abrasive cylinder drums (the inner drum having an abrasive outer surface while the outer drum has an abrasive inner surface), a shaft for rotating the drums, and a frame on which other components are mounted. The frames on which the drums are mounted are at an angle to the *horizontal*. Akintunde (2002) reported an average peeling efficiency of 83.0% and average tuber loss of about 5.38% for the machine.

1.3 Trend of Cassava Peeling Machine Development at the Federal University of Technology Akure

Olukunle and Adesina (2004) developed a hand fed cassava peeler in the Agricultural Engineering Department of the Federal University of Technology, Akure, Ondo State, Nigeria. It uses abrasive brush (Figure 5, Appendix 1), 120 mm diameter, 150 mm long mounted on a 25 mm shaft. The machine receives power from a 5 hp Honda petrol engine rotating at 200 to 3000 rpm. It consists of a protective hood to prevent splashing of dust and peels on the operator. The hood serves as a guide to direct the peel into the delivery chute. The machine drive system consists of belt-pulley mechanism with a speed ratio of 1:1 between the drive and the driven pulley. However, variation in speed can be achieved by throttling the engine. The cost of the machine was estimated at 750 US Dollars. The machine has a capacity of 8 tons/day and performs the dual role of peeling and grating.

An improved model on the above called model A and B was further developed by the same author by incorporating an automatic tuber feeding system. The machine was tested under various crop, machine and operational conditions. The machine was first demonstrated at the International Institute of Tropical Agriculture (IITA), Ibadan. The result shows that the peripheral speed of the brush influences the peeling efficiency greatly for all tuber sizes. The higher the peripheral speed, the greater the peeling efficiency within 500 to 1500 revolutions of the peeling brushes per minute.

Beyond this range, resident time of tuber within the chamber and clearance between the peeling brush and the guiding brush have significant effect on peeling efficiency. Auger speed and resident time of tuber in the chamber are inversely related. The higher the auger speed the lower the resident time of tuber in the chamber. At 50 rpm auger speed, peeling efficiency was highest for all variations in brush speed. Thus, it is desirable to keep auger speed low which in turn increases tuber contact with the peeling brush. However, the author observed that the major problem with the design include poor contact with peeling brush for tubers less than 10 cm in diameter, adjustment of peeling chamber not feasible during machine operation and optimum resident time not yet obtained.

Furthermore, Olukunle *et al.* (2005) did an appraisal of two models of hand fed and two models of self fed cassava peeling machines. This was done in order to determine the strengths and weakness of the previous designs. Particular attention was placed on the global trend in the development of cassava/tuber peeling machine. Further improvement was done on the existing models of the self-fed cassava peeling machine. Major area of improvement include, increase in the length of the peeling brush from 30 cm to 100 cm and automatic adjuster for a range of cassava tuber sizes. The machine, model C (Figure 6, Appendix I) was also tested under various crop, machine and operational conditions. The effect of brush type, speed and orientation on efficiency of the peeling process was determined. The result of the project was intended to serve as a basis for the commercial production and utilization of cassava peeling machines.

The increase in brush length and hence the resident time of tubers within the peeling chamber influenced the peeling process remarkably. The outer layer was completely removed in one pass of the tubers through the peeling chamber. This represents an appreciable improvement on the previous designs as well as on some machines presented by some fabricators at the International Institute of Tropical Agriculture, Ibadan. During the testing and performance evaluation of the machine, tubers were presented as cuttings of 20 to 25 cm long and at three different ranges of diameters as less than 8 cm, between 8 to 10 cm and greater than 10 cm. this was done to reduce or eliminate pronounced bends commonly found in cassava tubers. The three categories into which the tubers were divided also aided faster peeling process since the tuber monitor could be adjusted only thrice, each time to handle a specific guide of cassava tubers.

Resident time of cassava tubers in the peeling chamber was between 5 to 15 seconds with this design. It was discovered that resident time of tubers in the chamber influenced peeling efficiency but not independently of other parameters. A combination of resident time/ auger speed and other parameters became desirable to obtain optimum peeling efficiency. Auger speed of 50 to 150 rpm resulted in peeling efficiencies of between 70 to 92% at various peripheral speeds of the peeling brush. While it is desirable to reduce auger speed for higher peeling efficiency, greater challenge of adequate machine capacity arose. In the attempt to synchronize auger speed and brush speed to optimize the process, it was discovered that brush speed of 1000 to 1400 rpm and auger speed of 100 to 200 rpm represent feasible ranges of speed. However, tuber size would not significantly affect the peeling process when tubers have been graded approximately into correct sizes. Maximum machine capacity was 1000 kg/h compared with 23 kg/h recorded during manual peeling Alade (2005) and 500 kg/h for hand fed peelers.

Despite the advantages posed by the above models of cassava peeling machines viz: - elimination of manual intervention during the peeling process, overall reduction in drudgery and also increase in capacity. Further improvement was made on models A, B and C by the same author in order to enhance peeling efficiency and increase machine capacity. This new model, Double Action Self-Fed (DASF, Figure 1) provides a dual tuber path and specific peeling adjustment for a range of tubers. The major advantage is that fewer adjustments would be required during machine operation.

Meanwhile, significant improvements have been made in mechanizing cassava peeling operations, from the manual peeling tools to the more sophisticated automated cassava peeling machines. The double action cassava peeler which won the award of the 'most improved cassava peeling machine' seem to be in the vogue among the emerging technologies in the area of cassava peeling mechanization.

1.3 Justification of the Project

The process of manual peeling has been observed as tedious and time consuming, especially for large-scale factory operations as prevalent in starch extraction. Also since the process is energy consuming and can leads to finger injury. There is therefore an urgent need for the operation to be done mechanically. Although cassava peeling constitutes a major bottleneck in cassava processing, the increase in cassava yield made it important to develop a time and labour-saving technology for the peeling of cassava. This challenge is more urgent than further increase in cassava yield. However, several machines have been developed to peel cassava mechanically (Olukunle *et al.*, 2005; Ayeni, 2000; TNAU, 1989; Odesanmi, 1988; Nwokedi, 1084;

Odigboh, 1976; 1978; Cruz *et al.*, 1959; etc) but these have not solved the problem completely.

In other to meet the needs of cassava products required for human consumption by industries and still be economically viable. An effective and efficient cassava peeling machine should accommodate the larger varieties in tapers, shapes and sizes of the tubers and should remove all the peel with minimum tuber loss. Also, since there is urgent need for such cassava peeling machine there is need to evaluate the existing one in other to determine its suitability for market and urgently adapt, construct, and diffuse it to farmers so that spoilage of harvested cassava roots after harvest can be reduced to minimal level.

1.4 Objectives of the Project

1 To evaluate the performance of a Double Action Self-Fed (DASF) cassava peeling machine in terms of the efficiency, tuber loss and peel retention.

2 To investigate the influence of tuber size and brush speed on machine efficiency using simple statistical models.

3 To determine the economic viability of the machine.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Brief History of Cassava

Starchy root crops and tubers, including cassava, yam, sweet potato and Irish potato, provide cheap and readily available sources of calories for much of the world's population. The cassava plant has been classified botanically as ***Manihot utilissima Pohl*** of the family Euphorbiaceae. In recent publications, however, the name ***Manihot esculenta Crantz*** is being increasingly adopted.

Cassava and sweet potato are the most important root crops in the developing world, with a combined total annual production of around 300 million tonnes and cassava provides over 70 percent of the population's daily calorie intake in some part of sub-Saharan Africa (Azan-Ali *et al.*, 2003), especially in the tropical areas of Africa, Asia and Latin America, as well as source of carbohydrates in animal feed production (chips and pellets) and industrial raw materials such as starch and alcohol (Agbetoye, 2003).

Bokanga (2002) reported that cassava is the fourth supplier of dietary energy in the tropics (after rice, sugar and maize) and the ninth world-wide. Its cultivation and processing provide household food security, income and employment opportunities for 500 million people in Africa, Asia and the Americas. The crop is tolerance of low soil fertility, drought and most pest and diseases with no critical date of harvest, which make cassava a crop of primary importance for the food security of farmers living in fragile ecosystems and socially unstable environments (Bokanga, 2002).

Cassava is one of the major food plants first domesticated by American Indians. Agboola (1968) hypothesized that the introduction of cassava in Benin and Nigeria was either in 17^{th} or 18^{th} century. This introduction of cassava was from Brazil and West Indies to Southern and Eastern Nigeria (Ikpi and Hahn, 1989; Carter *et al.*, 1997). The Igbo migration was an important diffusion mechanism especially in the Eastern States of Nigeria because they have been in contact with cassava since its introduction at Owerri in the 17^{th} century (Agboola, 1979). Cassava has become the most widely spread crop in tropical Africa (Bafflour, 1978) while its spread in Nigeria was most rapid during the 20^{th} century due to the encouragement of the government. Since its introduction into African continent, cassava has become one of the dominant starch staples, particularly in the humid lowlands where it provides over 50 percent of the local diet (de Bruijn and Fresco, 1989). In Southern Nigeria, it has a consumption of about 20 million tons per year and also accounts for over 50 per cent of the caloric intake of the populace.

In the early 1960s, Africa accounted for 42% of world cassava production, in the early 1990s, Africa produced half of world cassava output, and because Nigeria and Ghana increased their production four fold (Nweke, 2004). Nigeria has been the world's leading cassava producer in the world since 1991 (FAO, 2001; Nweke, 2004). Nweke (2004) reported that the dramatic increase in cassava production occurred in Nigeria from 1984 to 1992.

Cassava is a good source of carbohydrates in the diets of the southern regions (Igbeka, 1985). It is a perennial shrub grown by planting a cutting from the mature stem. It is a crop tolerant of drought and infertile soils and can produce tubers as from

5 months, depending on the variety. These attributes have earned it a reputation as "farmer reserve crop" (Cock, 1985).

It is estimated that 164 million tons of cassava roots were produced in 1995 (FAOSTAT, 1997). Slightly more than half of that amount was produced in Africa, and the rest in Asia and Latin America. Cassava is a staple food in tropical countries and provides more than 10% of the daily dietary caloric intake to about 300 million people in African countries and Paraguay.

