INFLUENCE OF AGEING ON SELECTED ENGINEERING PROPERTIES OF CASSAVA [*MANIHOT ESCULENTA* (CRANTZ)] ROOTS

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DEDICATION

This work is dedicated to the Almighty Allah and for the benefit of mankind

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I certify that this work was carried out by **ORIOLA,** Kazeem Olaniyi under my supervision in the Department of Agricultural and Environmental Engineering, University of Ibadan.

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ABSTRACT

Postharvest processing of cassava roots is faced with problem of ineffective machines in Nigeria. Physiological changes associated with the common practice of leaving matured roots un-harvested until when needed may affect their engineering properties which determine design parameters. Information on the engineering properties of cassava as affected by age, needed for appropriate machine design is scarce. This study was conducted to investigate the influence of ageing on some engineering properties of cassava roots

Three cassava varieties, TME 419, TMS 30572 and TME 7, were each harvested at 12, 15 and 18 Months After Planting (MAP). Root mass, length, diameter and peel thickness at the top, middle and bottom sections, Peel Proportion by Weight (PPW) and Moisture Content (MC) were determined. In addition, Coefficient of Friction (COF), Coefficient of Internal Friction (CIF), Coefficient of Rolling Resistance (CRR), and strength properties (stress, stiffness and toughness) were also determined at the ages. The COF and CRR were determined on Stainless Steel (SS), Galvanized Sheet (GS) and wood surfaces. All were done according to ASABE standards. Data were analyzed using descriptive statistics, regression and ANOVA at $p = 0.05$.

Mass of TME 419 and TME 7 increased from 262.7±143.4 and 229.9±147.0 to 483.5±245.2 and 489.1±274.3 g between 12 and 18 MAP respectively, while TMS 30572 reduced after 15 MAP. Length and diameters of TME 419 and TMS 30572 reduced after 15 MAP while peel thicknesses increased with age. The TME 419 produced lowest PPW at 12 MAP and highest at 15 MAP while the moisture contents of roots ranged from 70.0% to 74.0% (wet basis). The COF of TMS 30572 across ages (12 to 18 MAP) ranged from 0.16 to 0.29, 0.42 to 0.53 and 0.61 to 0.79 on SS, GS and wood respectively. The TME 419 and TME 7 had the least COF on GS and wood at 15 MAP. The CIF peaked at 15 MAP for all the varieties. On all the surfaces, CRR peaked at 15 MAP for TMS 30572, decreased for TME 419, and decreased on SS and wood surfaces for TME 7, at this same age. The CIF decreased while COF increased with increase in MC. Age and MC significantly affected COF and CIF while peel significantly affected CRR. High COF on wood suggested high angle of inclination in wooden container design and storage structures. Low CRR implied that the roots would not slide but roll on all the surfaces. Peak stress, stiffness and toughness ranged from 0.41 to 1.30 N/mm^2, 3.22 to 9.28 N/mm^2 and 3.23 to 9.82 N.m respectively across ages and increased with increase in MC showing that roots require low power during processing. Influences of age and MC on the strength properties of TMS 30572 were not significant whereas TME 419 strength properties depended on age. Neither age nor MC significantly influenced the strength properties of TME 7.

Root age and variety strongly influenced the engineering properties of cassava roots. Machine designers therefore need to take into consideration the properties of cassava roots across ages and variety for effective mechanical processing operations.

Keywords: Cassava root age, Physico-mechanical properties, Postharvest processing.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

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, but it is now grown in all the tropical countries of the world. 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. The world's total land area under cassava cultivation was 16.8 million hectares in 2002 with estimated output of 184 million tons (FAO, 2004). Fifty four percent of this output figure came from Africa, while Asia, Latin America and the Caribbean accounted for twenty eight percent and nineteen percent respectively. Also, Sub-Sahara Africa accounted for fifty percent of the world's total land area under cassava cultivation, with an average yield of 10.2 tons/ha. Total world production of cassava in 2010 was 228 metric tons, harvested from 18.4 million hectares (FAO, 2011)

However, the level of cassava production in Nigeria is by far the largest in the world with its production level initially estimated at 37.5million tons per year (FAOSTAT, 2010) and currently estimated at 54 million tons per year (FAOSTAT, 2012). 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. It is often grown in Nigeria on farm sizes of about 2-3 hectares across the country with the North central zone (Kogi, Benue and Nassarawa States) being the highest producers with over 7 million tons of cassava between

2000 and 2002 (IITA, 2004) and the North East being the lowest producers with 0.14 metric tons.

1.2 Cassava Varieties

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 such as *Oko iyawo* (TME 7), *Ole-kanga* (TMS 30395), *Dan Warry*, and *Nwagoye* mature in twelve months and can remain in the soil for two years without deteriorating but, some improved cassava varieties such as the TMS 30572, TMS 4(2) 1425, TMS 98/0510 TMS 97/2205, TME 419 etc have been developed by the International Institute for Tropical Agriculture (IITA), Ibadan, in collaboration with the National Root Crop Research Institute (NRCRI), Umudike. These mature as early as six months after planting. They are high yielding with cyanide contents as low as 3.1mg/100g, high dry matter and starch content, and are more resistant to pests and diseases (Ikuomenisan, 2001; FIIRO, 2006). These beneficial attributes have boosted cassava yield by 40% (Nweke, 2004) and this, perhaps explains the increased production level in Nigeria which made her the world number one cassava producer (Kolawole *et al.*, 2010). Cassava 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 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; Agbetoye, 2005; Quaye *et al.*, 2009). 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.

Nweke (2004), however reported that the high yield obtained by planting these improved cassava cultivars often lead to another labour bottleneck at the harvesting and processing stages due to the labour-intensive nature of the traditional methods being utilized which consequently makes labour the main item in the cost of production of cassava-based products. Invariably, the number of scarce labour required for processing increases in direct proportion to yield, whereas, wages of hired labour are continually increasing thereby forcing a suspension of production in some cases. Addressing this problem through mechanization would not only improve productivity at reduced costs in cassava sub-sector, it would raise the farmers' income level and also confer attractive prices on cassava-based products of Nigerian origin in the international market as against the present situation where its prices make it unattractive (Nweke, 2004).

However, research works have always concentrated on increasing cassava yield through the development and diffusion of the improved varieties without corresponding follow-up studies on their engineering properties thereby making it extremely difficult to find relevant information for the purpose of designing machines for processing and handling of the tubers of these well adopted new improved cultivars in order to match processing with the increased yield. Information on the engineering properties of the crop is pertinent because irrespective of the class a given cassava variety belongs, a wide variation exists between the tubers especially the physical properties. A lot of differences exist in the shape, size, weight, diameter etc of tubers of different cassava clones as well as tubers harvested from the bottom of the same plant stem (Odigboh, 1976; Adetan *et al.*, 2003) which poses a major challenge to the efforts at mechanizing the postharvest operations of the tubers, most especially peeling.

1.3 Processing and Utilization of Cassava

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), and the physiological changes which accelerate rot and decay (Wenham, 1995). The best form of preservation and reduction of post harvest losses is therefore immediate processing into various shelf stable products.

Cassava is processed into some more stable and storable forms by variety of methods and used in diverse ways depending on the locality and preference. But, it is exclusively used as food in Africa, with minimal utilization for industrial purposes.

Although, it has the potential, cassava has so far contributed little to foreign exchange earnings, import substitution, industrialization and poverty alleviation in Nigeria. This may not be unconnected with the crude methods of producing and processing the crop which is characterized by low output capacity per day and drudgery, indicating the need for its production and processing to be urgently modernized or mechanized if the current and future industrial and international demand for the crop and its products is to be adequately met and sustained at affordable cost.

In fact, the ten percent substitution of wheat flour with cassava flour stipulated by the government in 2002 has been reduced to five percent at the end of the first quarter of 2007 due to the inability of Nigerian cassava farmers and processors to meet up with the challenges posed by the cassava initiative (Ajobo, 2007). This reduction happened at a time that the percentage was expected to be increased to about twenty five percent according to the initial calculations of the initiative**.**

1.4 Mechanization of Cassava Processing Operations

Mechanization of cassava processing operations will no doubt play a pivotal role in removing the drudgery associated with the traditional processing techniques and promote large scale production. The current traditional processing methods encourage waste as the crop is supplied in large quantity but processed (from peeling to the end products) manually. When peeling is done manually, more time is expended such that the tubers deteriorate, leading to waste, low yield and low product quality (Sheriff *et al*., 1995). Traditional chipping method also produces chips of unequal sizes and shapes leading to uneven and prolonged drying resulting in unhygienic and low quality products. The two operations of peeling and chipping are slow, tedious and dangerous as body injuries could be readily sustained, when carried out traditionally, thus further slows down the operations. Therefore, mechanization of these operations is imperative especially to match the rate of supply with the high demand initiated by the increase in number of cassava-based products and industries in the country.

Traditional cassava grating techniques is both dangerous and unhygienic as operators' fingers get injured easily and their hands could get the product contaminated. Grating is done traditionally over punched holes on a metal sheet by pressing and rubbing the tuber with fair pressure against the holes. This process is both energy and time consuming. It therefore fails to lend itself to increased production (Kolawole *et al.*, 2007)

Dewatering is another cassava processing operation which is a pre-drying alternative. It is traditionally done by bagging the mashed cassava and placing it under heavy materials like stones and scraped automobile engine blocks for 2-4 days for it to ferment at the same time. It is often necessary especially for *gari* and cassava flour production. The dewatering environment is often generally unsanitary and unwholesome. This method is definitely not employable for cassava flour production which requires no fermentation during dewatering. Also, the traditional *gari* processing method is characterized with low output, non-uniform product quality. Igbeka *et al.* (1992) as reported by Adzimah and Gbadam (2009) observed a wide variation in product quality from one operator to the other and at times from the same processor (from one batch to another), hence, the need for the mechanization of all the unit operations involved in cassava processing.

Mechanizing cassava processing operations would require the design and development of equipment such as peelers, graters, chippers, dewatering machines, pelletizers, dryer etc. A few machines have been developed to address these needs but they were not adequately design based on the engineering properties of cassava. These machines are generally characterized by poor efficiencies and they consequently enjoy low patronage from the processors which in turn makes it difficult for indigenous producers to meet the domestic and international demand both in quality and quantity. And, this has hampered the full exploitation of the crop as a fulcrum for driving the nation's economy in terms of job creation, energy supply, foreign exchange earnings, food security etc. which the Federal government cassava initiative set out to achieve. This is due to the inability of the cassava producers to meet the targeted supply level triggered off by the federal government directives of ten percent substitution of wheat flour with cassava flour - a consequence of the traditional processing techniques. It was envisaged by the Government that the former directive that 10% of wheat flour should be substituted for cassava flour would later be increased, and with time achieve 100% cassava flour for bread in the country as in Brazil, Thailand etc (Onwualu, 2007) Instead of the envisaged increased in the percentage of cassava flour to be substituted in wheat flour, a decrease to 5% was lately announced. The flour millers were eager to increase the cassava-wheat flour ratio but the commodity could not be found in the market – a situation attributed to the inability of the processors (not the growers) to match their production level with the increase in demand for their products, and low quality of the little that was produced (Ajobo, 2007) - A situation of large-scale demand but subsistent processing rate.

A lot of attempts are being made to develop some of these required equipment (Ezekwe, 1979; Odigboh, 1983; Ejovo *et al.*, 1988: Ajibola *et al.*, 1991; Cao *et al.*, 1995; Akinyemi *et al.,* 1999; Aravie and Ejovo, 2002; Akor and Zibokere, 2002). However, a major constraint is their poor quality and efficiencies. Data on the rate of adoption of these few equipment remain scanty but it is generally low because cassava processing operations is still largely done manually.

The problems with these machines include removal of unacceptable percentage of useful flesh during mechanical peeling, reduction in peeling efficiency with increased time of operation, production of grated cassava mash 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)

Based on the foregoing, it is apparent that, currently there is yet to be an indigenous cassava processing machine operating satisfactorily in the field in terms of efficiency, effectiveness and economy, although some level of success has been recorded with graters, dewatering tools and flash dryers (IITA, 2006; Kolawole *et al.*, 2010). The modest success recorded so far at the mechanization attempts is not unconnected with the dearth of relevant technical information on the engineering properties of the crop relating to each of the unit operations involved in its processing which would have guided the designers of these machines aright. This scarcity of relevant technical information on cassava in the form of data bank or baseline data can be attributed to the past lowly status of the crop in the society which accorded it little research attention relative to other crops like grains which are now enjoying full mechanization from planting to harvesting and processing. Methods of measuring the engineering properties of agricultural materials have long been developed and applied to many crops but not to most tropical crops especially cassava roots (Nwanekezi and Ukagu, 1999; Oke *et al.*, 2007). The direct consequence of which is the scarcity of sufficient data on the engineering properties of the root, hence, most of the existing cassava processing machines were merely fabricated without adequately following the appropriate design processes (Kolawole *et al.*, 2010).

1.5 Engineering Properties of Cassava Tubers and Products

Food materials, right from production to storage and consumption are subjected to various physical, mechanical, thermal and other engineering related processes. The engineering properties of biological materials play very important roles in the design of machines, processes, handling, and preservation operations. There are many engineering properties relevant to the mechanization of cassava processing operations with each stage requiring the determination of these properties specifically to suit a particular unit operation being considered. For instance, the mechanical properties of cassava determined by Aseogwu (1981) were in relation to reducing breakage during mechanical harvesting of cassava which may not be relevant or useful for the purpose of mechanizing the processing operations.

Effective mechanization of cassava peeling operation would require a good knowledge of the physical properties of the crop such as peel thickness, root surface taper angle, root diameter, length, tuber density, bulk density etc. All these properties would affect the geometry and orientation, among others, of the peeling knife or peeling mechanism of the machine. A good understanding of the coefficient of friction of the tuber on different surfaces, coefficient of rolling resistance etc may also be necessary. The low efficiency of the current peeling machines, most of which were developed by artisan is a proof of the fact that most of the above mentioned parameters were not considered properly or not considered at all during their development stages.

The bulk density, length, weight, diameter etc of the tubers are essential features that are needed to be considered for effective mechanical chipping and grating operations. Chipping of cassava tuber cannot be said to be effective until uniformly shaped chip can be obtained in order to ensure uniform drying of the chips/grates. Non-uniformity would make effective application and control of heat difficult during the drying or frying stage. Besides, it makes prediction and optimization of the drying rate and drying process difficult (Agbetoye and Oyedele, 2007; Diop, 1998).

Full mechanization of the dewatering operation would be essentially dependent on the knowledge of optimum final moisture content range. Kolawole *et al.* (2007a) reported that beyond certain range of moisture content during dewatering, the final product quality was not acceptable. Also the bulk density of the grated mash and that of the resulting cake are relevant mechanical properties in this regard including cake resistance to pressure, minimum pressure required for dewatering etc. All these affect the dewatering rate of the mash, likewise the particle size.