Despite its importance, cassava is mostly grown by small farmers on small plots of land. Urban consumers and factories obtain their cassava from rural areas where it is grown. Cassava is usually processed immediately after harvesting because it is highly perishable.

2.2 Uses of Cassava

2.2.1 Cassava as household food security

Cassava becomes the main source of calories in the diets of rural consumers. Farmers plant local varieties with low genetic potential and achieve low yields. In the rural food staple stage, cassava yields are low, around 10 tons per hectare production, harvesting, and processing tasks are carried out manually and farm households consume most of the output, (Nweke, 2004). Cassava is consumed mostly as dried roots and cassava leaves are the main vegetables in rural diets. In the urban food staple stage, cassava is primarily produced and processed as a cash crop for sale in urban markets.

About 80% of the world's cassava production is produced for human consumption (Chan, 1983). Bokanga (2002) noted that the average Nigerian meets about 95% of the minimum energy requirements mainly from cereals and roots and tubers, followed by grain legumes. Cassava is Africa's second most important staple food, after maize, in terms of calories consumed (Nweke, 2004). Its high yield in poor soils and ability to stay in the soil for periods after maturity make cassava an important food security crop in low-income countries (de Bruijn and Fresco, 1989). It is eaten as food in many forms such as 'Fufu', 'Tapioca', 'Garri', 'Pupuru', and 'Abacha' and cassava flour. The tuber may also be roasted or boiled for consumption (Bafflour, 1978). Its starchy roots are a major source of calories for more than 200 million people worldwide (Cock, 1985), and it is also one of the most efficient calories producers of all crop, supplying up to 250 kilo calories/ha/kg (Coursey and Hayness, 1970). 'Gari' is very popular in West Africa and is a staple food in Nigeria, Ghana and Togo. Its ability to store well and its acceptance as a "convenience" food is responsible for its increasing popularity in the urban areas of West Africa and Central Africa (IITA, 1990 and FAO, 1990). It is often consumed as the main meal in the form of dough or a thin porridge. Both are prepared in the household by mixing dry 'gari' with hot or cold water and cooking and served with soup or stew. 'Gari' is also eaten as snacks when mixed in cold water with sugar, and sometimes milk (Agbetoye *et al.*, 2006).

Cassava leaves are rich in protein, and are consumed as a vegetable in Zaire, parts of central Africa and some Eastern part of Nigeria (Sarma and Darunze, 1991). The protein level is however low in the fresh roots and is further decreased by processing (Cock, 1985).

Table 1: Average Composition of the Cassava root (common varieties at harvest time)

Composition	Percent (%)
Moisture	70.25
Starch	[1]21.45
Sugars	5.13
Protein	1.12
Fats	0.41
Fibre	1.11
Ash	0.54

[1] Bitter varieties usually average about 30% starch content. *Source :(Grace 1977)*

2.2.2 Cassava as animal feed

Akoroda and Arewa (1989) reported that cassava could be used as livestock feed for animals. It can be fed raw or boiled to pigs and other herbivorous while the leaves may be eaten as vegetables.

Spore (2005) reported that in Africa, less than 2% of cassava is used to feed animals, compared with 30% in Latin America. In Cameroon, researchers estimate that poultry farmers could cut production costs by 40% if they used cassava as part of their chicken's diet. On a global scale, animal feed represents the main outlet for cassava.

2.2.3 Cassava as industrial raw material

There are many industrial uses to which cassava lends itself. Cassava is used in the baking and confectionary industry (Basorun and Ayoade, 1996), the textile industry; and the paper industry and for the production of high quality adhesives and alcohol in the pharmaceutical industry. Wigbodus (1984) reported that cassava was first used as medicine for the cure of tuberculosis in Benin.

2.3 Mechanization of Cassava

Cassava is grown on small plots in most of the tropical world however, in some countries such as Nigeria and Brazil large plantations are springing up with growing interest in mechanization. Grace (1977) reported that the degree of mechanization depends on the amount of land, available labour in the area and general policy regarding the use of manual labour. However, other factors such as land tenure system, capital, etc., influence degree of mechanization.

The use of machinery for land preparation is preferable to manual labour to ensure the best possible seed bed for tuber development. Subsequent operations of planting, weeding, topping and harvesting can be done by hand as well as by machinery. The peculiar nature of the cassava crop presents a number of problems as regards mechanization, but it has been successfully mechanized to a degree in some countries.

2.4 Varieties of Cassava

Although cassava is an established commercial crop in many tropical countries and hundreds of varieties are in existence, little is generally known of the nomenclature and identification of varieties. Varieties are usually differentiated from one another by their morphological characteristics such as colour of stems, petioles, leaves and tubers; maturing time, shape and size of tuber; and yield. There are also cultivars and varieties described by the nutritive content of the tuber; the resistance of the plant to certain diseases and weeds or the climatic and nutrient requirements including fertilizers for maximum yield of the plant. Moreover, in many instances the same variety is known in various places by a number of names.

Grace (1977) reported that the numerous varieties of cassava are usually grouped in two main categories: Manihot palmata and Manihot aipi, or bitter and sweet cassava. This grouping is a matter of economic convenience, as it is difficult to distinguish the two groups by botanical characteristics. However, the distinction between them rests upon the content of hydrocyanic acid, which causes toxicity in the roots. This toxicity is not a variety constant but varies from place to place; all cassavas are now regarded as varieties of Manihot utilissima, and in certain circumstances a "bitter" variety may become "sweet" and vice versa. Hydrocyanic acid content tends to be higher on poor soils and in dry conditions. According to the recognized classification, sweet or nontoxic roots contain less than 50 milligrams of hydrocyanic acid per kilogram of fresh matter.

At one time it was thought that the toxicity of a cassava root was associated with species or variety, but the hydrocyanic acid content was found to vary markedly with growing conditions, soil, moisture, temperature and age of the plant. Certain varieties in Africa, for instance, were found to be innocuous in Dahomey and poisonous when grown in forest soils in Nigeria.

Nweke (1996) and Bokanga (1994) classified cassava varieties according to the levels of cyanogenic glucosides (hydrocyanic acid, HCN) in the root and leaves.

- Cassava with low HCN level: i.e. less than 50 mg per kilogramme fresh weight e.g. TMS4 (2) 1425, TMS30001.

- Cassava with intermediate levels of HCN: i.e. ranging between 50 and 100 mg per kilogramme fresh weight, e.g. TMS30572, TMS30555.
- Cassava with high HCN level: i.e. 100 mg per kilogramme fresh weight or more, e.g. TMS50395. The harvested in the forest and savannah ecologies of Nigeria are the bitter high cyanide containing varieties.

2.5 Harvesting of Cassava

Harvesting of cassava can be done throughout the year when the roots reach maturity. Maturity differs from one variety to another however; the harvesting of cassava is largely accumulated enough starch. The food quality of roots, particularly the starch content, increases with time up to an optimal period of 12 to 15 months after planting, after which there is a loss of quality, mainly due to increased lignifications, which causes the roots to become tough and woody (Bokanga, 2002; IITA, 1990; and Grace, 2004).

Harvesting of cassava root is usually done by hand. The plant is usually cut down at about 30 to 50 cm above ground to facilitate lifting. The protruding stem is used to lift the roots out of the ground. While lifting, care should be taken not to break the roots, as this will lead to losses if broken roots are not retrieved from the soil and also to contamination that may evolve into spoilage. Mechanical harvesting of cassava is difficult because of the non-uniform geometry of the roots in the ground. Nevertheless a few cassava harvesters have been designed and some are in operation, mostly by commercial farmers.

2.6 Yield of Cassava

Output varies greatly between regions. Nnodu (1997) reported that when cassava is grown by traditional tropical methods, yields lie between 5 and 20 tons per hectare, varying with the region, the variety, the soil and other factors. When the crop is given more attention, yields of 30-40 tons per hectare are obtained. But it is normal for some varieties, under appropriate cultivation methods, to yield over 60 tons per hectare (Nweke *et al.*, 2002).

2.7 Processing of Cassava Tubers

2.7.1 Why processing cassava?

The operations involved in the preliminary processing of the various forms or products of cassava include washing, peeling and size-reduction, drying and milling generally. The sequence of these operations commences soon as the roots are harvested. This is because cassava roots deteriorate within few days after harvest with the onset and rate of deterioration varying between cassava varieties (Wenham, 1995). Some varieties deteriorate within 24 hours of harvest while some can be left at room temperature for 7 to 11 days (Bootz, 1976).

Cassava deteriorates in quality soon after harvest, and this damage is aggravated when tubers are bruised (Agbetoye, 2003). They start deteriorating within 2 to 3 days, and rapidly become of little value for consumption or industrial applications (Bokanga, 1995). The deterioration can either be a discolouration of the cassava root tissue as a result of wounds and bruises caused by mechanical damage to the roots during harvest (Wenham, 1995) or infection of the wounds and bruise by micro-organism (Ingram and Humphries, 1972). Clarke (1987) observed that cassava must be processed or consumed within 48 hours. The tubers are usually bulky and heavy which makes transportation and storage very difficult and costly. Another reason for processing cassava tuber is that because it is a seasonal crop, harvest to extend its shelf life, to increase the palatability of cassava and also to decrease its cyanogenic potential (Bokanga, 1995). Lancaster *et al.*, (1982) reported that a great diversity of processing methods are found in the various parts of the world where cassava is consumed and these methods result in the production of a wide variety of food products. Methods of processing cassava range from simple methods such as boiling or roasting for sweet cassava varieties, to complex methods of fermentation used to produce food from bitter varieties of cassava (Coursey, 1973). The extent of removal of cyanogens or reduction in cyanide level from cassava roots by different methods of processing varies (Lancaster *et al.*, 1982).

However, cassava can be processed into several storage products in Nigeria as listed by RAIDS/IFAD (1991) which include cassava flour, gari, lafun, fufu, pupuru, abacha, dried cassava chips/pellets and other industrial products like starch and alcohol.

2.7.2 The steps involve in cassava processing

The first step in processing cassava roots is often to remove the peel, this result in a great reduction of the cyanogenic potential of the raw material, because the peel represents about 15% of the weight of the root, and its cyanogens content is usually 5 to 10 times greater than that of the root parenchyma (Bokanga, 1995). Processing cassava into storable and economic products involves different combinations and sequence of two or more of a number of processing steps. This includes; washing, peeling, splitting (i.e. chipping or slicing), pulping (i.e. crushing, grating or grinding), steaming, water expressing or dewatering, fermentation, pulverizing, sieving and roasting. Some work has been done on mechanizing the processing of cassava tubers by Odigboh and Ahmed (1982). Mechanical peeling of cassava constitutes a major bottleneck in the processing because of bewildering variety of shapes and sizes. However, peeling of cassava is normally done manually by woman and teenage girls, using knives. The rate could be as high as 350 kg per day of 8 hours per person (Igbeka *et al.*, 1992). The process is slow and labour intensive. Also, manual peeling is often time wasting and energy consuming which invariably leads to low productivity.

2.7.3 Losses and labour requirements in cassava processing

It has been established that the post-harvest system of cassava requires more labour than most other staple crops (IITA, 1996). One hectare of cassava containing 10 tons of roots (the average yield of Africa) needs approximately 721 man-hours to harvest and process: of this labour, 212 man-hours are needed for harvesting, 156 for handling, and 353 for processing.

The Collaborative Study of Cassava in Africa (COSCA) has shown that in 67 percent of cases, cassava processing activities were carried out by women only compared to 6 percent of cases for men only. Women along with children participated in another 19 percent of cases, and in 6 percent cases women worked alongside men. This represents 92 percent participation by women in cassava processing (Nweke, 1994). However, the numbers of men involved in cassava processing increases as the opportunities for commercialization increase (Ugwu and Ay, 1992). Although men are seldom involved in cassava processing operations, they tend to perform more of the heavy-duty farm operations. It was observed that as mechanized processing equipment (such as graters and mills) is acquired, men's participation in cassava processing tends to increase, since they often control and operate these machines. It appears therefore that gender role in cassava processing tends to change as processing becomes more mechanized.

With such a large number of processing steps, the opportunities for food loss in the whole system also become numerous. Major losses occur during processing (22.3 percent), harvesting (13.6%) and handling (8.5%). Harvesting losses are higher during the dry season because it is more difficult to dig; roots break and remain in the soil. The size, shape, hardness, moisture content and the type of equipment used affect the processing efficiency. Recently, IITA has assembled a technology package for cassava processing in rural areas (IITA, 1996). The package, which is in the form of a village processing centre, contains a chipping and grating machines, a pressing device, a mill, a gari fryer and sifters. Such package has tested and found to reduce food losses during cassava processing from 22.3% to 10.1% and labour input from 295.2 man-hours to 87.6 man-hours per 10 tons of cassava roots.

2.7.4 Machinery for processing cassava

The products derivable from cassava are enormous. So also is the machinery required to produce them. The machinery required for processing cassava depends on the types of product required. Agbetoye (2003) listed some of the various machines required for processing raw cassava tubers into its products as peeling machines; washing machines; grating machines; chipping and pelleting machines; presses (hydraulic and screw) for dewatering cassava mash; garifriers; sifters; pulverizers; dryers; starch extruders; etc.

Various machineries have been designed to aid the large scale processing of cassava. They include graters (Akinyemi and Akinlua *et al.*, 1999); peeling machines, dewatering presses; sifters and pulverizes for dried cassava mash and garifriers (Odigboh, 1983; Odigboh, 1982). Local fabricators produce some of these machines. The international Institute of Tropical Agriculture, IITA, Ibadan are producing some cassava processing machines on commercial bases. They include graters, chippers and dewatering presses. Agbetoye (2003) reported that the Alvan Blanch Corporation of England has produced some gari processing machines (fryers), which have been used at the Federal Institute of Industrial Research, Oshodi (FIIRO).

2.8 Mechanical Peeling of Cassava Tubers

2.8.1 Peeling of cassava

Cassava come in a bewildering variety of shapes and sizes, hence the only means of peeling the stuff at the village level is by hand, using a knife to remove the thin outer layer of the tuber; the process is slow and labour intensive, averaging 25 kg per man-hour, but it gives the best result. The women on the farm usually do the traditional processing of cassava. This opportunity cost of labour is certainly for most women a function of timing. The processing cost of large quantities of cassava may therefore become prohibitive if it places greater demand on female labour. Also manual peeling is often time wasting and energy consuming which invariably leads to low productivity. If any cassava peeling machine designed for smallholders can be identified it should be urgently put to on-farm test with a view to adapt, construct, and diffuse it to farmers.

Cassava peeling constitutes a major bottleneck in cassava processing. The increase in cassava yield has made it important to develop a time and labour-saving technology for the peeling of cassava. This challenge is more urgent than further increase in cassava yield. However, to meet the needs of cassava products required for human consumption by industries and still be economically viable.

2.8.2 *Methods of peeling cassava*

Igbeka (1985) reported five methods of peeling tubers as follows:

- ✓ **Chemical peeling machine**: tubers are soaked in a chemical solution and washed with water spray or wiped off mechanically. The danger of chemical contamination of the tubers makes it unsuitable for human consumption.
- ✓ **Steam peeling machine**: the tubers are introduced to a chamber where steam held under pressure is used to peel the tubers. This method is very expensive and requires a highly skilled operator.
- ✓ **Belt conveyor peeler**: cassava tubers are cut into slices, and placed on a conveyor (which has blades). The peel is removed through the action of the rotating abrasive surfaces.
- ✓ **Abrasive cylinder peeler**: the tubers are loaded into a vertical cylinder and covered. The peels are removed by the rubbing action of the peels on the abrasive (inner) surface of the cylinder. This system is easy to operate.

- ✓ **Rotating blade-mounted peeler**: the tubers are fed in a rotating ring, which has spring loaded blades fitted to it. The feeding mechanism is a reciprocating bar designed to push the tuber through the peeler at a pre-determined rate.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Cassava Variety

The cultivars used for the experiment is the IITA's new high-yielding Tropical Manioc Selection (TMS30572) variety with pest and diseases resistant ability (Aina *et al.*, 2004). This variety is common to local farmers in most West African countries especially Nigeria and Ghana (Oguntunde, 2005). Thus, the cassava tubers used for the experimentation were obtained from a local farm in Akure, Nigeria. The parameters used to evaluate the performance of DASF were the peeling efficiency, tuber loss and peel retention.

3.2 Description of the Machine

The DASF cassava-peeling machine (Figure 1) was the result of further improvement on models A, B and C (Olukunle and Ademosun, 2006) in order to enhance peeling efficiency and increase machine capacity. This machine provides a dual tuber path and specific peeling adjustment for a range of tubers. DASF cassava peeling machine consists of two conveyors arranged in parallel, two rotating brushes (Olukunle and Ademosun, 2006) 60 cm long mounted 90^0 on the auger conveyors, tuber inlets and outlets, tuber monitors, a protective hood, frame and transmission system.

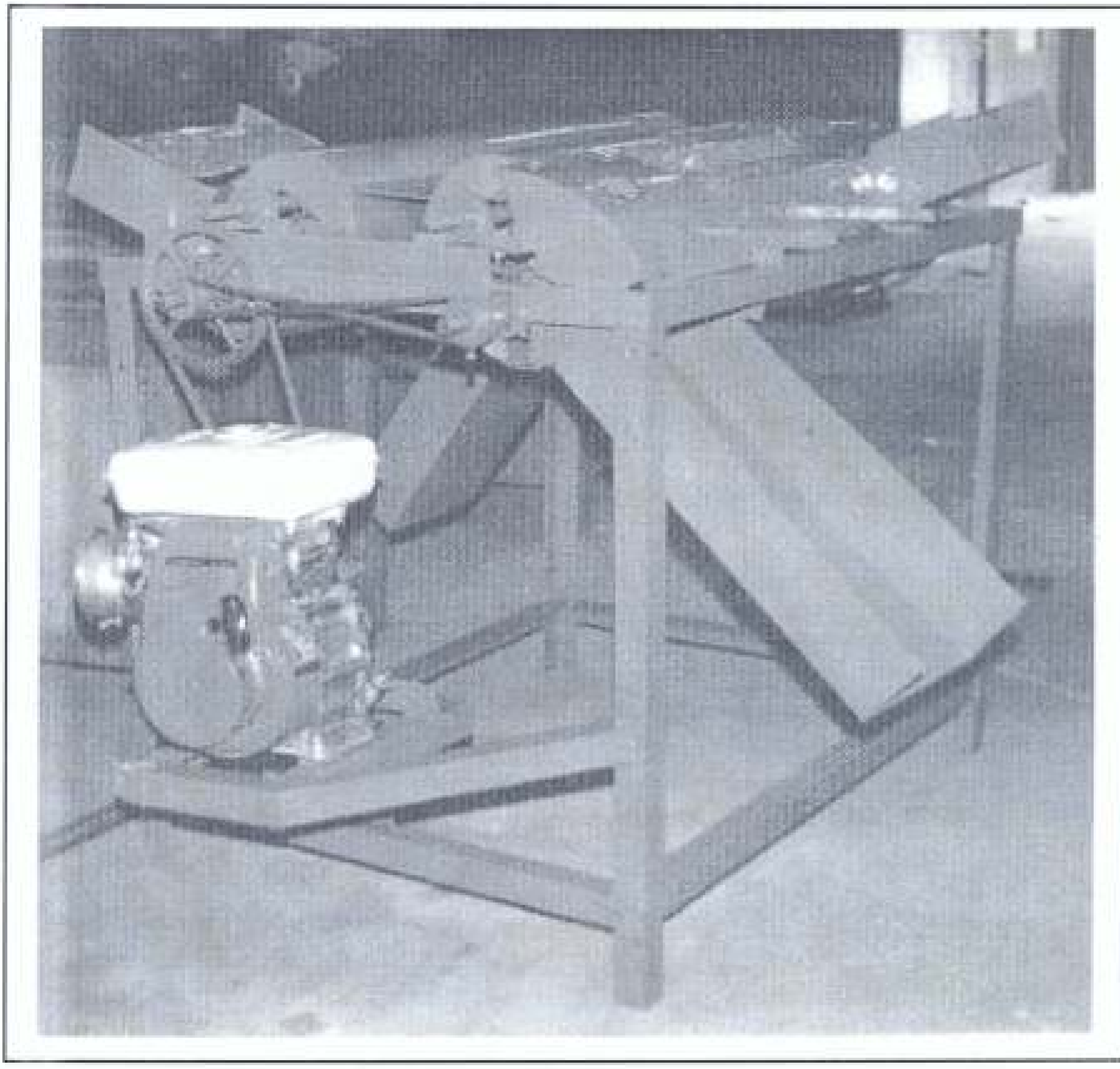

Figure 1: The Double Action Self-Fed (DASF) Cassava Peeling Machine

The machine impacts rotary/linear motion on the tuber, which also makes contact with, the peeling brush and thus provides the required peeling effect on the tuber. The rotary power for the auger and the peeling brush is obtained via a belt-pulley mechanism connected to a power source (7 hp Honda petrol engine). Tubers are fed into the two inlets simultaneously and the machine effects peeling on the tubers. The resident time is governed by the auger speed and the slippage provided by the combine action of the auger, the brush and the tuber monitor on the tuber. Auger and brush speeds have been synchronized from previous designs such that a predetermined speed ratio between the auger and the brush is obtained by throttling the power source. Most of the components having direct contact with tubers are made of stainless steel/galvanized steel in order to avoid food contamination.