The optimum chip size and shape and particle size of mash are some of the properties relevant to drying and frying of the products. Thermal conductivity, diffusivity and specific heat as a function of moisture content as well as the drying rate as a function of air temperature and speed are all essential properties, the knowledge of which are of great importance to development, prediction and optimization of heat treatment processes and control.

Cassava has transformed into an important industrial raw material for the production of quite a large number of products. However, its post harvest processing operations are still being done traditionally, thereby making processing of the crop to lag behind its production. Besides, its poor storability forces cassava farmers and users alike to leave the crop in the ground for a long period of time after maturity, a practice which gives rise to lignification of the tubers and changes in its engineering properties due to delayed harvesting operation thereby contributing to the challenges of mechanizing its postharvest operations

1.6 Objectives

The main objective of this study is therefore to study the influence of age and moisture content on selected physical and mechanical properties of three cassava varieties. The specific objectives are;

- To determine the following physical properties for the three cassava varieties; root length, diameter, peel thickness, peel proportion by weight, mass, and solid density at the ages of 12, 15 and 18 months after planting.
- To determine the coefficients of friction, internal friction and rolling resistance of the tubers on stainless steel, galvanized sheet and wood surfaces at ages 12, 15, and 18 MAP and moisture content of 40, 45, 50, 55 and 60% (wet basis)
- To determine the stress at peak, Young's modulus and the Energy to break for three cassava varieties at ages 12, 15, and 18 MAP and moisture contents of 50, 55, 60, 65, and 70% (wet basis).
- To study the variation of the engineering properties with moisture contents and tuber age within and across the three cassava varieties.
- To develop a mathematical model relating the engineering properties with moisture content and age.

1.7 Justification

The need for mechanization of cassava processing operations cannot be over-emphasized. The traditional processing methods are time consuming, tedious, at the mercy of the natural weather (for drying and frying), hazardous to operators, unhygienic and unsafe products with low quality, thereby enjoying low acceptability. More importantly it does not lend itself to large-scale production. The subsistent nature of this crude techniques make it difficult to fully exploit the benefits of the crop like other cassava producing countries of the world that are now enjoying 100% cassava- based bread, automobile fuel, starch etc. The Federal Government's directives that flour millers should include 10% of cassava flour in their product could not be sustained as this percentage has now been reduced to 5% due to the inability of cassava processors to provide the needed quality and quantity to meet the demand of the millers occasioned by the directive. Even at 5%, millers are still finding it very difficult to get enough of the commodity to meet their daily requirement. This problem could be attributed to the crude processing technology being employed in the country which hampers a positive response of the processors to the surge in demand to the tune of 600,000 tons of processed cassava per day. Same for the textile industries, pharmaceutical industries etc. and the home-stead (for consumption). Hence, the need for efficient mechanization of cassava processing operations to make cassava-based enterprises more attractive to stakeholders and more responsive to industrial demand has become increasingly important (FAO, 2002, Agbetoye, 2003; 2005; Davies *et al.*, 2008).

Moreover, processing cost has been the major single factor in the cost of production of cassava products due to the prevailing traditional method being used. The key to cassava's future in global and domestic starch markets, according to IFAD/FAO (2004) will be improvements in efficiency and quality, and a reduction in production costs. This can only be achieved through the development of more efficient and effective cassava processing machines produced from results of in-depth research studies on the currently scarce engineering properties of the tuber and its products.

A successful mechanization effort depends heavily on this knowledge which is presently inadequate, but can only be solved through an in-depth study of the engineering properties of the roots relevant to all its processing stages as suggested by Agbetoye (2005) that design engineers and processors should start all over again from fundamental principles such as the engineering properties of the roots, among other things, in order to generate design data for eventual development of improved cassava processing machines. Additionally, studying the engineering properties of the tubers with respect to age may be necessary, since the lately harvested tubers would still end up being processed and handled with machines. Therefore, this study attempts to provide this needed technical information, (with respect to tuber age) sufficient enough to form a data base which would promote a scientific design and development of effective and efficient mechanized postharvest cassava processing equipment and processes so as to remove the negative attributes of the manual processing methods and enhance a full exploitation of the numerous benefits of the crop.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General

The vast number of products derivable from cassava both domestically and industrially, coupled with the ever increasing global demand for its products in the form of chips and pellets, is fast turning the plant into a wonder crop that earns foreign exchange for the producing countries (Olukunle *et al.*, 2010). However, Nigeria, even though the world leading cassava producer, is presently under utilizing the commercial potential of the crop (Ajibola, 2000), due largely to the prevalence of traditional processing methods employed (Westby, 2002). This, perhaps, accounts for the present situation in the country whereby limited quantities of cassava-based products are exported as a result of the inability of such products to meet the international standards for healthy foods (Adetunji and Quadri, 2011). Igbeka, (1985), Agbetoye, (2003), and Agbetoye and Kolawole, (2007) have all at different times underscored the need to mechanize cassava processing operations in order to eliminate the undesirable attributes of the traditional processing methods and more importantly to enhance the commercial value of its products as well as supporting national economic and industrial growth.

Processing cassava into different finished or semi-finished products entails a lot of unit operations which includes all or some of the following; peeling, chipping, grating, pressing, milling, sifting, frying, drying etc. 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 its 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).

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Several attempts have been made at full mechanization of cassava processing operations especially for *gari* production. These have resulted into 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 (Akande and Ogundele, 2005); various types of cassava chipping machines (Raji and Igbeka, 1994; Bamgboye and Adebayo, 2009). However, most of these machines have been widely acknowledged as being inefficient (Adetan *et al*., 2006; Davies *et al*. 2008; Kolawole *et al.*, 2010). For instance Bamgboye and Adebayo (2009) reported that the efficiency of their cassava chipping machine was 60.1% with a percentage loss of 5.5%. Also, Davies *et al.* (2008), in a survey conducted to assess the level of mechanization of cassava processing operations in Iwo Local Government Area of Osun State, Nigeria, reported that peeling, washing, chipping, drying and gari frying operations are still predominantly done manually. Adetan *et al*. (2003) also confirmed this and proceeded to study the engineering properties of the roots relevant to its mechanical peeling operation. This is due to the fact that the properties of cassava roots reported in previous studies were either unsuitable or insufficient to form a database for the scientific design and development of cassava processing machines (Adetan *et al.*, 2003). This gives room for the use of values of engineering parameters that were haphazardly determined with limited samples whenever the need to design and develop handling machines for the roots arises (as in Ashaolu, 1989 and Akintunde and Akintunde, 2001 and, Bamgboye and Adebayo, 2009).

2.2 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. Before now, most of the research efforts at developing a suitable peeler have been concentrated on the use of abrasive drum to achieve the peeling (Ezekwe, 1979; Nwokedi, 1984). 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.

Akintunde *et al.* (2005) also designed a cassava peeling machine that worked based on the 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 the opposite directions. They reported a peeling efficiency of 83% and an average percentage flesh loss of 5.38% but they concluded that 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 be due to the force required to bring about peeling which was not actually used in the design calculations, instead, the report appeared to have based the calculation on the torque needed to peel cassava and an arbitrary values seemed to have been used.

Ejovo *et al.*, (1988) later developed a rotary batched cassava peeler that worked based on a novel peeling concept involving compression of the unpeeled tuber against a sharpedged 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 the importance of the stage of maturity of the roots to the success 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). Adetan *et al.* (2006) also modeled and validated a model with data from the 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 most 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.

A collaborative work between IITA and FUTA in 2005 was reported to have resulted in the development of a single and double gang hand-fed peeling machine which peels 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 (Akande and Ogundele, 2005), likewise cassava chippers (Kordylas, 1990; Ajibola *et al.* 1991; Balasubramanian *et al.*, 1993; Raji and Igbeka, 1994; 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 (presses) 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 Iwo Local Government of Osun State. Alagbe (2012) confirmed these shortcomings of the grating machines and further added that the grating rate was slow unless pressure was applied with the use of a short stick to force the tubers onto the surface of the grating mesh, thereby necessitating the need to station a person permanently on the operation. Consequently, the cost of operating the machine rose, thereby reducing the profit margin of the processors.

Another major problem is the different particle sizes obtained from the various types of graters (Igbeka *et al*., 1992; FIIRO., 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 and Agbetoye 2007). 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 well as the upright section of the press due to 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 which consequently makes the work tedious and limited the capacity of the press per batch. (Alagbe, 2012). 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 cassava roots.

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 acquisition of any 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.* (2007a).

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). Iwuoha (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. Aliyu and Jubril (2009) also developed and tested a solar dryer and concluded that its performance was affected by cloudy weather and rain. Existing models of indigenous cassava flash dryers are not yet efficient. They have limited capacities with poor fuel or energy efficiencies (Agba, 2008). Ajao and Adegun (2009) reported a 57.1% dryness of cassava mash from a mini flash dryer after three passes and concluded that a greater need for improvement in component designing, assembly and testing over a period was necessary for better performance. It is noteworthy, however, that no evidence of consideration of the engineering properties of cassava were found in the processes leading to the development of most of these dryers.

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 than the first and that drying is controlled by liquid diffusion.

Cassava mash frying (also known as garification), is traditionally done by continuously turning the mash (in batches) in a big pan over a firewood stove. This method is time consuming and hazardous to the operators as the smoke from the fire affects their eyes. Also, the product quality varies between batches as the naked eyes are employed to test the quality in order to know the appropriate time to terminate the frying operation on a batch. Some gari frying machines have been attempted but with modest success (Odigboh and Ahmed 1982; Igbeka and Akinbolade 1986). The machines were found to be too complex for rural operator to maintain and for local artisans to fabricate. Besides they were too expensive even now that it is yet to be perfected (Samuel *et al*., 2010).

Olomo and Ajibola (2006) reported a good yield and better quality of starch from oven-dried cassava chips and flour as compared to those obtained from the sun dried cassava chip material. Hence, better exploit of the crop is guaranteed with improved processing techniques, thereby making the mechanized processing effort imperative.

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 problem 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 that 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 by the end users before adopting a new cassava processing technology which most of the existing machines currently lack.

2.3 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 to study 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 out without conscious effort at studying the effects of age on these properties.

In 1981, Aseogwu determined the stress relaxation modulus and creep compliance of cassava tubers which he thought were 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 numbers of specimens were used to study most of these parameters. For instance, these authors used only three specimens each to determine the five studied mechanical properties. 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 and 0.28 N/mm^2 for unpeeled and peeled tubers respectively) were closer to the 0.676 - 9.6N/mm^2 reported by Odigboh (1983) but in wide variation to the 21.8 – 87N/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.

Ademosun *et al.* (2012) also studied the engineering properties of eighteen months old cassava roots of unspecified variety which were obtained from two different locations in Nigeria and classified the roots based on the soil type and soil fertility of the locations where they were harvested. They reported the influence of environmental factors such as soil type and fertility on the physical properties of the roots and concluded that their results confirmed the influence of physico-mechanical properties of cassava roots on mechanical peeling.

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 0.047 N/mm^2 and 0.032 to 0.093 N/mm^2 were reported for compressive stress and strain respectively. Values ranging from 0.187 to 0.112 and 0.140 N/mm^2 to 0.048 N/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, Nwangugu 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.

2.4 Effects of Age on the 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 until 16 months in Thailand (Sriroth *et al*., 1999), up to 24 months in Nigeria (Ngendahayo and Dixon, 1998) and occasionally up to 48 months (Odigboh, 1976). Although, economic reasons are cited at times, but the main reason for this practice often time, 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).

However, only a few numbers of publications was found on the influence of tuber age on the engineering properties of cassava roots. 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. Only Kolawole *et al.*, (2007a) actually studied the influence of tuber age on the engineering properties of cassava by determining 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, as reported in section 2.2) 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.

Adejumo *et al.* (2011), in a review, underscored the importance of detailed information such as root age and varieties, among other things, in the study of cassava starch quality as these are some of the major factors that greatly affect the quality of starch products.

Also, Alagbe (2012) acknowledged the influence of tuber age on gari quality and yield, as well as the ease of peeling of the tubers. He, however, pointed out that this is not applicable to all the cassava varieties.

In addition, Prapapan *et al*. (2008) investigated the influence of tuber age and growing season on cassava starch granule size distribution of three Asian cassava cultivars. Their results showed that both age and prevailing environmental conditions at the time of harvest of the roots significantly influenced the size of the starch granules. The granule size of the starch was found to increase with age especially in the first six months after planting. Tubers of the cassava plants planted at the beginning of the raining season were also found to possess larger starch granules than those planted at the beginning of the dry season, implying that increased moisture or otherwise may affect the size of the starch granules of cassava when other factors are kept constant.

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 root.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Two improved cassava cultivars and one local cultivar namely TMS 30572, TME 419 and TME 7 respectively were used in this study. Cuttings of the two improved cassava varieties were obtained from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The cuttings of the local variety popularly called *Oko-iyawo* (TME 7) were sourced from local farmers. The three cassava varieties were selected for their popularity among the cassava farmers in Nigeria especially in the south-western part of Nigeria. These cuttings were used to establish an experimental farm in Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. The farmland was divided into three portions for each of the three cassava cultivars studied. A plant spacing of 1m x 1m was used with the stem cuttings placed in the soil in slanting position. The planting was deliberately done in April so that the period of the experiment fell within the raining season, as such, the moisture content of roots would naturally be around 65 – 70% (wb) (Ejovo *et al.* 1988; and Balasubramanian *et al.* 1993; Nwangugu and Okonkwo, 2009).

3.1.1 Preparation of Samples

The samples used for the determination of the coefficients of friction and internal friction were produced from freshly harvested tubers from the research farm which had earlier been established for this purpose. The rootss were cleaned and carefully cut, manually, into sizes of (30 x 20 x 10) mm using very sharp stainless steel knives (Chijindu *et al.*, 2008; Palaniswami and Peter, 2008; Tunde-Akintunde and Afon, 2009). The initial moisture content of the tubers was first determined with the use of an OHAUS MB 35 Halogen moisture analyzer. Thereafter, the samples were placed in a DHG 9101.1SA (UK) oven which had already attained a temperature of 70^{o}C. They were brought out in batches after attaining the desired moisture contents of 40, 45, 50, 55, and 60% (wb) and placed in a dessicator for about an hour for moisture equilibration before being used for experimentation.

The samples used for the determination of the strength properties were conditioned in the same way but in this case cylindrical samples of length 60mm and diameter 30mm were used (Kolawole *et al.*, 2007b). The compressive strength experiments were conducted with the Universal Testing Machine (Testometric series M500-25DDBMTCL-25kN).

3.2 Experimental Procedures

3.2.1 Measurement of Physical Properties of Cassava Tubers

Determination of the engineering parameters of each of the cassava varieties was carried out at 12, 15 and 18 Months After Planting (MAP) using fifty root samples selected randomly from the harvested lots. Whole length (in mm) of one hundred and fifty (150) pieces of cleaned unpeeled whole tubers, fifty (50) pieces from each of the three cassava varieties were measured with the use of a (0.01mm precision) vernier caliper and tape rule and subsequently recorded. The masses of each of the above mentioned unpeeled tubers (g) were determined with an electronic balance (Mettle Instrumente PJ6 (Switzerland) and subsequently recorded.