3.2.1 Design considerations of the machine

In order to obtain high efficiency and reliability, the machine was designed based on the following considerations (Olukunle and Ademosun, 2006). The equipment should:

1. be relatively cheap and be within the buying capacity of local farmers,
2. be able to peel different varieties, shapes and sizes of cassava,
3. be made with readily available materials,
4. reduce the labour input in traditional methods of peeling,
5. have higher capacity compared to manual operations,
6. be simple to operate and maintain by local farmers who do not have any formal education.

3.3 Classification of Tubers

Tubers used for the experiment were classified into three (I, II and III) Table2. The major diameter (length) and the intermediate diameter (thickness/diameter) were considered criteria for classification. The classification was used for proper clearance setting of the inlet and the outlet of the tuber monitor.

Table 2: Classification of tubers

Class	Length (cm)	Width (cm)	Tuber monitor clearance (cm)	
			Inlet	Outlet
I	15-20	5.0-6.0	5.5	4.5
II	21-30	6.0-7.5	6.5	5.5
III	31-40	7.5-8.0	8.0	7.0

3.4 Traditional Peeling of Cassava

Two methods of traditional/manual peeling were carried out: - Normal and Careful peelings.

3.4.1 Normal peeling

36.5 kg of cassava tuber were taken, divided into five and peeled manually. The time taken to peel the tubers and weight of peel and flesh removed were taken and recorded.

3.4.2 Careful peeling

35 kg of cassava were peeled carefully without any loss of useful tuber while removing the peel completely. The values obtained were used to determine the proportion by weight of peel 'p' in the root, using the relation:

$$p = \frac{M_{pc}}{M_s} \quad (1)$$

Where M_{pc} = *weight of peel collected through careful peeling*

M_s =*weight of sample*

3.5 Mechanical peeling

To evaluate the performance of DASF Cassava Peeling Machine, the factors selected were the variability in size and speeds of rotary wire auger and wire brush. Three speeds were selected by synchronizing auger and brush speeds (i. e. 1000:1400; 1500:2100; and 2000:2800 rpm). The machine was powered by a 7 hp Honda petrol engine, which transmits rotary motion to both the rotary wire brush and the auger through the belt-pulley mechanism. The tuber monitors (inlet and outlet) were set to give clearance for tuber according to their sizes. A 10 kg weight of cassava was fed into the inlet hopper. The speeds of the auger and the rotary brush, and time taken for peeling were recorded. The weight of peeled tubers, the peel weight (plus tuber portion which was removed together with peel) and time of operation was recorded. Each experiment was replicated five times. However, the peel remaining on the tuber after one pass through the machine was removed manually. The weight of peel removed by knife, weight of completely peeled tuber M_c, weight of peel collected through the peel outlet of the machine M_{pts}, weight of tuber portion which was removed along with the peel by the machine M_f, were determined from the following relations: -

$$M_b = M_c + M_f + M_{pr} + M_{po} \tag{2}$$

$$M_{pt} = M_c + M_{pr} \tag{3}$$

$$M_{pf} = M_{po} + M_f \tag{4}$$

$$M_p = M_{po} + M_{pr} \tag{5}$$

$$M_p = pM_b \tag{6}$$

$$pM_b = M_{po} + M_{pr} \tag{7}$$

where M_b, = *weight of cassava tuber before machine peeled in kg*

M_{pr}, = *weight of peel removed by hand after machine peeled in kg*

M_{pt},, = *weight of cassava tuber after machine peeled in kg*

M_p = *weight of peel in kg*

and p = proportion by weight of peel in the tuber respectively.

By solving the above, M_c, M_{po} and M_f were obtained. The peeling efficiency and tuber loss were calculated using the equation given by Agrawal (1987).

$$\eta = \frac{M_{po}}{M_{pr} + M_{po}} \tag{8}$$

and

$$\lambda = \frac{M_f}{M_c + M_f} \tag{9}$$

where η = *peeling efficiency*

ℓ = *tuber loss*

M_{po}, M_{pr}, M_c and M_f remain as defined above. The functional requirements of the peeling machine were such that it should have high peeling efficiency and low tuber loss simultaneously. Therefore, the performance of the machine was further evaluated quantitatively by combining both terms above into a single measure, such as the peel retention. The following formula for peel retention (μ) was, therefore, worked out based on material balance equation (Mc Cabe *et al.*, 1985):

$$\mu = \left(\frac{M_{pr}}{M_{pr} + M_{pw}}\right) \text{x} \left(\frac{M_f}{M_t + M_f}\right) \quad (10)$$

3.6 Data Analysis and Modeling of DASF Peeler Evaluation Parameters

The descriptive statistics of the mean and standard deviations of the above parameters were estimated. Mean comparison evaluation parameter for different treatments, based on tuber sizes and speed, were investigated using Analysis of Variance (ANOVA) and Least Significant Difference (LSD). Regression models of the general form:

$$y = \beta_o + \sum_{i}^{n} \beta_n x_n \quad (11)$$

were used to explain the influence of tuber size and brush speed on machine efficiency, tuber loss and peel retention. Where y, the explained variate, represents any of the evaluation parameters (i. e. η, λ and μ), β_o is the model constant, β_n is the coefficient of the variables and x_n is the explanatory variates (n = 1-3).

CHAPTER FOUR

4.0 ECONOMIC ANALYSIS

4.1 Determination of the Machine Capacity:

Total mass of peeled cassava tubers = 450 *kg*

Total time taken for the operations = 0.3 *h*

Therefore, the relation gives the capacity of the machine:

$$\text{Machine capacity} = \frac{\text{Mass of peeled tubers (kg)}}{\text{Time taken (h)}} \qquad (12)$$

$$= \frac{450\ (kg)}{0.3\ (h)}$$

$$= 1500\ kg/h$$

4.2 Determination of the Rate of Fuel Consumption by the Machine:

Total volume of fuel consumed = 0.290.4 *ml*

Total time of operation = 0.3 *h*

Therefore, fuel consumption in liter/hour is given by:

$$\text{Fuel consumption} = \frac{\text{Fuel consumed (l)}}{\text{Time of operation (h)}} \qquad (13)$$

$$= \frac{0.2904}{0.3}$$

$$= 0.969\ l/h$$

4.3 Determination of Cost of Fuel/Hour:

Volume of fuel required per hour = 0.969 *liter*

Cost of fuel per liter in Naira = ₦65.00

Cost of fuel/hour required = *Volume of fuel/hour* x *Cost per liter* (14)

$= 0.969 \times 65$

$= ₦62.99$

4.4 Determination of Fuel required by the Machine to peel 1ton of Cassava Tuber:

From the capacity of the machine determined (4.1). 1*ton* of the tuber will be peeled in 0.2 *h*. Therefore, to operate the machine for 0.2 *h*, fuel required will be given thus:

For 1 hour, fuel required =0.646 *liter*

For 0.2 hour, fuel requires will be $= 0.969 \times \frac{2}{3}$

=0.646 *liter*

4.5 Determination of Cost of Fuel required for 1ton of Cassava Tuber:

Volume of fuel required =0.323 *liter*

Cost of fuel per liter in Naira = ₦65.00

Therefore,

Cost of fuel require/ton = *volume of fuel/ton* x *cost/liter* (15)

$=0.64 \times 65$

=₦41.99

4.6 Determination of the Wage of the Machine Operator:

The operator's salary is assumed to be ₦ 10,000.00 per month. Therefore, the DASF operator will be expected to collect ₦ 384.62 per day (26 working days, Saturdays inclusive) or ₦ 48.08 per hour (8 working hours).

4.6.1 Determination of the operator's wage/ton:

For 1hour of operation, operator's wage =₦48.08

For 0.2 *h* of operation, wage will be $= ₦48.08 \times \frac{2}{3}$

$= ₦32.05$

4.7 Determination of the Cost of Operating the Machine/Hour:

Cost of operation per hour = Cost *of fuel/hour + Wage of operator/hour* (16)

To achieve the machine maximum capacity, $1^1/_2$ *ton/h*, two operators will be required.

Therefore,

Overall cost of operation/hour = *Cost of fuel/hour + Wage of operators/h* (17)

$= ₦[62.99 + 2(48.08)]$

$= ₦159.15$

4.7.1 Determination of cost of operating the machine/ton:

Cost of operation/ton = *Cost of fuel/ton + Wage of operators/ton* (18)

$= ₦[41.99 + 2(32.05)]$

$= ₦\ 106.09$

4.8 Determination of Cost of Manual Peeling:

Cost charged for about 2.5kg tubers = ₦5.00

Therefore, 1 *kg* of tuber will cost $= \frac{5.00}{2.50}$

20.27 *kg* will cost $= \frac{5.00}{2.50} \times 20.27$

$= ₦40.54$

CHAPTER FIVE

5.0 RESULTS AND DISCUSSIONS

5.1 Rate of Peeling and Peel Thickness

The result of normal peeling, Table 3 showed that the rate of manual peeling varied from 20.27 kg/h to 23.33 kg/h and averages 20.27 kg/h. This almost falls within 11.0 kg/h to 22.0 kg/h when five varieties were investigated by Sheriff *et al.* (1995), but less than 43.75 kg reported by Igbeka *et al.* (1992). The range obtained was so closed because, larger tuber sizes were considered for this study.

Table 3: Results of Normal and Careful peeling

	Normal						Careful			
	M_a	M_{pm}	M_f	M_p	T	R	M	M_{pc}	p	T
Min	7.000	2.400	0.100	2.100	18.00	20.270	3.600	0.700	0.1400	24.000
Max	7.600	3.000	0.300	2.700	22.00	23.333	4.300	1.400	0.2800	27.000
Mean	7.300	2.700	0.220	2.480	19.60	20.270	3.980	1.020	0.2040	25.667
SD	0.255	0.255	0.084	0.245	1.517	1.8948	0.235	0.235	0.0469	1.1595

Where: M *represents weight tuber after peeling*

M_{pc} *represent weight of peel collected*

p represents proportion of peel present in the root

T *represents the time of peeling*

M_a *represents weight of tuber before normal peeling*

M_{pm} *represent weight of peel and flesh removed*

M_p *represents weight of peel only*

M_t *represents weight of tuber only*

R *represent rate of peeling in kg/h*

NB: all weight measured in kilogram (kg).

The proportion of peel in the cassava roots, *p*, ranges from 0.14 to 0.28 and averages about 0.204. This is in reasonable agreement with, but higher than the ranges of 0.085 to 0.170 and 0.106 to 0.215 reported by Ezekwe (1979) and Adetan *et al.* (2003) respectively (Table 4). The difference is perhaps because of the environmental factors of the farm area where the cassava tubers used for the experiment were obtained.

Table 4: Results of previous studies compared with new study

Range (kg/h)	Proportion of peel	Reference
11 – 22	N	Sheriff *et al.* (1995)
N	0.085 – 0.170	Ezekwe (1979)
N	0.106 – 0.215	Adetan *et al.* (2003)
N (43.75)	N	Igbeka *et al.* (1992)
20.27 - 23.33	0.140 - 0.280	This study

N – Not given, average in parenthesis

5.2 Summary Statistics of Machine Performance

Figure 2 showed that the efficiency decreases as the speed of operation increases. Tuber loss was almost the same for all the classes at speed ratio 1000:1400 rpm (Figure 3). Figure 4 shows that peel retention decreases with increase in speed ratio, except for classes II and III at the speeds 1000:1400 and 1500:2100 rpm.