The same specimens whose lengths and weights were earlier measured (as above) were marked into three portions (head, middle and tail) and their diameters (mm) measured along these marked portions from the head to the tail along two perpendicular lines with a vernier caliper and the average values for the readings at each portion of the tuber were calculated. Thus three tuber diameters were obtained for each tuber. The tubers were then cut into three slices along the marked lines. Subsequently the peels (periderm + cortex) were carefully and neatly unrolled from the flesh (without any flesh loss to the peel). The thickness of the peels (in mm) unrolled from each of the slices was then measured with the caliper to obtained three values of peel thickness from each tuber (Plate 3.1).

Plate 3.1: Peel Thickness being measured with a Vernier Caliper

3.2.1.1 Peel Proportion by Weight

Freshly harvested tubers were weighed and the mass was recorded (M_1). The peels were then carefully removed as explained above. The peels from each of the tubers were then weighed (M_2) and recorded as shown in Plate 3.2 (Tabatabaeefar, 2002; Raji and Ahemen, 2011; Ademosun *et al*., 2012). Then the peel proportion by weight (PPW) (in percentage) compared to the tuber weight (M_1) was determined using Equation 3.1 (Adetan *et al.*, 2003).

$$PPW = \frac{M_2}{M_1} X100 \qquad (3.1)$$

3.2.1.2 Solid Density

Whole tuber of unpeeled cassava was weighed and the mass (M, g) recorded. It was dropped into a big cylinder of known volume which was filled to the brim with water. The over-flown water was then collected and the volume (V, cm^3) measured with measuring cylinder and recorded. The density (g/cm^3) was subsequently calculated using Equation 3.2;

$$D = \frac{M}{V} \qquad (3.2)$$

3.2.2 Determination of Mechanical Properties of Cassava Roots

3.2.2.1 Coefficients of Rolling Resistance

The inclined plane method was employed to determine the coefficients of friction and rolling resistance. A whole clean tuber was carefully placed on an inclined plane with adjustable angle of inclination (tilting top). The angle of inclination was raised until the tuber started rolling down the plane (Plate 3.3). The top of the table was then tilted with the specimen until the tuber just started rolling down the inclined plane. The angle at which this occurs was measured and recorded (Ejovo *et al.*, 1988). This was done using the periderm, the cortex, and the tuber flesh in turns on stainless steel, galvanized sheet and wood surfaces. The coefficient of rolling resistance was calculated from the formula,

$$\mu = R \tan \theta \qquad (3.3)$$

Where,

μ = Coefficient of rolling resistance

R = Average radius of the tuber

θ = Angle of inclination at the start of rolling or sliding

Each measurement was replicated five times for each variety of cassava.

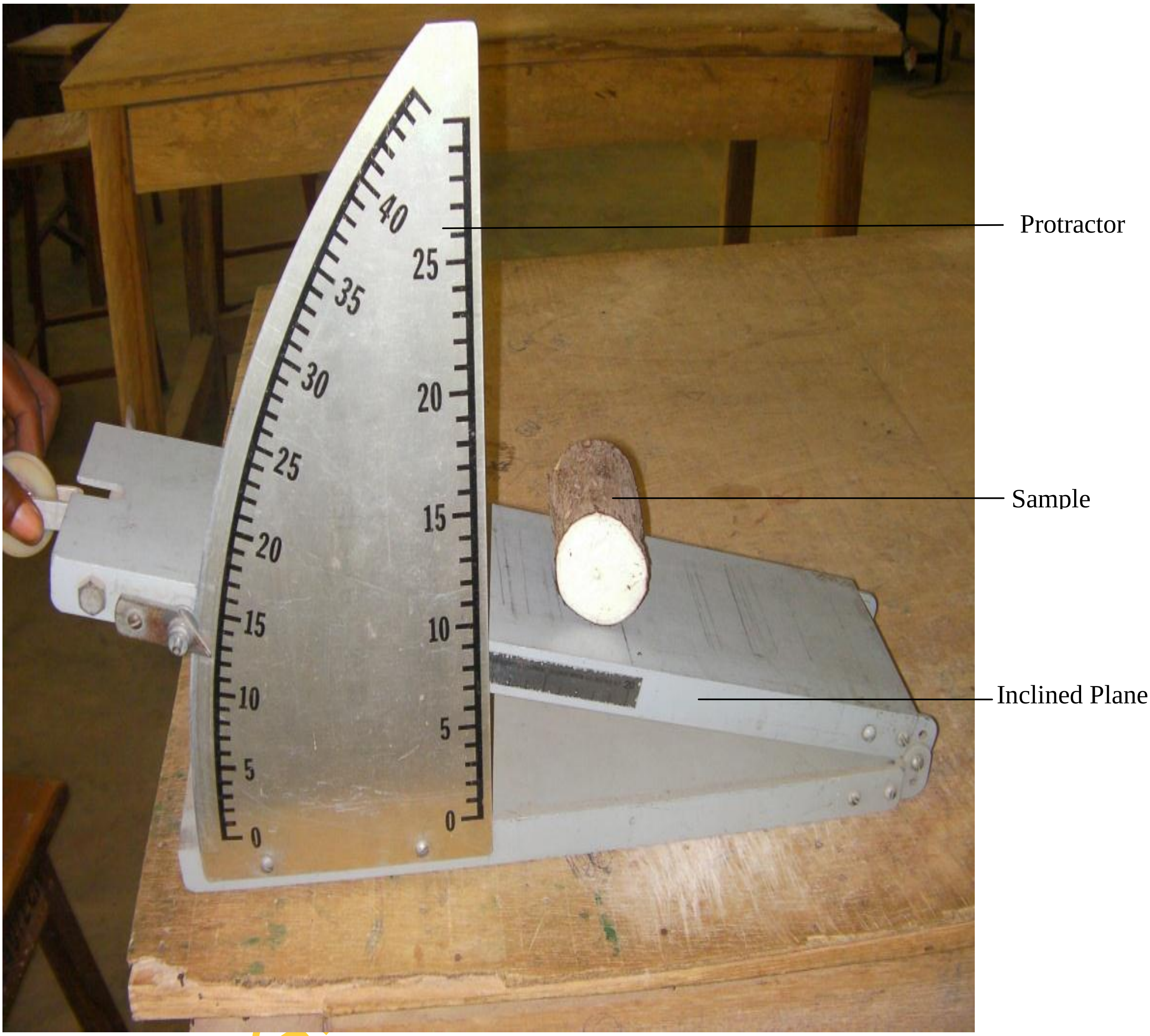


Plate 3.2: Setup for the Determination of Coefficient of Rolling Resistance

3.2.2.2 Determination of Coefficient of Friction of Cassava Roots

The coefficient of friction of the roots was determined using the inclined plane with adjustable top (Plate 3.4). Cassava chips of size 30 x 20 x 10 mm (Chijindu *et al.*, 2008; Tunde-Akintunde and Afon, 2009) was placed on the table and tilted until sliding occurred. The angle at which this occurs was noted and recorded. The tangent of this angle gave the coefficient of friction of the chip (Raji and Ahemen, 2011). This experiment was replicated five times each and the values averaged. The coefficient of friction was determined at different moisture contents of 50, 55, 60, 65, and 70% (w.b) for all the varieties studied.

3.2.2.3 Determination of Coefficient of Internal Friction of Cassava Roots

The coefficient of internal friction of cassava roots was determined using chip samples of size 30 x 20 x 10 mm. A big wooden frame of size 30 x20 x 10cm and a smaller guide block of size 20 x 10 x 10 cm were used in addition to a frictionless pulley, a chord and a scale pan (Plate 3.5).

The two guide blocks were filled with chip samples. The smaller frame was placed atop the bigger. A light chord attached to the smaller frame was passed over the frictionless pulley. The other end of the chord bored the scale pan. Weights were then added to the scale pan until sliding occurs. The weight (W_1) causing the sliding was noted and recorded. The smaller block was then emptied and placed back on the bigger frame and the experiment repeated. The weight (W_2) causing sliding of the empty frame was also noted (Akaimo and Raji, 2006; Raji and Ahemen, 2011). The coefficient of internal friction was then calculated at the above mention moisture contents as;

$$\mu = \frac{W_2 - W_1}{W} \qquad (3.4)$$

Where,

$W_2 – W_1$ = Weight required to slide the sample material (g)

W = Weight due to the sample material in the cell = vol. of cell (cm^3) x bulk density (g/cm^3).

μ = Coefficient of internal friction

Five replicates of each experiment were produced at each moisture level.

3.2.2.4 Determination of Compressive Strength Properties of Cassava Tubers

Strength properties such as force at peak and force at break, stress at peak and stress at break, modulus of elasticity, deformation at peak and deformation at break were those parameters that were determined for the tubers using the Universal Testing Machine (ASABE Standard, 2000). Already conditioned samples were placed in turns, under the jaws of the UTM (Testometric M500 – 25KN) and compressed to failure at plunger speeds of 50mm per minute (Plate 3.6). The force-deformation plots of the tests were automatically generated on computer attached to the machine. Each of the experiments was replicated five times.

3.3 Statistical Analysis

The data obtained were analyzed using descriptive statistics, regression and Analysis of Variance (ANOVA) at p = 0.05 using SPSS 15 software. Analyses of Variance of the mean values of the engineering properties studied were carried out to determine the level of significance of the differences in the measured parameters over the period of the study. Regression analysis was used to show the type of mathematical relationships between respective independent variables of moisture content, age and varieties and the engineering properties studied. Various mathematical models were tested for each of the engineering properties to arrive at, and establish the model that best suit the relationship between the independent variables (moisture content, age, and varieties) and the response variables using Essential Regression (E-REGRESS).

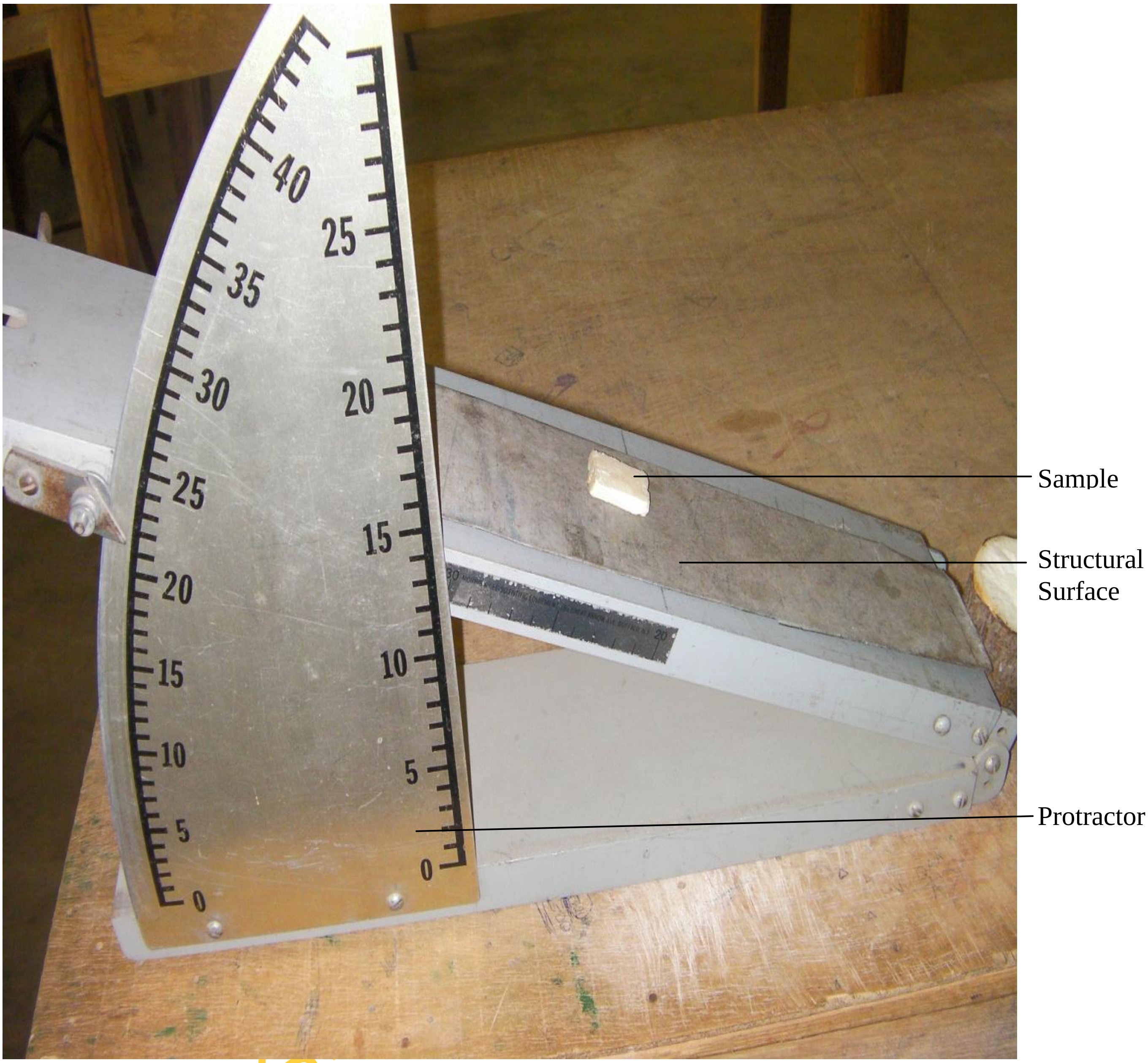


Plate 3.3: Setup for the Determination of Coefficient of Friction

Plate 3.4: Setup for the Determination of Coefficient of Internal Friction

Plate 3.5: Universal Testing Machine used for Compressive Strength Tests

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical Properties of Cassava

The values of the selected physical properties of TMS 30572, TME 419, and TME 7 at moisture contents ranging between 72.0 and 74.0% (wet basis) are presented in Appendixes A1 to A9 while a summary of the results are shown in Tables 4.1. Tables of Analysis of Variance are in Appendix F.

4.1.1 Physical Properties of TMS 30572 Cultivar

The mean length, D_H, D_M, and D_T at the ages of 12, 15 and 18 MAP were found to be 295.64, 38.33, 38.06 and 30.28; 324.36, 42.00, 45.58, and 33.87; and 288.02, 41.87, 43.80 and 33.87 mm respectively. Mean peel thickness at the head (P_H), middle (P_M) and tail (P_T) portions of the roots at 12, 15, and 18 MAP were 1.36,1.33, 1.22 mm; 3.13, 2.87, 2.03 mm and 3.69, 3.27 and 2.58 mm respectively. The mean mass, density, and peel proportion by weight (PPW) at 12, 15 and 18 MAP were 298.12g, 1.07g/cm^3 and 17.89%; 486.99g, 1.04g/cm^3 and 17.74%; and 478.11g, 0.81g/cm^{3}and 18.54% respectively (Table 4.1).

Table 4.1: MEANS OF PHYSICAL PROPERTIES OF CASSAVA AT DIFFERENT AGES

	TMS 30572 (MAP)			TME 419 (MAP)			TME 7 (MAP)		
Parameters	**12**	**15**	**18**	**12**	**15**	**18**	**12**	**15**	**18**
Length (mm)	295.64	324.36	288.02	300.08	344.18	320.90	232.98	263.90	320.14
Diameter									
Head (mm)	38.33	42.00	41.87	36.67	41.07	39.05	38.98	37.30	43.32
Middle (mm)	38.06	45.58	43.80	38.32	39.00	40.10	38.66	35.26	45.20
Tail (mm)	30.28	33.87	33.87	29.27	28.66	27.29	27.77	26.06	33.80
Peel Thickness									
Head (mm)	1.36	3.13	3.69	1.37	2.74	2.78	1.30	3.91	4.60
Middle (mm)	1.33	2.87	3.27	1.38	2.56	2.70	1.23	3.22	4.52
Tail (mm)	1.22	2.03	2.58	1.19	2.22	2.18	1.26	2.91	4.06
Mass (g)	298.12	486.99	478.11	262.65	459.25	483.48	229.78	441.10	489.11
Volume (cm^3)	290.64	483.50	572.40	286.24	473.32	480.17	226.02	464.90	439.50
Density (g/cm^3)	1.07	1.04	0.81	0.90	0.97	1.01	1.02	0.91	1.14
PPW (%)	17.89	17.74	18.54	18.81	24.09	21.05	17.36	21.30	20.67

The length and diameter were highest at the age of 15 months. The lowest mean length of 288.02 mm was, however, obtained at 18 months while the lowest values for diameter were obtained at the age of 12 months after planting. This tends to suggest that the tubers were still growing up to 15 months while shrinkage occurred towards 18 months. This may be due to the on-set of dry season (October) which resulted into loss of moisture from the tubers at the time the crop was 18 months old as pointed out by Prapapan *et al.* (2008) that molecular processes underlying root and starch physiology may be affected by prevailing environmental conditions at the time of harvest. The lengths were however, in good agreement with the mean value (316.6 mm) reported by (Ejovo *et al.*, 1988), especially at the age of 15 months old, but higher than the mean length (228mm) reported by Adetan *et al.*, (2003).

Also the roots of the TMS 30572 were longer (90 to 644 mm) than those reported by Ademosun *et al.* (2012) whose values ranged from 140 to 460 mm but with larger diameters (31.08 to 136.63 mm) especially at location classified as very fertile. The mean diameter reported by Adetan *et al*. (2003) was also slightly higher (46.2 mm) even though the TMS 30572 cassava variety (18 months old) was one of the two varieties used in their experiments. The variations may be due to the fact that growth and development of the root are a function of climatic conditions and soil type (Odigboh, 1976; Santisopasri *et al.*, 2001; Ademosun *et al.* 2012) and that their tubers were probably harvested in the raining season. The D_M values were the highest (except at 12 MAP) while the D_T values were the least implying that the roots of the TMS 30572 cultivar were not conical as those of Ejovo *et al.* (1988) but elongated ovoid in shape as described by Odigboh (1976).

The average peel thicknesses were 1.36, 1.33, and 1.22 mm at the head (P_H), middle (P_M) and tail (P_T) respectively for 12 MAP, 3.13, 2.87, and 2.03 mm for 15 MAP and 3.69, 3.27 and 2.58 mm respectively for 18 MAP. This implies that the peel thickness increased with the age of the tubers just like the diameter and length Figure (4.1).

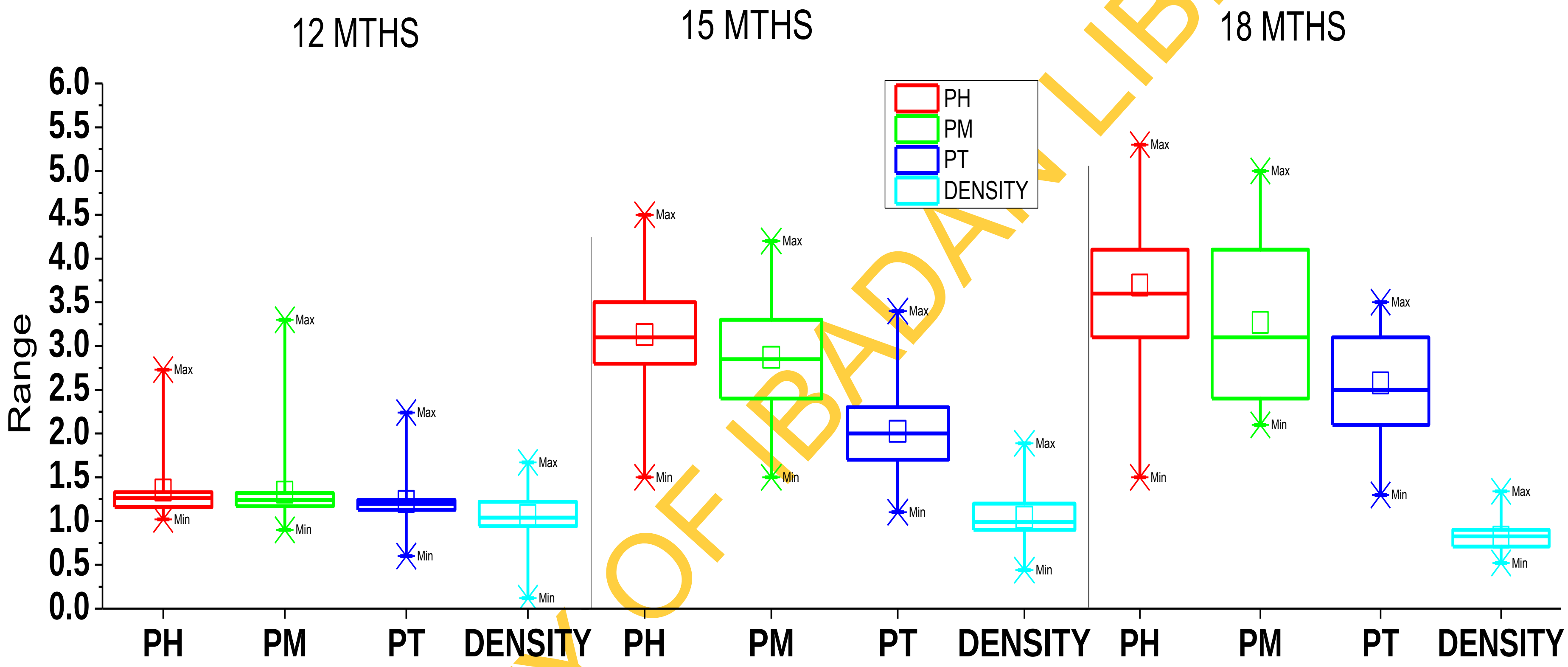


Figure 4.1: Variation of Peel Thickness and Density of TMS 30572 with Root Age

On the other hand the density decreased with age from 1.07 g/cm^3 at 12MAP down to 0.81 g/cm^3 at 18 MAP (Table 4.1). The peel proportion by weight (PPW) reduced from 17.89% at 12 months old to 17.74% at the age of 15 months and increased slightly to 18.54% as it approached the age of 18 months. This is an indication that the optimum age at which more flesh but less peel can be obtained from the root is 15 MAP, while more peel percentage could be obtained at 18 MAP, depending on the proposed end use (either for human consumption or animal feeds). The range of PPW was less than the range (20-35%) reported by Ekundayo (1980) but the mean values were in good agreement with the values of peel proportion by weight (10.6-21.5%) reported by Adetan *et al.* (2003) and Ademosun *et al.* (2012).

The results of the analysis of variance of the physical properties of this cassava cultivar show that the influence of age on the tuber length, the $D_{H,}$ D_T and PPW was not statistically significant ($p > 0.05$). It was, however significant on D_M, $P_{H,}$ $P_{M,}$ and P_T with the mean of the D_M of the 15 and 18 months old tubers being homogenous.

4.1.2 Physical Properties of TME 419 Cassava Cultivar

Results of the engineering properties studied for the tubers of the TME 419 cultivars are presented in Table 4.1. The mean length, (D_H), (D_M), and (D_T) for the roots of the TME 419 cultivar at the ages of 12, 15, 18 MAP were found to be 300.08, 36.67, 38.32 and 29.27 mm; 344.18, 41.07, 39.00 and 28.66; and 320.90, 39.05, 40.10 and 27.29 mm respectively. Mean peel thickness at the head (P_H), middle (P_M) and tail (P_T) portions of the roots at 12, 15, and 18 MAP were 1.37, 1.38 and 1.19; 2.74, 2.56 and 2.22 mm and, 2.78, 2.70, and 2.18mm respective. The mean mass, density and peel proportion by weight (PPW) at 12, 15, and 18 months old were 262.65g, 0.90g/cm^3 and 18.81%; 459.25g, 0.97g/cm^3 and 24.09%; and 483.48g, 1.01g/cm^3 and 21.05% respectively.

It was observed that the two improved cassava varieties (TMS 30572 and TME 419) exhibited almost the same physical properties within the study period. For instance, the length and diameter were very close except that TME 419 variety were generally slightly longer while the TMS 30572 tubers were just slightly bigger (in diameter) and heavier. This may be due to the fact that they were cloned from the same institute and probably from similar cassava parent varieties (Alves, 2002). The percentage of peel by weight of the TME 419 cultivar was generally higher than those of the TMS 30572 (Tables 4.1), and the highest peel percentage was obtained at 15MAP, (Figure 4.2) indicating that the TME 419 cassava varieties may be more suited for livestock feed production most especially at 15MAP while TMS 30572 is more suited for human consumption since less peel and more flesh could be obtained from its tubers. Statistical analysis for the TME 419 cultivar showed that the influence of age on P_H, P_M and the P_T was highly significant ($p < 0.05$) even though the peel thicknesses of the 15 and 18 months old tubers were homogenous. However, the influence of age on the tuber length, D_H, D_M, D_T and the density of tubers was not statistically significant.

4.1.3 Physical Properties of TME 7 Cassava Cultivar

The summary of the results of the physical properties of the local cassava cultivar (TME 7) are also presented in Table 4.1. It shows that the mean length, D_H, D_M and D_T of the roots of TME 7 cultivar at the ages of 12, 15, and 18 MAP were found to be 232. 98, 38.98, 38.66 and 27.77 mm; 263.90, 37.30, 35.26 and 26.06; and 320.14, 43.32, 45.20 and 33.80 respectively. The mean P_H, P_M and P_T of the roots at 12, 15, and 18 months were 1.30, 1.23, and 1.26; 3.91, 3.22, and 2.91 mm, and 4.60, 4.52 and 4.06 mm respectively. The mean mass, density, and peel proportion by weight (PPW) at 12, 15, and 18 MAP were 229.78, 1.02g/cm^3 and 17.36%; 441.10g, 0.91g/cm^3 and 21.30%; and 489.11g, 1.14g/cm^3 and 20.67% respectively.

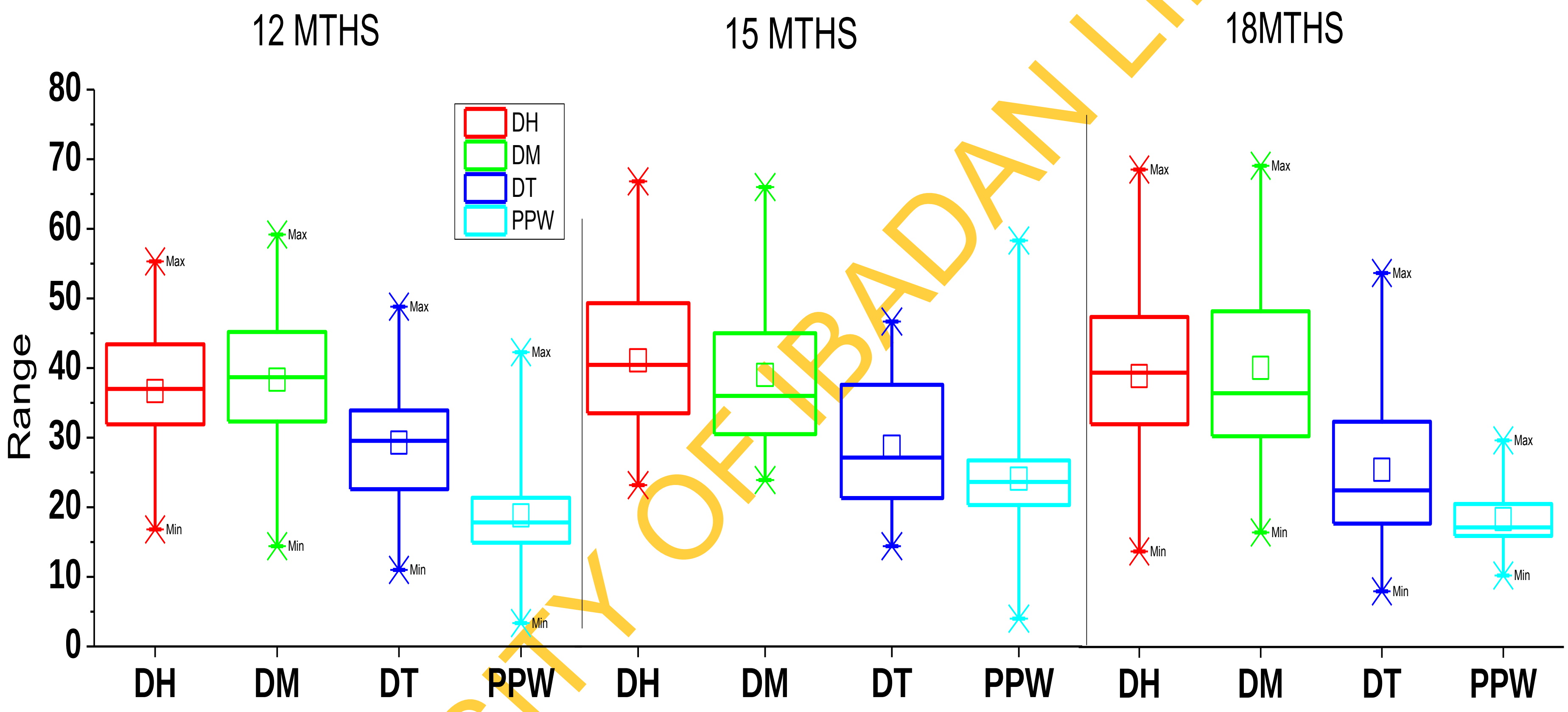


Figure 4.2: Variation of Root Diameter and Peel Proportion by Weigth of TME 419 Cassava Cultivar with Age

The results show that length and diameter of the tubers were found to be highest at the age of 18 months and lowest at 12 months. This is an indication that the tubers continued to grow and develop throughout the study period unlike the improved varieties whose sizes have started depreciating at 18 months. This fact was corroborated by the good physical appearance and healthy state of the slices cut out of the 18 months old tubers of the TME 7 cultivar during experimentation while the other two (improved) varieties have started showing signs of spoilage. The values were however, in good agreement with the root length of 316 mm reported by Ejovo *et al*. (1988), especially at 18 MAP. This is probably due to the fact that a local cassava cultivar harvested at about the same age (18-20 months) was also used for the study.