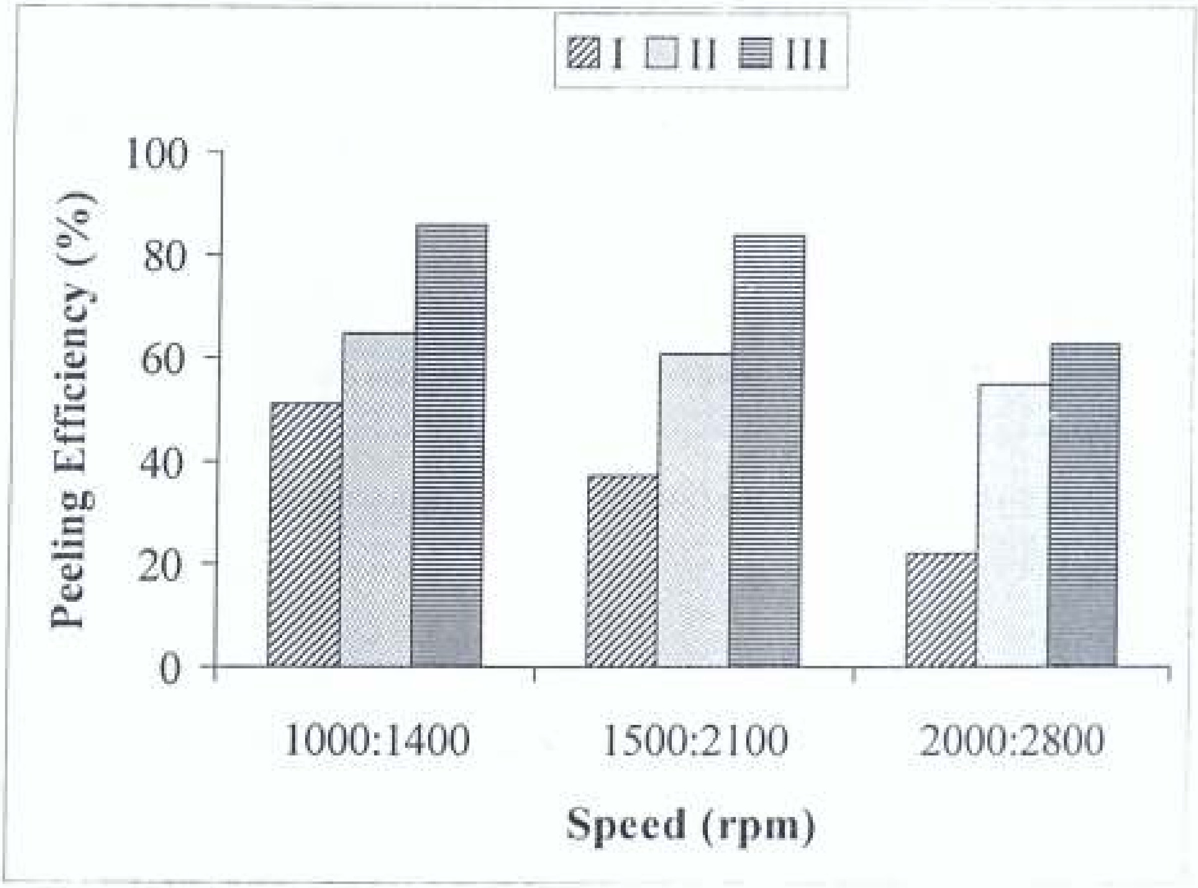

Figure 2: Effect of auger:brush speed ratio and tuber size on peeling efficiency

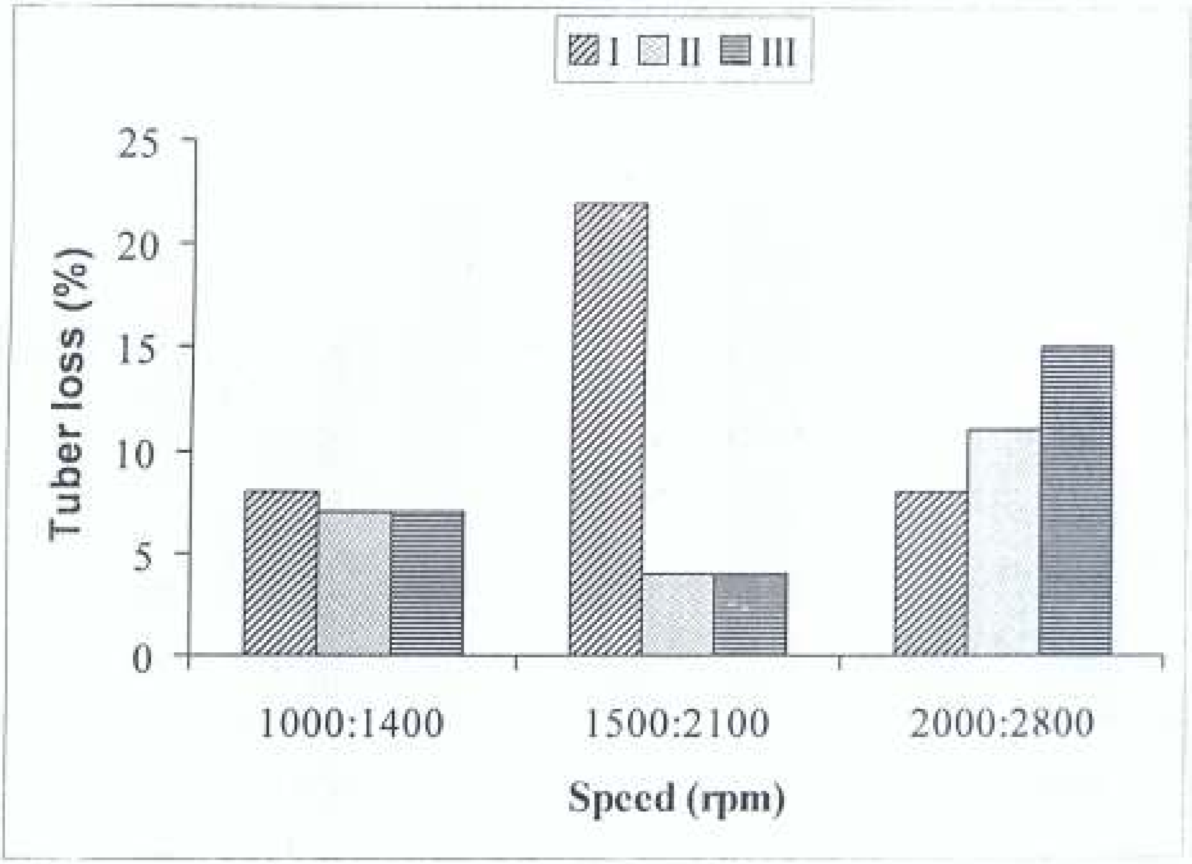

Figure 3: Effect of auger:brush speed ratio and tuber size on tuber loss

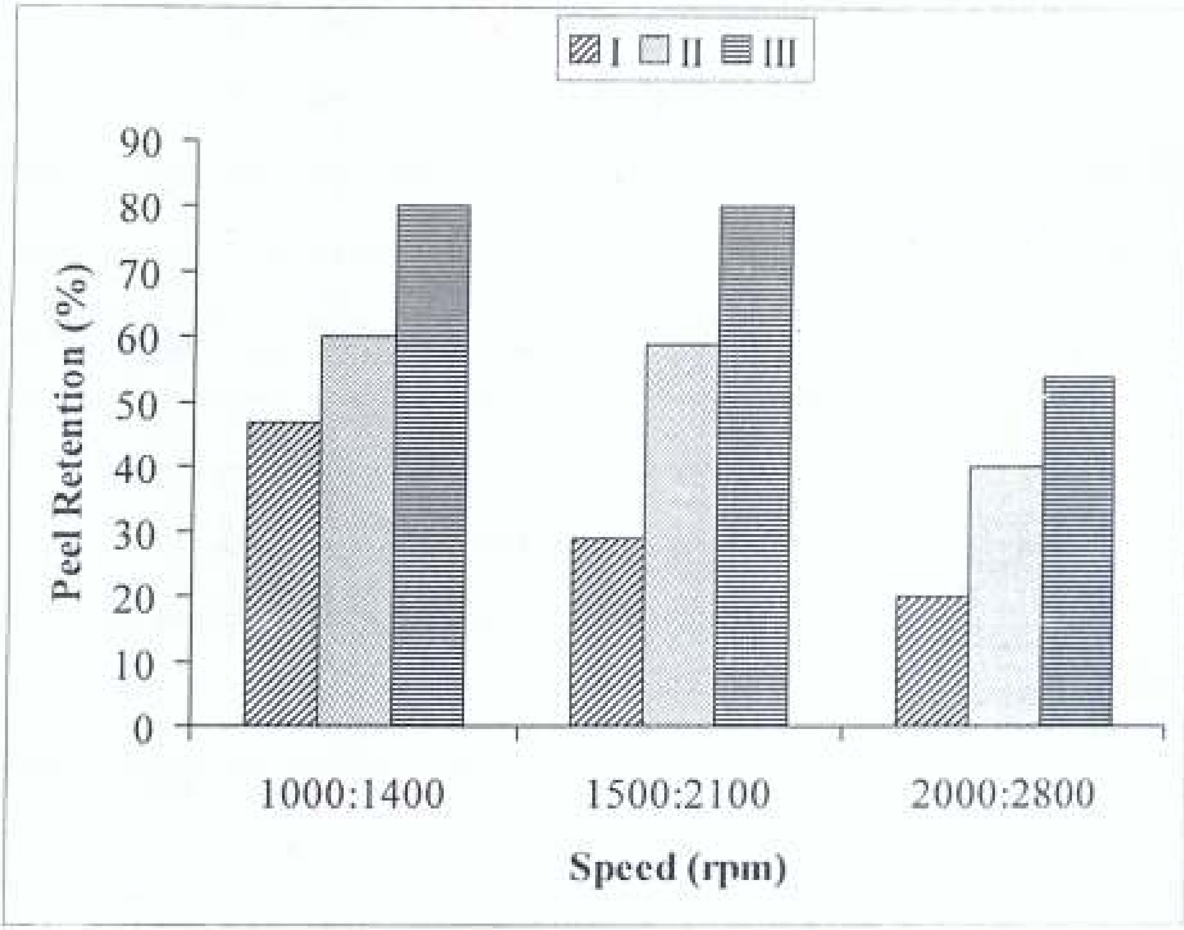

Figure 4: Effect of auger:brush speed ratio and tuber size on peel retention

Table 5 shows the descriptive statistics of tubers classes. At speed ratio 1000:1400 only, class III tubers had the maximum peeling efficiency (90%) while classes II and I each had minimum peeling efficiency of 41%. The mean tuber loss was almost the same for all the three classes at this speed ratio. When the three speeds ratios (auger:brush) were compared the results showed that the minimum and maximum peeling efficiencies in class I tubers are 20% and 61%. All the three classes of tubers had the minimum tuber loss of 2% each, while the maximum tuber loss of 27% occurred in classes III and I. The peel retention observed was minimal in class II (18%) and maximum of 88% occurred in class III tubers.

Table 5: Summary of descriptive statistics of tuber classes

	Class of tubers	Speed ratios (rpm)								
		1000:1400			1500:2100			2000:2800		
		η	λ	μ	η	λ	μ	η	λ	μ
in	I	0.41	0.02	0.35	0.22	0.15	0.19	0.20	0.05	0.20
	II	0.41	0.02	0.35	0.51	0.02	0.50	0.41	0.07	0.18
	III	0.80	0.02	0.72	0.80	0.02	0.72	0.51	0.05	0.37
ax	I	0.61	0.15	0.60	0.61	0.27	0.48	0.41	0.12	0.38
	II	0.80	0.15	0.74	0.71	0.07	0.70	0.71	0.17	0.55
	III	0.90	0.10	0.88	0.90	0.05	0.88	0.71	0.27	0.67
ean	I	0.51	0.08	0.47	0.37	0.22	0.29	0.22	0.08	0.20
	II	0.65	0.07	0.60	0.61	0.04	0.59	0.55	0.11	0.40
	III	0.86	0.07	0.80	0.84	0.04	0.80	0.63	0.15	0.54
)	I	0.10	0.05	0.12	0.15	0.04	0.13	0.15	0.03	0.14
	II	0.15	0.05	0.16	0.07	0.02	0.07	0.11	0.04	0.14
	III	0.06	0.03	0.07	0.06	0.01	0.07	0.08	0.09	0.12

5.3 Effect of Tuber Size on Machine Performance

The Analysis of variance (ANOVA) and Least Significant Difference test was used to investigate the effect of tuber size on the parameters of evaluation of the machine. The result (Table 6) shows that class of tuber was highly significant for the evaluation of the efficiency and peel retention ($p<0.05$) for all the three classes of tubers. Whereas, for tuber loss at $p>0.05$, which means that class of tuber was not significant for tuber loss since tuber loss occurred in all the three classes of tubers.

Table 6: ANOVA result for evaluation parameters and the effect of tuber sizes

Evaluation parameter		Sum of squares	df	Mean square	F	Sig.
η	Between Groups	0.31100	2	0.15500	13.237	0.001
	Within Groups	0.14100	12	0.01170		
	Total	0.45200	14			
ℓ	Between Groups	0.00012	2	0.000060	0.031	0.97
	Within Groups	0.02344	12	0.001953		
	Total	0.02356	14			
μ	Between Groups	0.26600	2	0.133000	9.410	0.003
	Within Groups	0.17000	12	0.014130		
	Total	0.43500	14			

The LSD test was carried out for all the sizes of tuber at a constant speed 1000:1400 rpm (auger:brush). The result revealed that there were significant differences in the efficiency between classes I and II at the 0% level (Table 7). However, no significant difference was observed between classes I and II, whereas the difference between II and III was significant (p<0.05). There were no significant differences in tuber loss for evaluating DASF peeler in between all the three classes. Peel retention was significant between I and III, or II and III, but not significant between I and II (p=0.109).

Table 7: Evaluation parameters and the effect of tuber sizes

Evaluation parameter	(I) FAC	(J) FAC	Mean difference (I-J)	Sig.	Remark
η	I	II	-0.1380	0.067	NS
	I	III	-0.3500	0.000	S
	II	III	-0.2120	0.009	S
ℓ	I	II	0.0060	0.834	NS
	I	III	0.0060	0.834	NS
	II	III	-0.0000	1.000	NS
μ	I	II	-0.1300	0.109	NS
	I	III	-0.3240	0.001	S
	II	III	-0.1940	0.024	S

NS- Not significant; S- Significant

5.4 Effect of Machine Speed on DASF Peeler Performance

Table 8 shows the ANOVA result when the size of tuber was kept as a constant and speed varied. The result shows that speed of operation was highly significant for the evaluation of efficiency and peel retention at $p<0.01$, whereas speed of operation was significant for tuber loss at the 23% level.

Table 8: ANOVA result for evaluation parameters and the effect speed ratios

Evaluation parameter		Sum of squares	df	Mean square	F	Sig.
η	Between Groups	0.16500	2	0.082640	18.896	0.000
	Within Groups	0.05248	12	0.004373		
	Total	0.21800	14			
ℓ	Between Groups	0.03077	2	0.015390	5.222	0.23
	Within Groups	0.03536	12	0.002947		
	Total	0.06613	14			
μ	Between Groups	0.22500	2	0.113000	15.016	0.001
	Within Groups	0.09004	12	0.007503		
	Total	0.31500	14			

The result of LSD Table 9 shows speed as a varied factor while the size of tuber was treated as a constant. No significant difference was observed between S_1 and S_2 for peeling efficiency, but there were significant differences between S_1 and S_3, or S_2 and S_3 ($p<0.01$). There were significant differences in tuber loss in evaluating DASF peeler performance between S_1 and S_3, though low, also between S_2 and S_3, however no significant difference was observed between S_1 and S_2.

Table 9: Evaluation parameters and the effect of speed ratios

Evaluation parameter	(I) FAC	(J) FAC	Mean difference (I-J)	Sig.	Remark
η	S_1	S_2	0.020	0.641	NS
	S_1	S_3	0.232	0.000	S
	S_2	S_3	0.212	0.000	S
ℓ	S_1	S_2	0.032	0.370	NS
	S_1	S_3	-0.076	0.047	S
	S_2	S_3	-0.108	0.008	S
μ	S_1	S_2	0.000	1.000	NS
	S_1	S_3	0.260	0.000	S
	S_2	S_3	0.260	0.000	S

NS- Not significant; S- Significant

5.5 Modeling Result

The regression statistics for the models explaining variations in the peeling efficiency, tuber loss and peel retention are shown in Table 10. Tuber size alone explained about 75% of the variations in peeling efficiency with an overall standard error of 0.11 (p = 0.002). The model coefficients were significant at 5% and 1% levels. Speeds of operation explained a lower and insignificant (p>0.5) value of variance (R^2 = 0.19) in peeling efficiency. The combined effects of the variables explained a higher proportion of variance in peeling efficiency with R^2 of 0.95, estimated error of 0.55 and p<0.001. Tuber size explained a grater portion of variability in efficiency than speed (Table 10). A unit increase in tuber size (Φ) would result in an increase of about 21% in peeling efficiency whereas a corresponding unit increase in speed would only increase the efficiency by 4%.

Generally, the effect of tuber size on tuber loss seems to be insignificant. Explanatory variable Φ yielded an 8.1% coefficient of determination as compare with 7.5% for peeling efficiency. The combine effects barely explained about 15.6% with overall standard error of 0.068. However, the higher absolute value of the coefficient of Φ showed that a greater portion of the variability in tuber loss is explained by this variable. Furthermore, the negative sense of the coefficient (Table 10) show that a unit increases in Φ would lead to a reduction of about 1.9% in tuber loss whereas a unit increase in speed would result in about 0.8% increase in tuber loss.