However, the mean length of the local cultivar was higher than the 228 mm reported by Adetan *et al.* (2003), but the mean diameter at the middle were very close (45.20 mm) especially for the 18 MAP old root samples although the mean diameter at the head in the two studies were considerably different probably due to varietal differences. Also, D_H was generally highest while D_T values were the least except at 18 MAP when the D_M was greater than the D_H implying that the roots of the local cassava variety were conical in shape (Odigboh, 1976), especially when they are less than 18months old (Figure 4.3). The peel thicknesses were found to increase with the age, as well as diameter of the tubers just like those of the improved varieties, while the density decreased up to 15MAP and later increased towards the age of 18 MAP where the highest value was obtained (Table 4.2). The average peel thickness which ranged from 4.06 – 4.60 mm for 18 MAP roots (the highest in this study) were observed to be higher than the range of average values of 1.9-2.8 mm reported by Ejovo *et al.* (1988) and the 2.21 mm reported by Adetan *et al*. (2003) for roots of the same age bracket. It was, however, in agreement with the 1.62- 4.34mm reported by Ademosun *et al.* (2012). The values of the peel proportion by weight were within the range of 10-21.5% reported by Adetan *et al.* (2003) and Ademosun *et al.* (2012). The peel proportion by weight increased from 12 to 15 months and decreased slightly as it approached the age of 18 months but were generally lower than those of TME 419, hence, less suitable for feed production than TME 419. Statistical analysis showed that the length, D_T, and D_M of the 12 and 15 months old tubers was homogeneous whereas those of the 18 months old were distinctively different from the younger ones and the influence of age on all the parameters studied was significant ($p < 0.05$) except D_H.

In the overall, the influences of age and variety on the physical properties were tested using the randomized blocked two way ANOVA and the result showed that length, PPW, D_T, and P_H, were significantly influenced by the tuber age, variety and the interactions of both factors whereas mass, D_H and P_M were influenced by tuber age alone. Density was only influenced by the interactions of age and variety. The skewness and kurtosis analysis for the frequency distribution curve for the 50 readings taken for each dimension are shown in Figure 5.1 (a – c) for each of the cassava varieties studied. The curves show near to normal distribution for the length with the peaks being around the means which agrees with earlier results by Irtwange and Igbeka (2002) for two African yam bean accessions, Taser *et al.* (2005) for vetch seed and Akaaimo and Raji (2006) for *Prosopis Africana* seeds. This is an indication that the axial dimensions are relatively uniform and these are useful information in the design of separation and size reduction systems. Skewness characterises the degree of symmetry of a distribution around its mean. Positive skewness indicates a distribution with an asymmetric tail extending towards more positive values (skewed to the right) and vice versa for negative. Kurtosis characterises the relative peakedness or flatness of a distribution compared to normal distribution (Table 4.2).

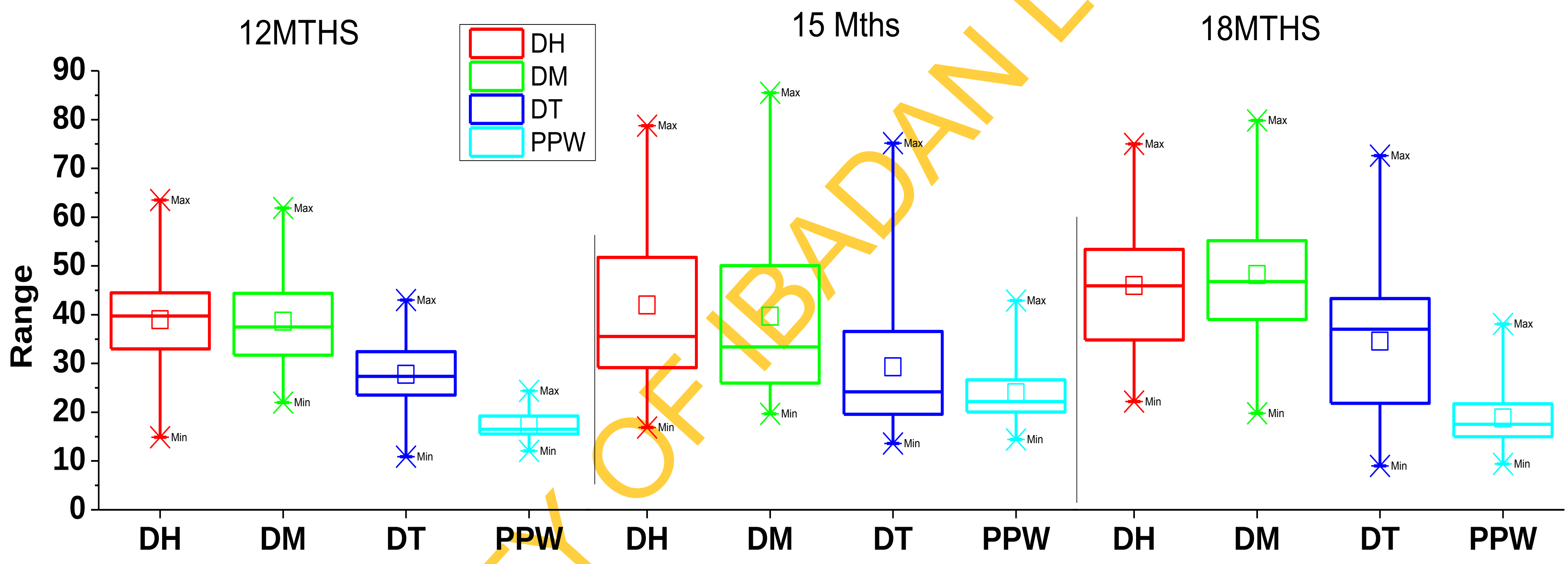
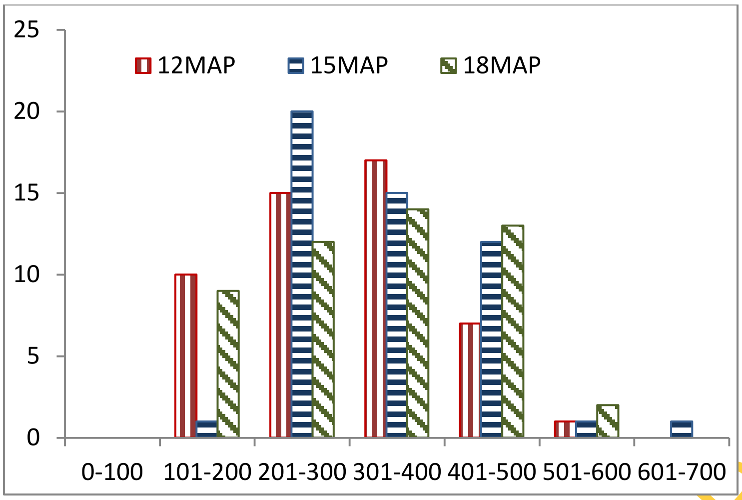


Figure 4.3: Variation of Root Diameter and Peel Proportion by Weigth of TME 7 Cassava Cultivar with Age



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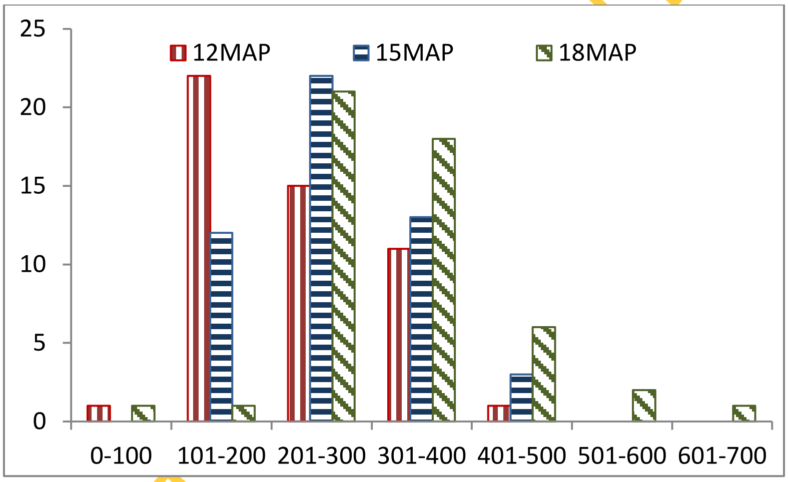

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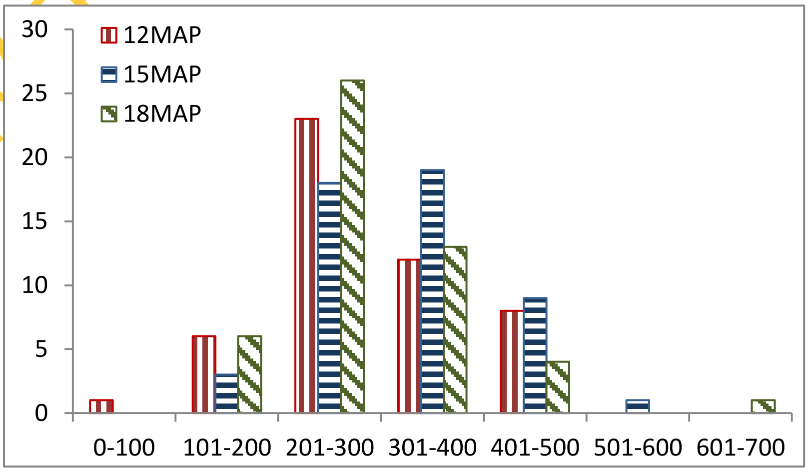

c

Figure 4.4: Distribution of length (mm) for (a) TME 419 (b) TME 7 and (c) TMS 30572

Table 4.2: Level of Statistical Distribution of Length and Diameter at the Head (D_H)

	TME 419 (MAP)			TME 7 (MAP)			TMS 30572 (MAP)		
length	**12**	**15**	**18**	**12**	**15**	**18**	**12**	**15**	**18**
Kurtosis	-0.892	0.813	-0.872	-0.445	0.400	1.395	-0.422	-0.049	4.185
Skewness	0.145	0.845	-0.093	0.318	0.473	0.712	0.232	0.187	1.556
D_H									
Kurtosis	-0.237	-0.421	-0.260	0.813	-0.422	-0.427	0.823	-1.045	-0.003
Skewness	-0.291	0.483	-0.026	-0.642	0.798	0.511	0.393	-0.229	0.510

4.2 Mechanical Properties of Cassava

4.2.1 Coefficient of Friction of Cassava

The coefficient of friction (COF) of TMS 30572, TME 419 and TME 7 used in this study on the three different surfaces of stainless steel, galvanized sheet and wood at the ages of 12, 15 and 18months after planting (MAP) are presented in Appendixes B1 to B27 while a summary of the results is shown in Table 4.3

4.2.1.1 Coefficient of friction of TMS 30572

The COF of TMS 30572 on stainless steel surface over the period of study with the regression equation of each of them is presented in Figure 4.5. It shows that the COF increased with increase in moisture contents at all ages even though the 15 MAP samples gave the highest. This may be due to the fact that the moisture made the starchy surface of the samples to become stickier thereby increasing the force of adhesion between the surface of the samples and that of the stainless steel as the samples' moisture content increased. Besides, cassava starch is known to have high swelling power (Nwokocha *et al.*, 2009) in water which results in increased surface area of its granules, thereby increasing the friction between the samples and the stainless steel as the moisture content was increased. The high R^2 values (0.9757-1) show that the linear equations perfectly explain the relationship that exists between the COF and moisture content of the samples.

The gradient of the graphs was lowest at 18 months (0.02) while it was highest at 12 months (0.04) such that its values of coefficient of friction were increasingly approaching those of 15 months as the moisture content increased. This trend suggests that the coefficient of friction at 12 months old could be higher than those of 15 months old samples at elevated moisture contents (above 60% wb). This behaviour suggests a strong influence of moisture content and tuber age on the coefficient of friction of TMS 30572 on stainless steel surface simply because the root was still young and has not attained its peak growth.

Table 4.3: Mean Coefficient of Friction of Cassava Cultivars at different Ages

		TMS 30572			TME 419			TME 7		
Surface	**MC (%)**	**12 mths**	**15 mths**	**18 Mths**	**12 mths**	**15 Mths**	**18 mths**	**12 mths**	**15 mths**	**18 mths**
	40	0.20	0.23	0.16	0.21	0.19	0.19	0.21	0.18	0.18
Stainless	**45**	0.21	0.25	0.17	0.22	0.21	0.21	0.22	0.19	0.20
Steel	**50**	0.23	0.26	0.18	0.24	0.21	0.24	0.23	0.21	0.21
	55	0.26	0.28	0.19	0.26	0.23	0.26	0.24	0.23	0.21
	60	0.28	0.29	0.20	0.28	0.26	0.28	0.25	0.25	0.23
	40	0.42	0.44	0.45	0.43	0.36	0.45	0.43	0.37	0.39
Galvanized	**45**	0.45	0.45	0.46	0.45	0.38	0.46	0.43	0.39	0.39
Sheet	**50**	0.46	0.47	0.47	0.49	0.41	0.49	0.49	0.42	0.45
	55	0.52	0.49	0.48	0.52	0.43	0.56	0.53	0.46	0.47
	60	0.53	0.51	0.50	0.53	0.46	0.58	0.55	0.48	0.49
	40	0.61	0.68	0.65	0.61	0.58	0.67	0.61	0.57	0.68
Wood	**45**	0.67	0.71	0.66	0.63	0.61	0.70	0.62	0.60	0.75
	50	0.69	0.74	0.67	0.69	0.64	0.74	0.67	0.63	0.79
	55	0.74	0.78	0.68	0.73	0.65	0.78	0.75	0.66	0.83
	60	0.76	0.79	0.71	0.75	0.70	0.79	0.78	0.70	0.89

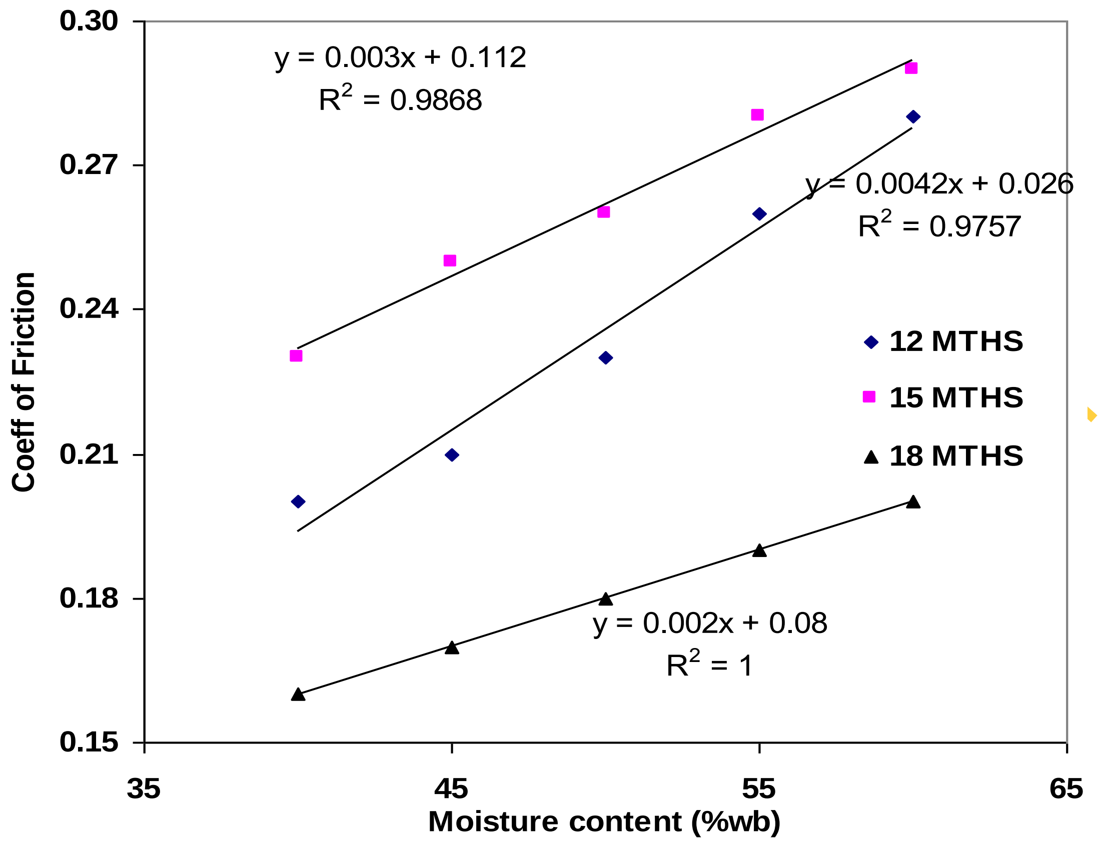

Fig. 4.5: Coefficient of Friction and Moisture Content for TMS 30572 Cultivar on Stainless Steel Surface

The highest COF of this cassava cultivar on stainless steel obtained with 15 months old samples may be due to the fact that the crop has just actually attained its peak of growth and development and the dry matter and fibers have fully developed coupled with the fact that this is the peak starch production age (Ntawuruhunga *et al.*, 1995), thereby making the surface of the 15 months old samples to stick best consequently producing the highest COF. The lowest COF obtained at 18 months is simply attributable to the reduced starch deposit in the flesh as the plant age exceeded 15 months. The range of values of COF (0.16-0.29) was however in good agreement with that (0.213) reported by Ejovo *et al*. (1988) for cassava flesh on aluminum, even though they did not consider the influence of moisture content in their study. The difference may be due to age, moisture content and different cassava varieties used in the two studies. The effect of age on COF of TMS 30572 was very significant ($P < 0.05$) on stainless steel surface.

The range of values of the coefficient of friction of TMS 30572 on galvanized sheet surface at the age of 12 months after planting were found to be between 0.42 and 0.53 for sample moisture content range of 40 - 60% (wet basis). The corresponding values for 15 months old samples ranged from 0.44 - 0.51 while the values at 18MAP ranged from 0.45 to 0.50 respectively (Table 4.3). Figure 4.6 shows the graph of the COF against moisture content on galvanized sheet with the regression equation and R^2. It shows that a positive linear relationship exists between the coefficient of friction and moisture content. However, the COF only increased with age at low moisture content up to about 50% (wb) beyond which the highest values were obtained at the age of 12 months while the lowest were obtained from 18 months old samples, where the highest value for 12 month was 0.53 whereas the highest value at the age of 18 month was 0.50. The combination of the effects of fibre formation and the level of starch available at the surface of the samples may account for this behaviour. A point of intercept exists for the three graphs at the moisture content of 48% (wb) where the coefficient of friction is the same for all the ages (Figure. 4.6).

The low COF values at moisture contents below 50% may be due, more to the tenderness of the fibres of the sample at that age than, to the starch content while the effects of the starch level prevailed at moisture contents above 50% MC. The least value of coefficient of friction of TMS 30572 on galvanized sheet surface (0.61) was, however, higher than the 0.364 reported by Ejovo *et al.* (1988) for cassava flesh (unspecified cultivar) on mild steel at unspecified moisture content thereby making comparison difficult.

The difference in the studied behaviour across the ages on galvanized sheet was, statistically significant ($P < 0.05$), although the 18 and 15 MAP samples were homogeneous on one hand while the 18 and 12 MAP samples were also homogeneous on the other. The 12 and 15 months old samples were, however, distinctively different.

The range of values of coefficient of friction of TMS 30572 on wood at 12 months was 0.61 – 0.76. The corresponding values at 15 MAP was 0.68 – 0.79, while it was 0.65 – 0.71 at 18 months. The COF was highest at the age of 15 months and lowest at 18 months, following the same trend as obtained on stainless steel except that the COF on wood were about three times higher (Table 4.3 and Figure 4.7).

Also, Figure 4.7 shows that the coefficient of friction of TMS 30572 on wood surface increased with increase in moisture and the slope of the graph of the 12 months old samples was the highest while that at 18 months was the lowest (0.03). The COF values were generally highest at 15MAP and lowest at 18MAP except at 40% moisture content where the 12 months old samples gave the lowest COF. At 45% moisture content, the coefficient of friction was the same for both 12 and 18 months old cassava samples, beyond which the 18 months old samples exhibited the lowest coefficient of friction while the values of the 12 months old samples increased steadily approaching those of the 15 months old. The same factors responsible for the behaviour on galvanized sheet may have caused this.

The effect of tuber age on COF of TMS 30572 on wood was very significant ($P < 0.05$). Expectedly, the values of the COF on wood were the highest, while those on stainless were the least, due to the difference in the degree of smoothness of the surfaces, wood being the least smooth. The lowest COF value (0.61) on wood obtained in this study is however slightly higher than the 0.404 reported by Ejovo *et al.* (1988) for cassava flesh on wood while the highest COF value (0.76) is also slightly higher than the 0.68 reported by Ashaolu (1989) and used by Bamgboye and Adebayo (2009) in designing a cassava chipping machine.

4.2.1.2 Coefficient of friction of TME 419

The frictional behaviour of TME 419 cassava cultivar on stainless steel surface over the moisture content and age range studied is as presented in Table 4.3 while Figures 4.8 present the information in graphical form. The trend of the relationship between moisture content and COF is the same as in TMS 30572 where the coefficient of friction generally increased with increase in moisture content. However, unlike the TMS 30572 cultivar, the 15 months old samples had the lowest coefficient of friction (0.19-0.26) on stainless steel especially at moisture contents between 50 and 60% (wb), whereas, the mean values were the same (0.19-0.21) for both 15 and 18 months old samples at moisture contents less than 50% while the 12 months old samples had the highest (Table 4.3). This behavior may probably be explained by the starch structure and starch granule size distribution of cassava, the profile of which has been reported by Sriroth *et al.* (1999) as changing with age at harvest as well as cassava variety, thus an inherent characteristic which is peculiar to the cassava cultivar concerned may be responsible. The results of the analysis of variance showed that the effect of age on COF of the TME 419 on stainless steel surface was not significant with the means of the 12, 15 and 18 months old samples being homogeneous.

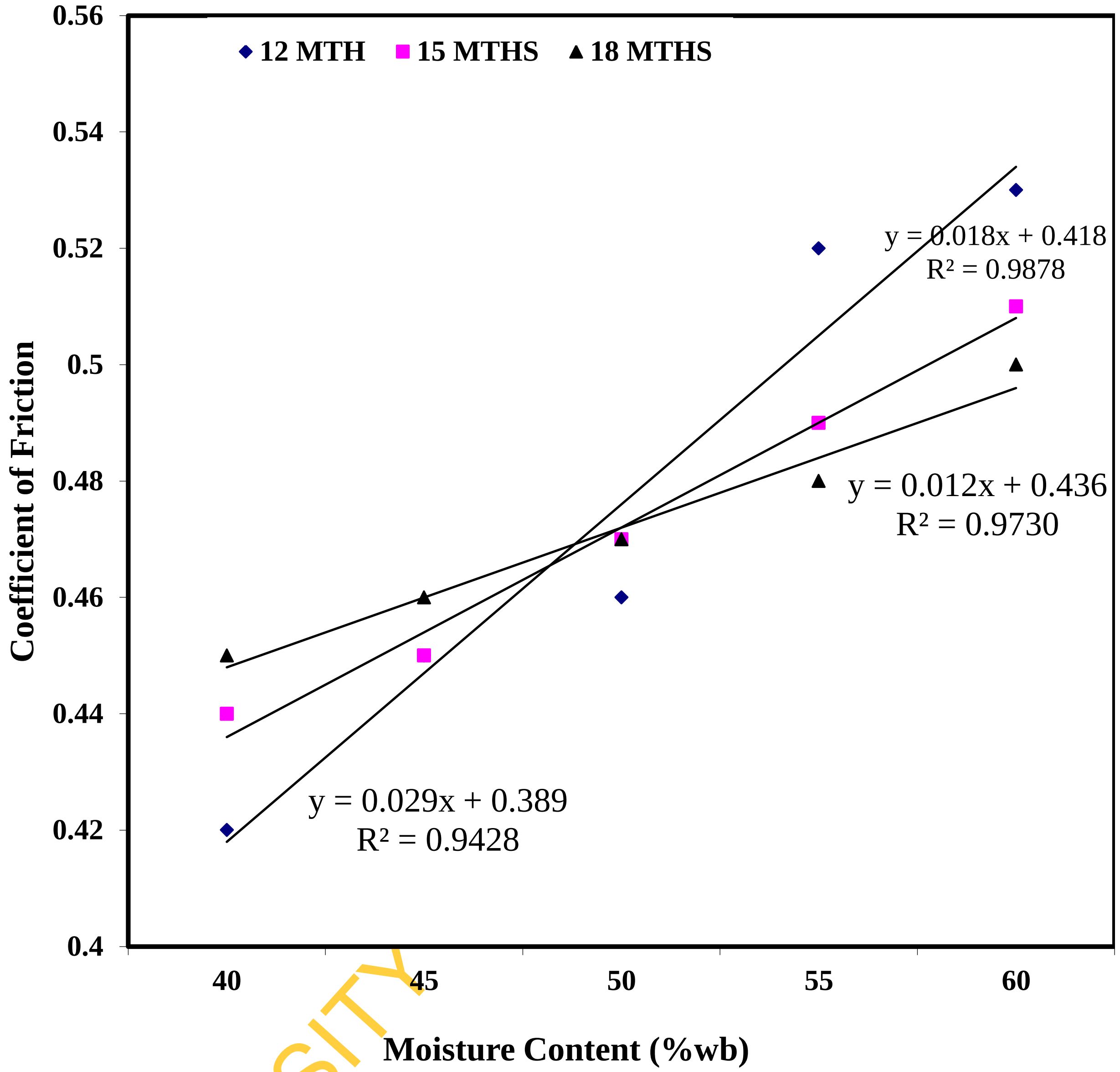

Fig 4.6: Coefficient of Friction and Moisture Content for TMS 30572 on Galvanized Sheet

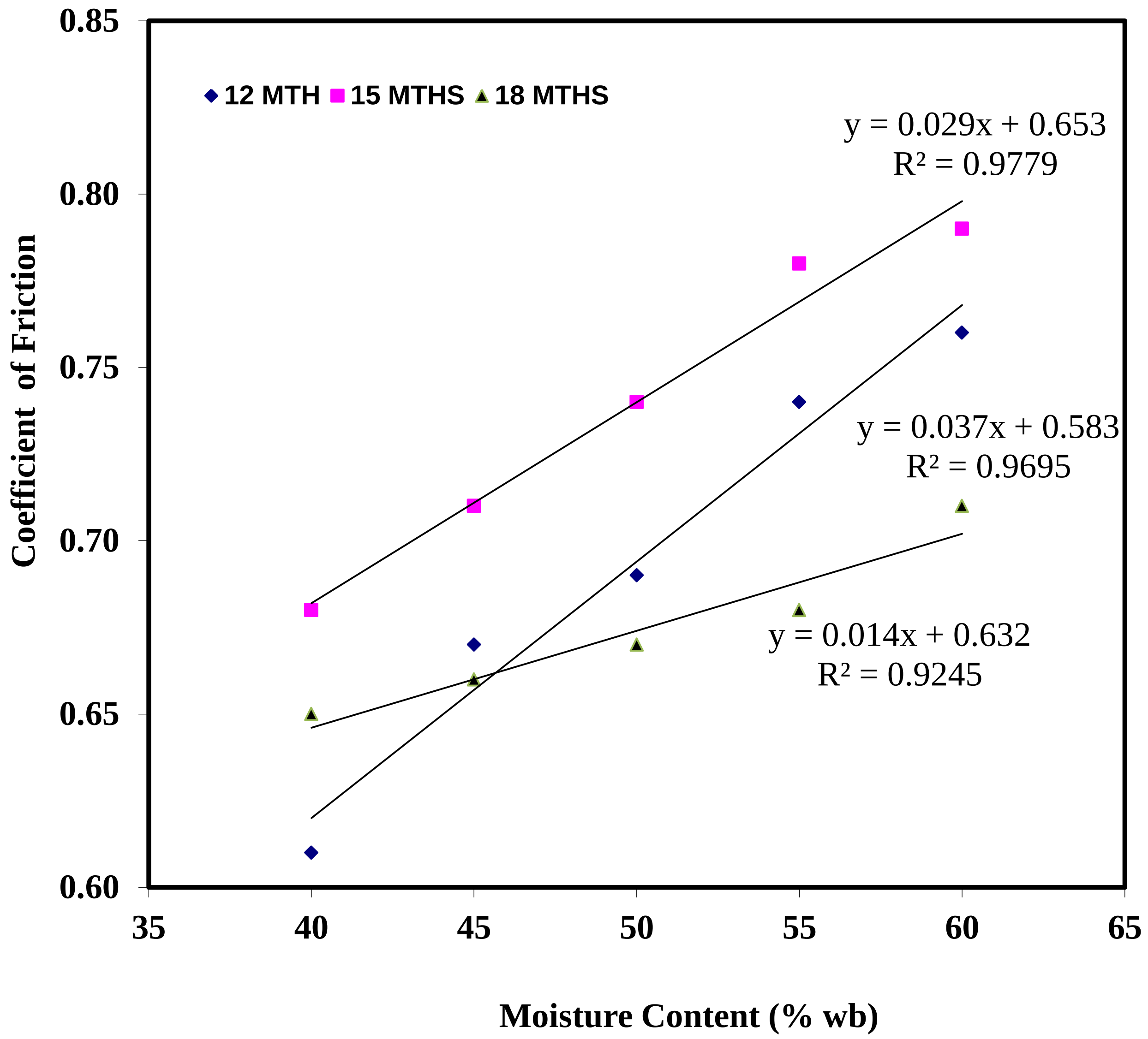

Fig. 4.7: Coefficient of Friction and Moisture Content for TMS 30572 on Wood Surface