This result is in agreement with results from manual/careful peeling in which the percentage of tuber loss is far lower in very big tubers compared to smaller/thinning tubers.

Table 10: Regression statistics for models explaining the effect of tuber size and brush speed on machine performance parameters

Predicted parameter	Model variables	Model coefficients			Model parameters p-value			Overall statistics		
		β_o	β_1	β_2	β_o	B_1	β_2	R^2	SE	p-value
η	Φ	-0.751(0.29)[a]	0.021(0.05)	-	0.037	0.002	-	0.75	0.11	0.002
λ	Φ	0.218(0.06)	-0.019(0.02)	-	0.212	0.459	-	0.08	0.06	0.459
μ	Φ	-0.746(0.34)	0.195(0.05)	-	0.062	0.007	-	0.67	0.13	0.007
η	V	0.893(0.25)	-0.044(0.03)	-	0.009	0.236		0.19	0.20	0.236
λ	V	0.040(0.08)	0.008(0.01)	-	0.617	0.475	-	0.08	0.06	0.475
μ	V	0.890(0.24)	0.052(0.03)	-	0.007	0.154	-	0.27	0.19	0.154
η	Φ, V	-0.439(0.16)	0.205(0.20)	0.044(0.01)	0.036	0.000	0.004	0.95	0.55	0.000
λ	Φ, V	0.163(0.18)	-0.019(0.03)	0.008(0.01)	0.402	0.477	0.492	0.16	0.06	0.601
μ	Φ, V	-0.378(0.17)	0.195(0.02)	0.052(0.01)	0.067	0.000	0.002	0.94	0.06	0.000

[a] Standard error given in parentheses

Regression results for peel retention (Table 10) yielded similar patterns with that of the peeling efficiency with lower goodness-of-fit parameters in some of the cases considered. For example, tuber size explained 67% of the variations in peel retention whereas both explanatory variables explained 94%, which are lower in values compared to peeling efficiency. However, unlike peeling efficiency, which tends to reduce with increasing speed, more peels are retained on tubers with increasing speed. The reason is not far-fetched. If the delay or resident time of the tubers inside the chamber is increased, there is tendency to remove more peel. Else decreased resident time occasioned by increasing auger speed would lead to more peels retained on the tubers. This result suggests that a compromise in parameters setting must be made for optimum performance of the peeler.

The third independent variable of the multiple linear regression models is the interaction term between Φ and V ($\Phi \times V$). Generally this term was not presented in Table 10 because it added less than 11% of the explained variance in all the cases and this was adjudged insignificant for inclusion in the results presented.

5.6 Result of Economic Analysis of DASF Peeler

Table 11 shows the summary of the economic analysis of DASF peeler. The capacity of the machine averages 1500 kg/h. The fuel consumption rate of the gasoline engine was at about 0.969 l/h. However, the cost of operating this machine per hour is about ₦ 159.15, operators wage inclusive, whereas, cost of peeling per hour manually is about 40.54 (at ₦ 5.00 per 2.5 kg) with a very low output 20.27 kg/h. There was no breakdown of any component of the machine during operation. The machine worked well and handling of tubers for their peeling was accomplished with ease.

Table 11: Summary of the economic analysis of the DASF peeler

Cost of producing the machine	₦ 250,000.00
Machine capacity	1500 kg/h
Fuel consumption per hour	0.968 l/h
Fuel consumption per ton	0.1936 l/t
Fuel cost per hour	₦ 62.99
Fuel cost per ton	₦ 41.99
Operators required	2
Operators wage per hour (x2)	₦ 96.16
Operators wage per ton (x2)	₦ 64.10
Cost of operation per hour	₦ 159.15
Cost of operation per ton	₦ 106.09
Cost of manual peeling per ton (@₦5.00/2.5kg)	₦ 2,000.00
Cost of peeling 20.27 kg/h (@₦5.00/2.5kg)	₦40.54
Money saved per ton over manual peeling	₦ 1,893.91

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

Results of the performance evaluation of DASF peeler showed higher throughput capacity of about 1500 kg/h, with maximum peeling efficiency of 90% and favourable economic advantage over manual methods of peeling cassava. Thus, the machine is adjudged suitable for small to medium scale cassava processors. The machine performed satisfactory with minimum breakdown during operation. The regression models developed in this study could be used to estimate machine functional performance using tuber size and brush speeds. Thus, the peeling efficiency could be determined from:

$$\eta = 0.205\Phi + 0.044V - 0.435 \quad (19)$$

with R^2 of 0.95, Standard Error of 0.55 and $p<0.0001$ where Φ is size of tuber (cm) and V is brush speed (rpm). Maximum efficiency was observed when the tuber size was largest. A unit increase in size of tuber (Φ) would result in an increase of about 21% in peeling efficiency whereas a corresponding unit increase in speed (V) would only increase the efficiency by 4%. This study provides useful information for engineers and food processors to improve the performance of automated cassava peelers.

Furthermore, the results obtained show that the machine could be very useful where considerable quantities of tubers have to be peeled in limited time. The adoption of DASF peeler by small-scale cassava processors should go a long way in preventing spoilage of harvested cassava roots since cassava deteriorate in quality soon after harvest. Further research for development is recommended to increase efficiency, reduce tuber loss, and improve in the aesthetics of the original design and also in the simplicity of the machine.

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Appendix I

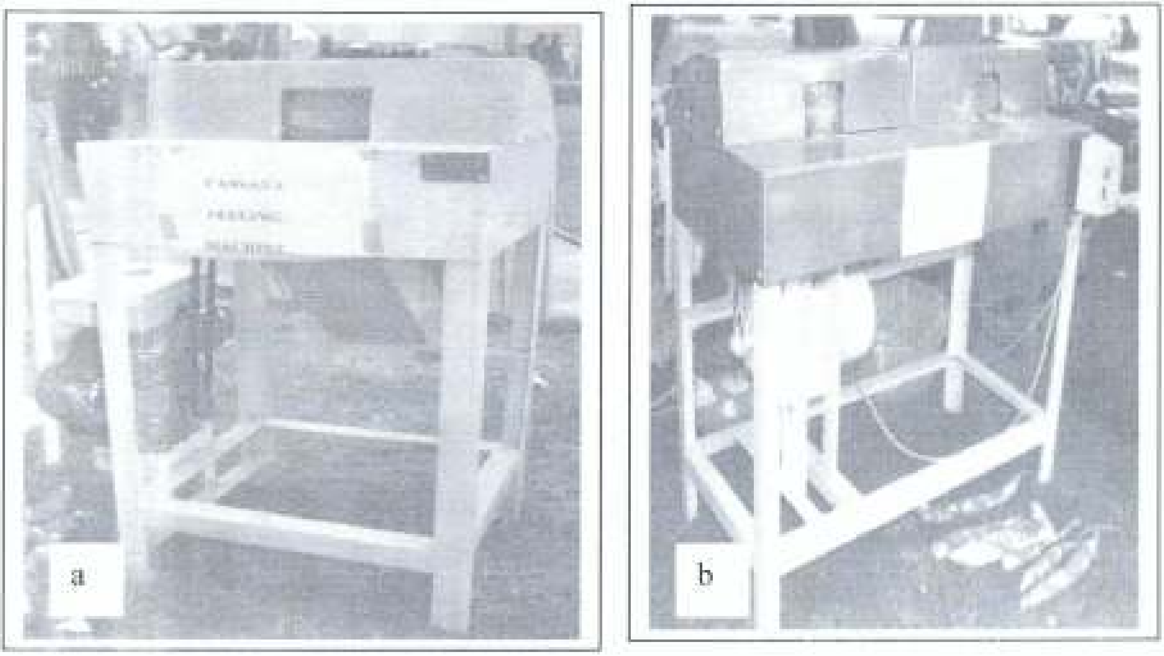

Figure 5 (a). Single Gang (Model A) and (b). Double Gang (Model B) Cassava Peeling Machines.

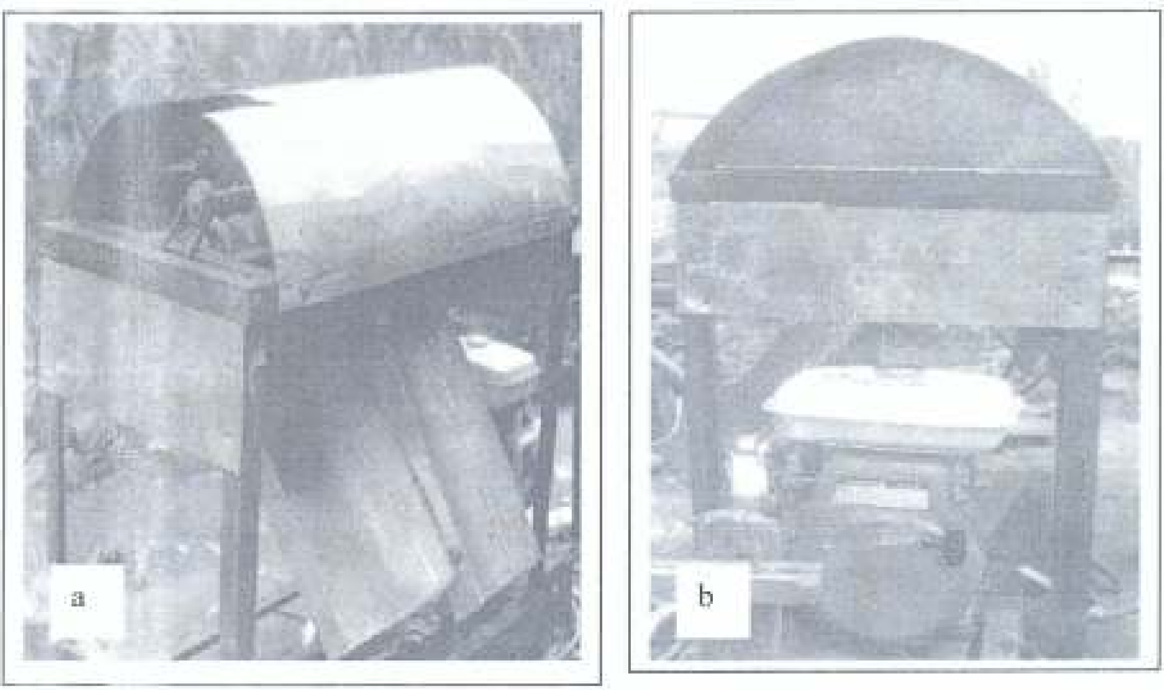

Figure 6 Self-Fed Cassava Peeling Machine Model C (a) Sides A and (b) Sides B.