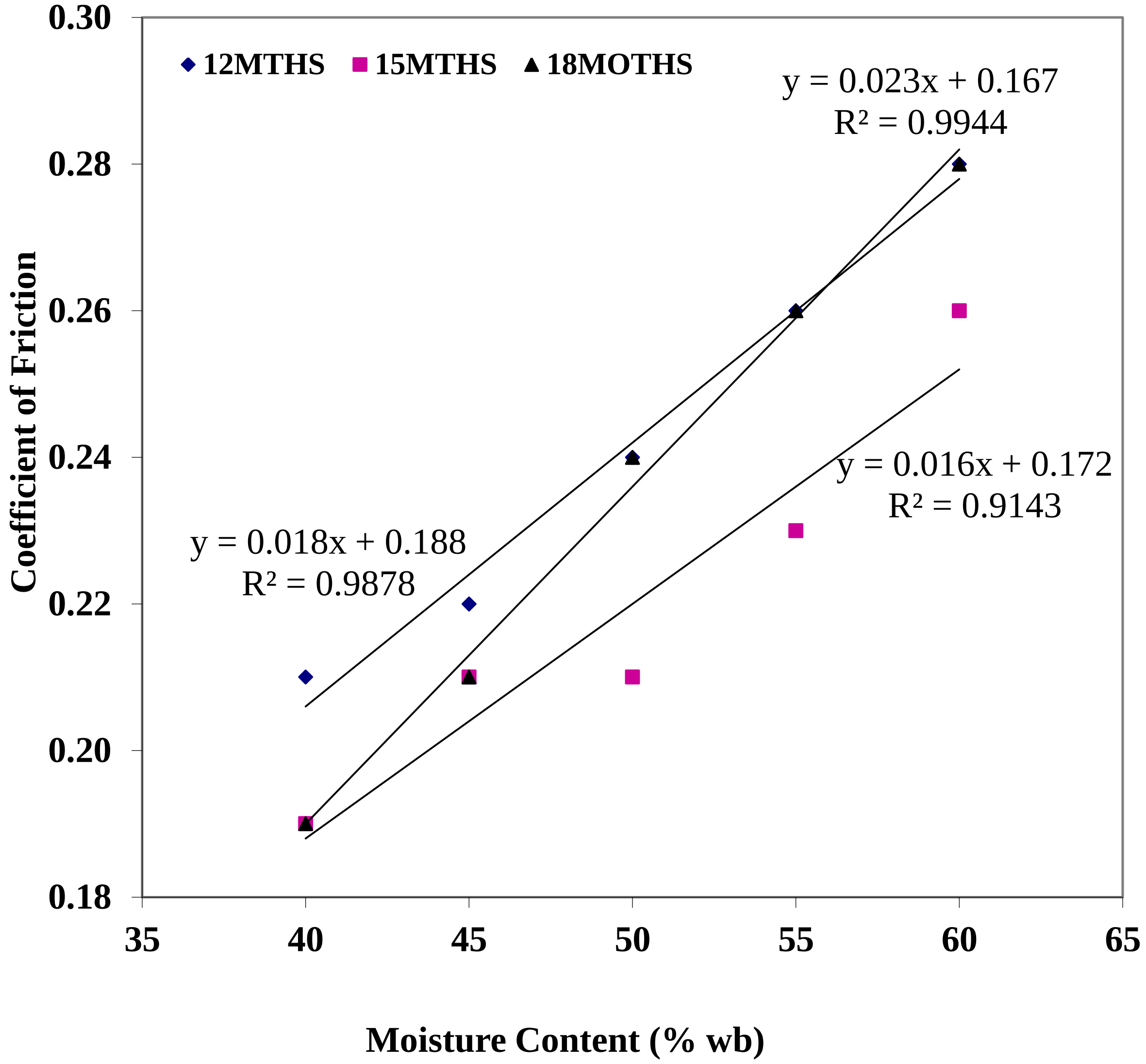

Fig. 4.8: Coefficient of Friction and Moisture Content for TME 419 on `Stainless Steel Surface

The coefficient of friction of TME 419 on galvanized sheet over the range of moisture content and age studied are as presented in Table 4.2 while Figure 4.9 prepresent the information in graphical form. It was found that the COF were generally the least (0.43 – 0.53) at 15MAP and highest (0.45 – 0.58) at 18MAP. Expectedly, the values were higher than those obtained on stainless steel. The influence of lignification may be responsible for the increases in the values of the COF at 18MAP as the level of starch deposit in the cassava flesh is expected to have reduced considerably at this age (Ngedahayo and Dixon, 1998), while the tubers grow woody and consequently became relatively rough, and when in contact with another relatively rough surface (galvanized sheet) led to high COF values.

However, the lowest COF obtained at the age of 15MAP suggest that the influence of age alone may not completely explain the behavior of the tubers. Complexity of the effects of the interactions of the granule structure, granule size and, granule size distribution of both the cassava samples (at different ages) and the structural surfaces is highly suspected to be responsible for this behaviour.

It was also observed from Figure 4.9, that the coefficient of friction values of TME 419 on galvanized sheet at both the 12^{th} and the 18^{th} months were very close at moisture contents of 40 and 45% (wb) beyond which the gap became wider as a result of the greater gradient (0.065) of the 18 months old sample compared to the slope of 0.05 at 12 months. The influence of tuber age on the coefficient of friction of TME 419 cassava cultivar on galvanized sheet was, however, found to be statistically significant over the ages studied although the means of the 12 and 18 months old samples were homogeneous.

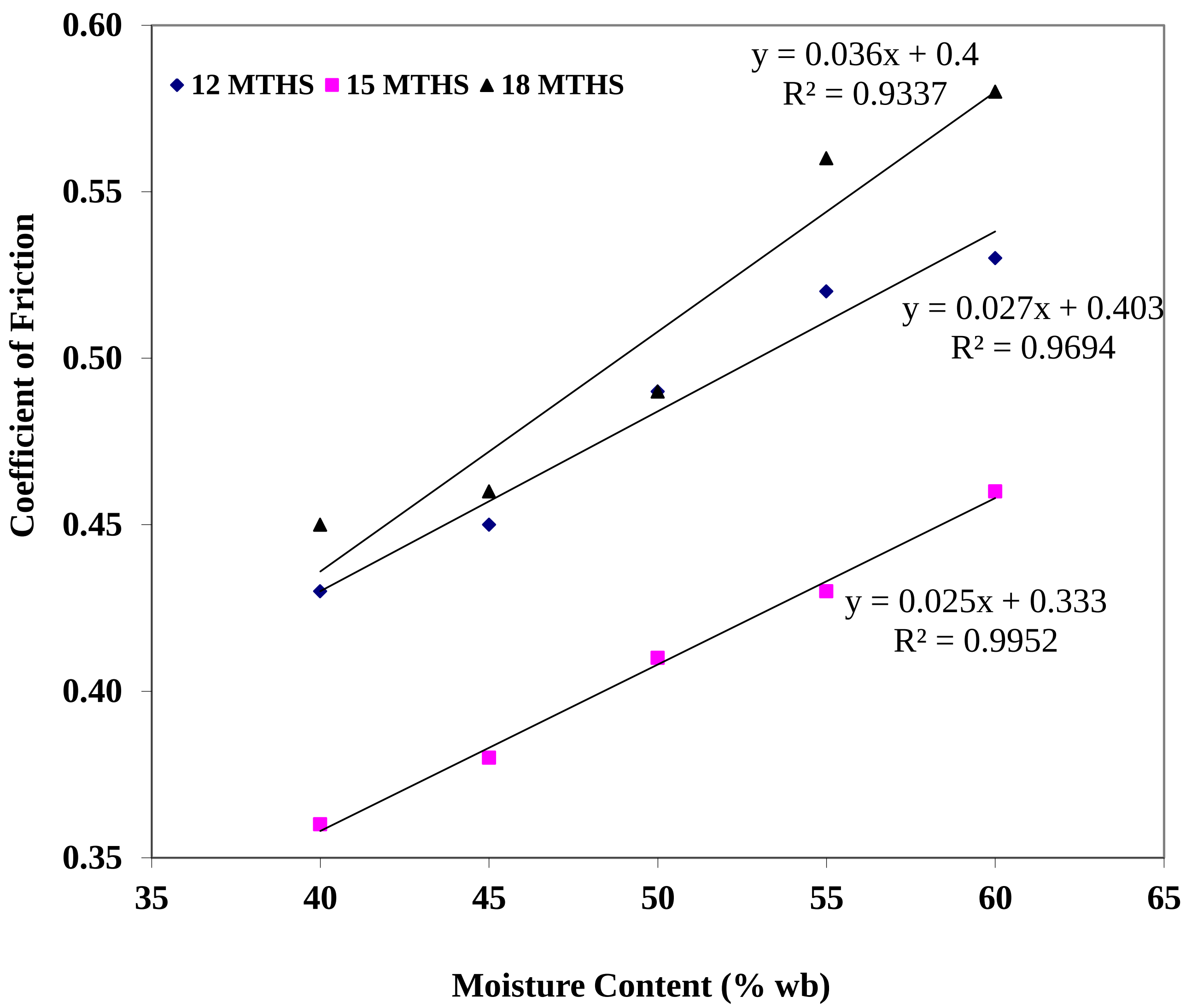

Figure 4.9: Coefficient of Friction and Moisture Content for TME 419 on Galvanized Sheet

The graph of the means of the coefficient of friction of TME 419 cultivar on wood is presented in Figure 4.10 along with the linear regression equations and their R^2. It had its coefficient of friction on wood ranging from 0.58 to 0.79 over the three ages studied. The range was 0.61 to 0.75 at 12 months, 0.58 to 0.70 for 15MAP, while the corresponding values were 0.67 to 0.79 at 18 MAP (Table 4.3). The lowest range of values was obtained at the age of 15 months while highest was at 18 months old.

The COF was found, from Figure 4.10, to have assumed the same trend as obtained on galvanized sheet where the highest values were obtained at 18MAP with the least at 15MAP. The same reason adduced for the behaviour of this cultivar on galvanized sheet explains this too i.e the fibres in the tubers may have grown woody resulting in the highest COF values obtained at18MAP. Expectedly, however, the COF on wood were generally higher (0.58 – 0.79) than those on galvanized sheet and stainless steel simply due to the fact that the wood is known to be the roughest of the three surfaces used. The lowest value of coefficient of friction recorded for TME 419 on wood (0.58) was even higher than the highest value of 0.56 reported by Raji and Ahemen (2009) for *Tacca* tuber and 0.404 reported by *Ejovo et al.* (1988) for cassava tuber on wood (at unspecified moisture content). Similarly, the values of COF obtained for this cassava variety on stainless and galvanized sheet surfaces were higher than those reported by Ejovo *et al*. (1988) on aluminum and mild steel. Varietal differences and different soil conditions as well as the prevailing weather conditions at the time of harvest may be responsible for the differences (Sriroth *et al.* 1999). Again, the effect of age on the coefficient of friction of this cultivar on wood was statistically significant over the studied age.

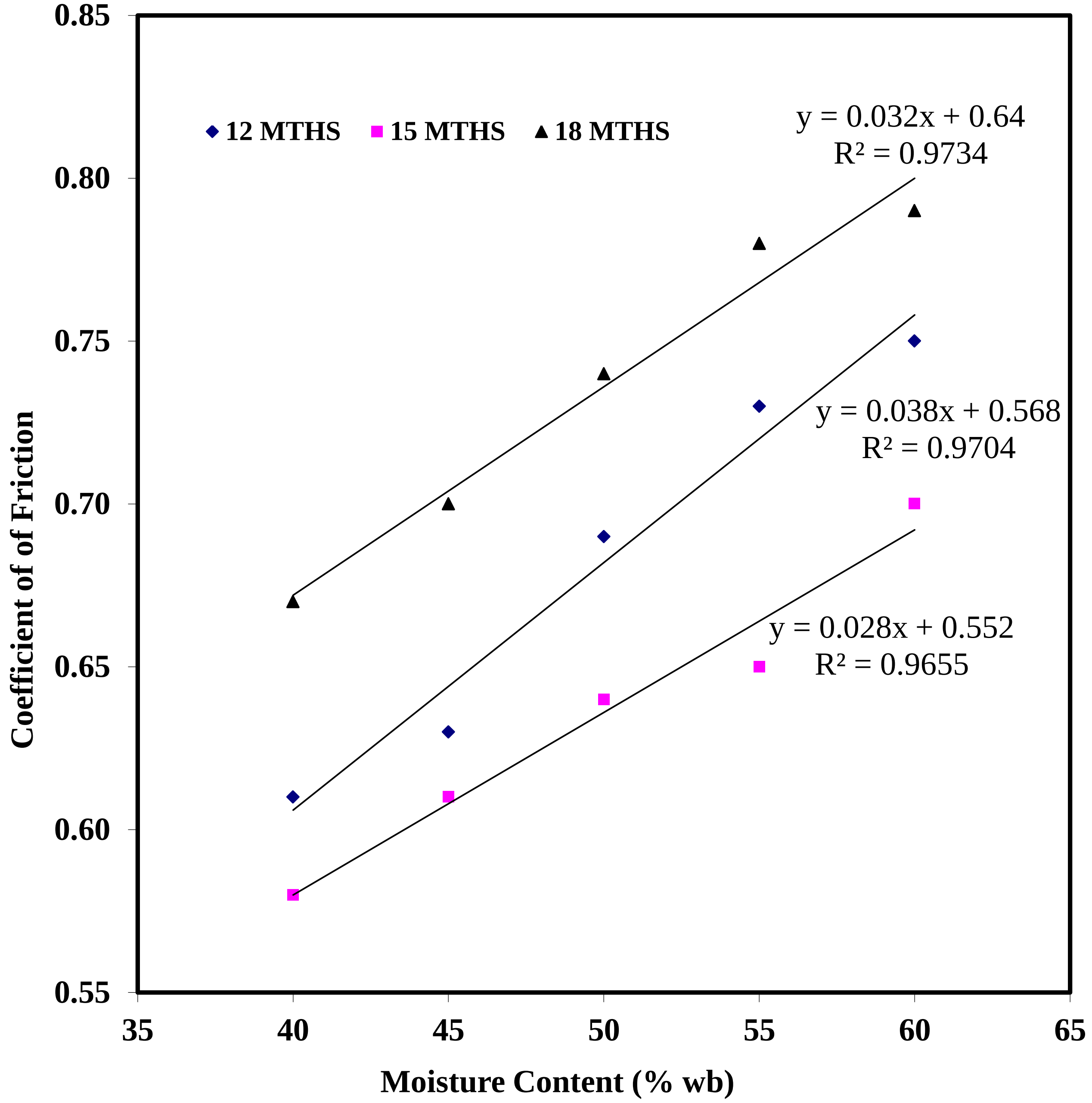

Figure 4.10: Coefficient of Friction and Moisture Content for TME 419 on Wood

4.2.1.3 Coefficient of friction of TME 7

The coefficient of friction of the local cassava cultivar (TME 7) on stainless steel surface at the ages of 12, 15, and 18 respectively is presented in Figure 4.11 while the means are as presented in Table 4.3. It shows that the values of the COF were lowest at the 18MAP and highest at 12 MAP within the range of moisture content studied, indicating that the COF decrease with increase in tuber age. It, however, increased with increase in the moisture contents of the samples. The high R^2 values of the graphs strongly suggest a linear relationship between the COF and moisture content.