Appendix II

Descriptive Statistics of Class A tubers at 1000:1400rpm

Trial	M_{pi}	M_{pd}	F	M_c	M_{pr}	M_{po}	M_f	η	L	e
1	8.0	2.0	24	6.8	1.2	0.84	1.16	0.41	0.15	0.35
2	8.4	1.6	28	7.6	0.8	1.24	0.36	0.61	0.05	0.58
3	8.6	1.4	26	7.8	0.8	1.24	0.16	0.61	0.02	0.60
4	8.4	1.6	26	7.2	1.2	0.84	0.76	0.41	0.10	0.37
5	8.4	1.6	25	7.4	1.0	1.04	0.56	0.51	0.07	0.47
Min	8.0	1.4	24	6.8	0.8	0.84	0.16	0.41	0.02	0.35
Max	8.6	2.0	28	7.8	1.2	1.24	1.16	0.61	0.15	0.60
Mean	8.36	1.64	25.8	7.36	1.0	1.04	0.60	0.51	0.078	0.474
SD	0.219	0.219	1.483	0.385	0.200	0.200	0.385	0.100	0.050	0.115

Descriptive Statistics of Class B tubers at 1000:1400rpm

Trial	M_{pt}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_f	η	ℓ	e
1	8.2	1.8	26	7.4	0.8	1.24	0.56	0.61	0.07	0.56
2	8.4	1.6	25	7.8	0.6	1.44	0.16	0.71	0.02	0.69
3	7.8	2.2	28	7.4	0.4	1.64	0.56	0.80	0.07	0.74
4	8.2	1.8	27	7.6	0.6	1.44	0.36	0.71	0.05	0.68
5	8.0	2.0	27	6.8	1.2	0.84	1.16	0.41	0.15	0.35
Min	7.8	1.6	25	6.8	0.4	0.84	0.16	0.41	0.02	0.35
Max	8.4	2.2	28	7.8	1.2	1.64	1.16	0.8	0.15	0.74
Mean	8.12	1.88	26.6	7.4	0.72	1.32	0.56	0.648	0.072	0.604
SD	0.228	0.228	1.140	0.374	0.303	0.303	0.374	0.149	0.048	0.157

Descriptive Statistics of Class C tubers at 1000:1400rpm

Trial	M_{pi}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_r	η	ℓ	e
1	8.0	2.0	22	7.2	0.4	1.64	0.76	0.8	0.10	0.72
2	7.8	2.2	23	7.8	0.2	1.84	0.16	0.9	0.02	0.88
3	8.0	2.0	28	7.2	0.2	1.84	0.76	0.9	0.10	0.81
4	8.0	2.0	24	7.4	0.4	1.64	0.56	0.8	0.07	0.74
5	7.4	2.6	24	7.4	0.2	1.84	0.56	0.9	0.07	0.84
Min	7.4	2.0	22	7.2	0.2	1.64	0.16	0.8	0.02	0.72
Max	8.0	2.6	28	7.8	0.4	1.84	0.76	0.9	0.10	0.88
Mean	7.84	2.16	24.2	7.4	0.28	1.76	0.56	0.86	0.072	0.798
SD	0.228	0.228	1.304	0.245	0.109	0.109	0.245	0.055	0.033	0.067

Appendix III

Descriptive Statistics of Class A tubers at 1500:2100rpm

Trial	M_{pi}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_f	η	ℓ	e
1	6.8	1.6	0.44	6.8	1.6	0.44	1.16	0.22	0.15	0.19
2	5.8	1.4	0.64	5.8	1.4	0.64	2.16	0.31	0.27	0.22
3	6.2	1.4	0.64	6.2	1.4	0.64	1.76	0.31	0.22	0.24
4	6.2	0.8	1.24	6.2	0.8	1.24	1.76	0.61	0.22	0.48
5	6.0	1.2	0.84	6.0	1.2	0.84	1.96	0.41	0.24	0.31
Min	5.8	0.8	0.44	5.8	0.8	0.44	1.16	0.22	0.15	0.19
Max	6.8	1.6	1.24	6.8	1.6	1.24	2.16	0.61	0.27	0.48
Mean	6.2	1.28	0.76	6.2	1.28	0.76	1.76	0.372	0.22	0.288
SD	0.559	0.559	1.140	0.374	0.303	0.303	0.374	0.149	0.044	0.116

Descriptive Statistics of Class B tubers at 1500:2100rpm

Trial	M_{pt}	M_{pf}	T	M_{c}	M_{pr}	M_{po}	M_{f}	η	ℓ	e
1	8.8	1.2	25	7.8	1.0	1.04	0.16	0.51	0.02	0.50
2	8.6	1.4	22	7.8	0.8	1:24	0.16	0.61	0.02	0.60
3	8.2	1.8	22	7.4	0.8	1.24	0.56	0.61	0.07	0.57
4	8.4	1.6	23	7.6	0.8	1.24	0.36	0.61	0.05	0.58
5	8.4	1.6	22	7.8	0.6	1.44	0.16	0.71	0.02	0.70
Min	8.2	1.2	22	7.4	0.6	1.04	0.16	0.51	0.02	0.5
Max	8.8	1.8	25	7.8	1.0	1.44	0.56	0.71	0.07	0.7
Mean	8.48	1.52	22.8	7.68	0.8	1.24	0.28	0.61	0.036	0.59
SD	0.228	0.228	1.304	0.179	0.141	0.141	0.179	0.070	0.023	0.072

Descriptive Statistics of Class C tubers at 1500:2100rpm

Trial	M_{pt}	M_{pt}	T	M_c	M_{pr}	M_{po}	M_r	η	ℓ	e
1	8.0	2.0	22	7.8	0.2	1.84	0.16	0.9	0.02	0.88
2	7.8	2.2	23	7.6	0.2	1.84	0.36	0.9	0.05	0.85
3	8.0	2.0	28	7.6	0.4	1.64	0.36	0.8	0.05	0.76
4	8.0	2.0	24	7.8	0.2	1.64	0.36	0.8	0.05	0.78
5	7.4	2.6	24	7.2	0.2	1.64	0.96	0.8	0.03	0.72
Min	7.4	2.0	22	7.2	0.2	1.64	0.16	0.8	0.02	0.72
Max	8.0	2.6	28	7.8	0.4	1.84	0.96	0.9	0.05	0.88
Mean	7.84	2.16	24.2	7.60	0.24	1.72	0.44	0.84	0.04	0.798
SD	0.261	0.261	2.280	0.245	0.089	0.110	0.303	0.055	0.014	0.066

Appendix IV

Descriptive Statistics of Class A tubers at 2000:2800rpm

Trial	M_{pt}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_f	η	ℓ	e
1	6.6	1.2	21	7.4	1.4	0.64	0.56	0.31	0.07	0.29
2	6.4	0.8	20	7.6	1.6	0.44	0.36	0.22	0.05	0.21
3	8.0	1.0	18	7.0	2.0	0.04	0.96	0.02	0.12	0.02
4	7.2	0.8	20	7.4	1.8	0.24	0.56	0.12	0.07	0.11
5	6.8	1.4	19	7.4	1.2	0.84	0.56	0.41	0.07	0.38
Min	6.4	0.8	18	7.0	1.2	0.04	0.36	0.02	0.05	0.02
Max	8.0	1.4	21	7.6	2.0	0.84	0.96	0.41	0.12	0.38
Mean	7.0	1.04	19.6	7.36	1.6	0.44	0.6	0.216	0.076	0.202
SD	0.632	0.261	1.140	0.243	0.323	0.322	0.376	0.153	0.026	0.142

Descriptive Statistics of Class B tubers at 2000:2800rpm

Trial	M_{pi}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_f	η	ℓ	e
1	8.6	1.4	22	7.4	1.2	0.84	0.56	0.41	0.07	0.38
2	8.2	1.8	19	7.2	1.0	1.04	0.76	0.51	0.10	0.46
3	7.8	2.2	21	7.2	0.6	1.44	0.76	0.71	0.10	0.18
4	7.6	2.4	21	6.6	1.0	1.04	1.36	0.51	0.17	0.42
5	8.0	2.0	20	7.2	0.8	1.24	0.76	0.61	0.10	0.55
Min	7.6	1.4	19	6.6	0.6	0.84	0.56	0.41	0.07	0.18
Max	8.6	2.4	22	7.4	1.2	1.44	1.36	0.71	0.17	0.55
Mean	8.04	1.96	20.6	7.12	0.92	1.12	0.84	0.55	0.108	0.398
SD	0.385	0.385	1.140	0.303	0.228	0.228	0.303	0.114	0.037	0.137

Descriptive Statistics of Class C tubers at 2000:2800rpm

Trial	M_{pt}	M_{pf}	T	M_c	M_{pr}	M_{po}	M_f	η	ℓ	e
1	7.2	2.8	22	6.4	0.8	1.24	1.56	0.61	0.20	0.49
2	6.8	3.2	20	5.8	1.0	1.04	2.16	0.51	0.27	0.37
3	8.2	1.8	19	7.6	0.6	1.44	0.36	0.71	0.05	0.67
4	7.6	2.4	20	7.0	0.6	1.44	0.96	0.71	0.12	0.62
5	8.0	2.0	21	7.2	0.8	1.24	0.76	0.60	0.10	0.54
Min	6.8	1.8	19	5.8	0.6	1.04	0.36	0.51	0.05	0.37
Max	8.2	3.2	22	7.6	1.0	1.44	2.16	0.71	0.27	0.67
Mean	7.56	2.44	20.4	6.8	0.76	1.28	1.16	0.628	0.148	0.538
SD	7.56	2.44	20.4	0.707	0.167	0.167	0.707	0.084	0.087	0.117