The behaviour of the samples across age with respect to COF suggests that the younger the tubers and the higher the moisture content the higher the coefficient of friction. This may be explained by the tenderness of the fibers of the crop, coupled with the high starch content of the crop at this early stage of maturity which probably led to a high adhesive force between the surface of the samples and the very smooth surface of the stainless steel while a low level of starch at older age may be responsible for the lowest COF values obtained at the 18^{th} month as the effects of the rough fibers of the tubers at 18 MAP was unable to offset that of the strong adhesive strength between the 12 months old samples and the stainless steel surface. Analysis of variance of the COF of the local cassava cultivar on stainless steel surface shows that the effect of age on the coefficient of friction of this cultivar on stainless was statistically significant with the 15 and 18 months old exhibiting statistically insignificant difference in their behaviour.

Also, the graphs of the coefficient of friction of the samples of the local cassava cultivar on galvanized sheet surface over the studied ages are presented in Figure 4.12. It shows that the coefficient of friction of this cassava cultivar increased with increase in moisture content and it was highest at the age of 12 but lowest at 15 months old.

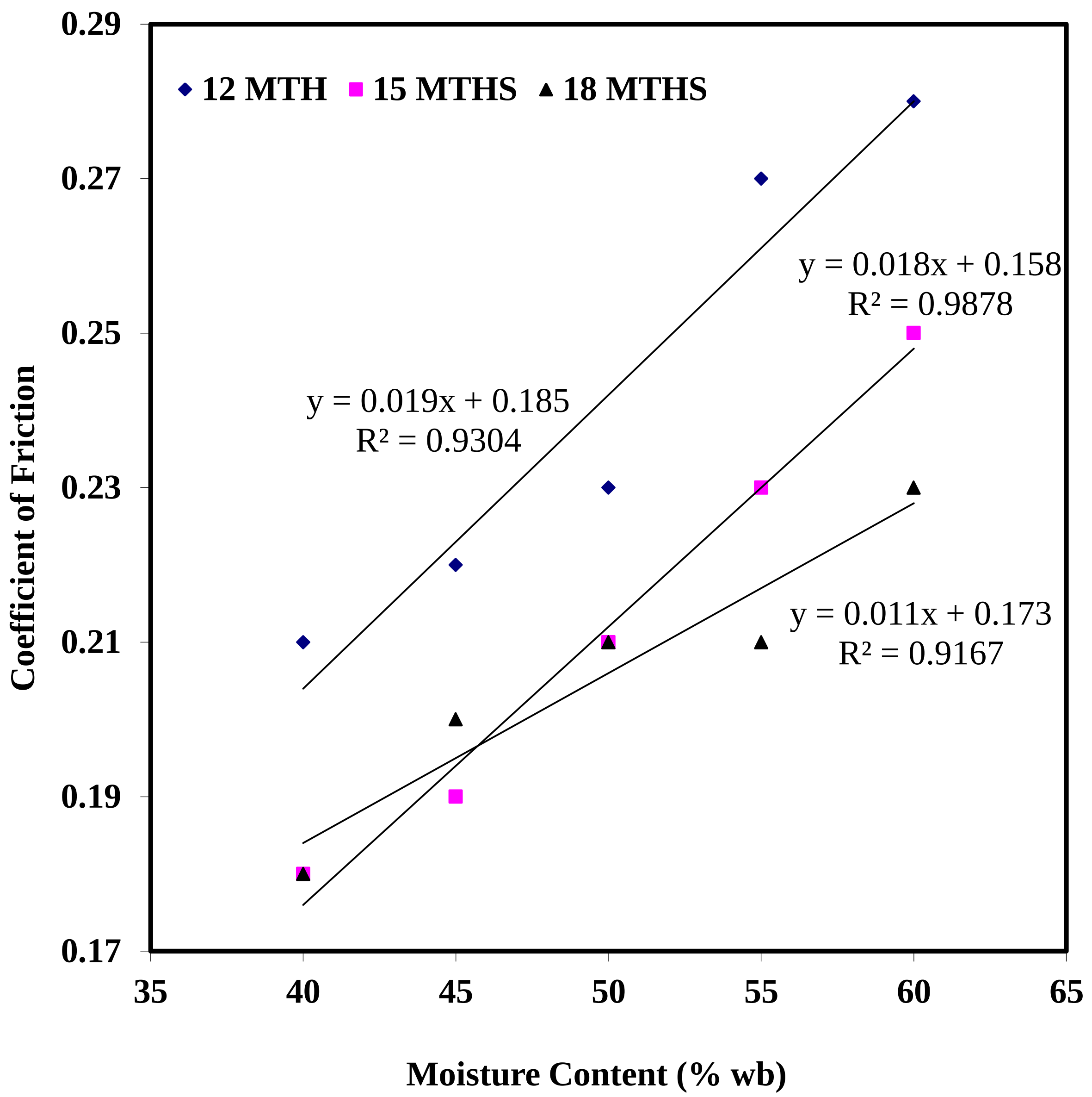

Figure 4.11: Coefficient of Friction and Moisture Content for TME 7 Cultivar on Stainless Steel

The behaviour of the samples on galvanized sheet with respect to COF differs slight from what was obtained on stainless steel. Although the 12 months old samples still recorded the highest values, but the lowest values were now obtained with the 15 months old samples. This may be due to the influence of the interactions of the micro-structures of the biomaterials (cassava samples) and the structural surfaces (stainless steel, galvanized sheet and wood)

The range of values of the coefficient of friction of this cassava variety on galvanized sheet (0.37-0.55) are in agreement with the range of 0.34-0.48 reported by Raji and Ahemen (2009) (for Tacca tuber on galvanized) especially for the 15 months old samples. The COF of the TME 7 on galvanized sheet also increased with increase in moisture content. The graphs show the tendency of the COF of the 18 months old samples to be the same with that of 15 months old if the moisture content is increased further while the COF of the 18 months old sample tends to meet that of 12 months if the moisture level is further reduced below 40% (Figure 4.12). The variation in the behaviour of the samples over age with respect to coefficient of friction on galvanized sheet was highly significant.

The range of values of coefficient of friction of TME 7 on wood at 12 months was 0.61 – 0.78. The corresponding values at 15 month was 0.58 – 0.70, while it was 0.68 – 0.89 at 18 months. The range of values over the three ages studied was 0.58 to 0.89 (Table 4.3). Figure 4.13 shows the graphs of the coefficient of friction of TME 7 on wood surface across the ages studied.

These values were well above the range (0.49-0.56) reported by Raji and Ahemen (2009) for another tuber (*Tacca* tuber) on wood surface. Ajav, (1998) also reported a mean coefficient of friction of 0.6 for yam tuber sett without specifying the surface or the moisture content. Also, the COF being reported here for the local cassava variety on the three surfaces were generally higher than those reported for aluminum, mild steel and galvanized sheet by Ejovo *et al.* (1988).

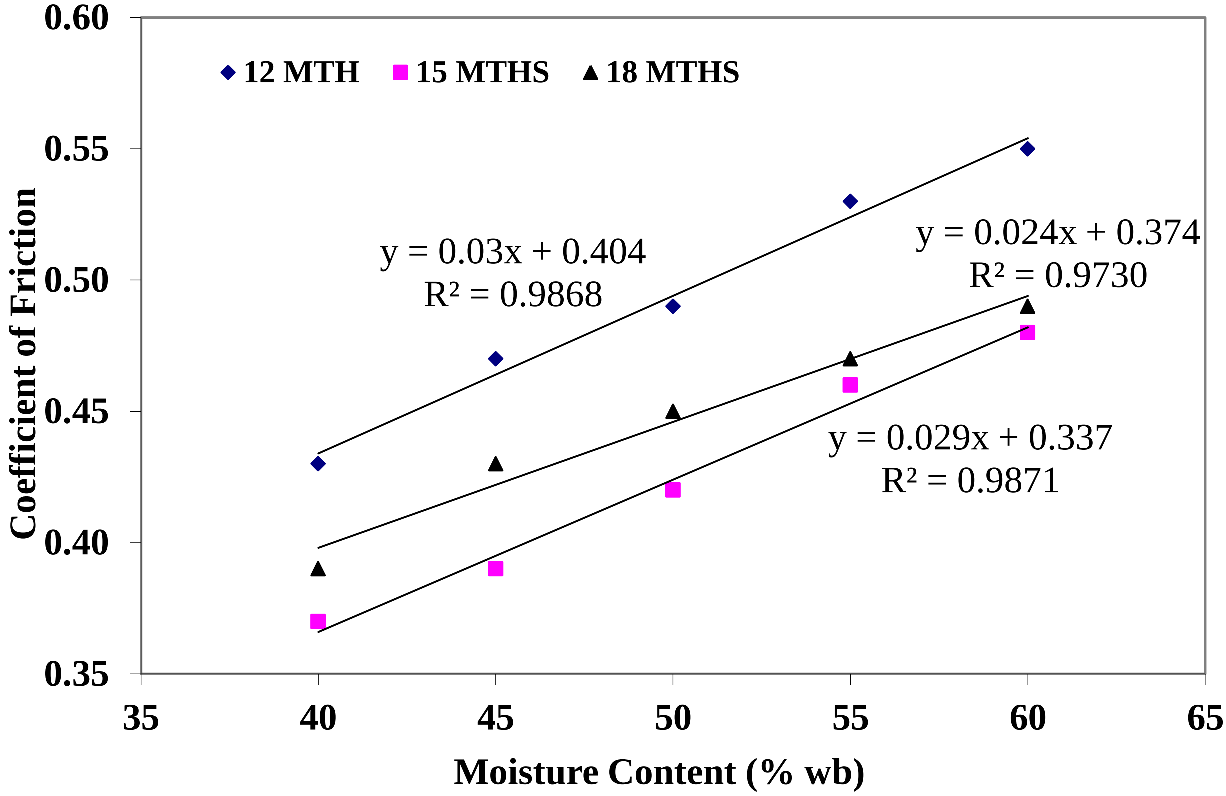

Fig. 4.12: Coefficient of Friction and Moisture Content for TME 7 Cultivar on Galvanized Sheet

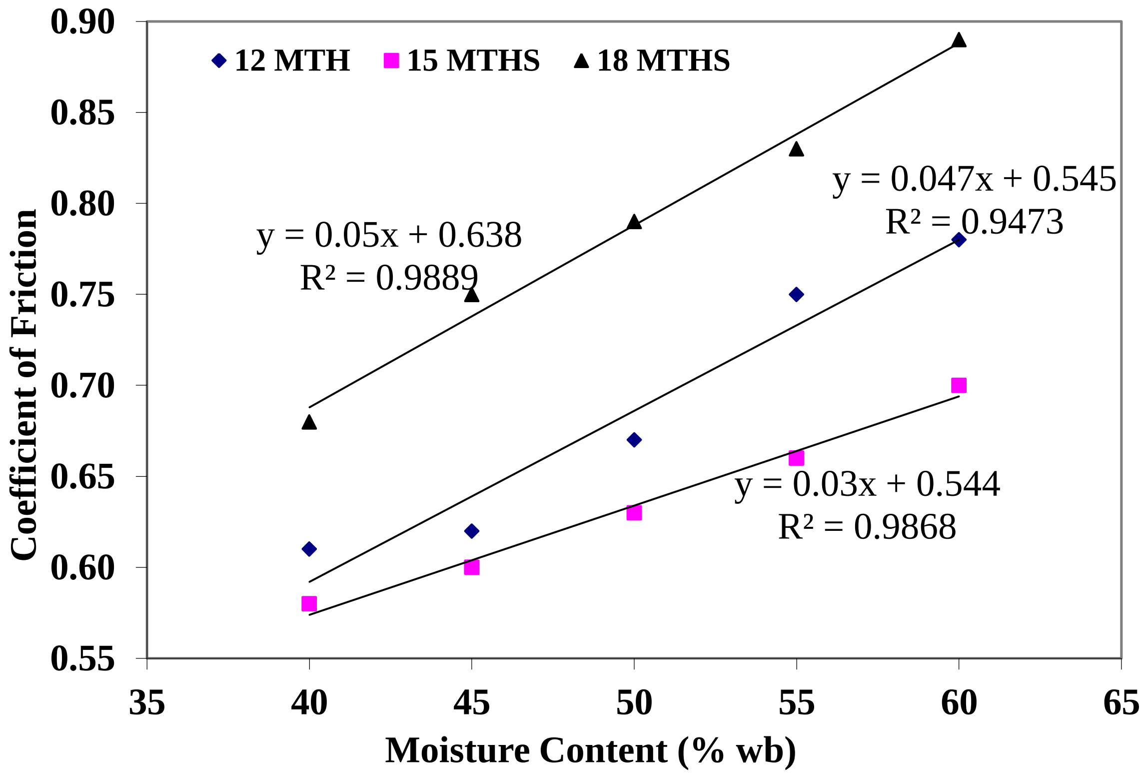

Fig. 4.13: Relationship between Coefficient of Friction and Moisture Content for TME 7 on Wood Surface at different Ages

The coefficient of friction of TME 7 on wood surface were the highest ranging between 0.68 and 0.89 across all the ages and moisture contents studied, and this was obtained at the age of 18 months. The effect of age on coefficient of friction of the cultivar on wood surface (and the two other surfaces) over the range of ages studied was found to be highly significant ($P < 0.05$).

However, among the three varieties of cassava studied, the 30572 cultivar had the lowest COF on stainless steel surface (at 12 MAP) at low (40%) moisture content and the highest COF when the moisture content was raised to 60%. It also had the highest COF at 15 MAP on all the three structural surfaces used irrespective of the moisture content of the samples. It, however, had the least COF on stainless steel and wood at 18 MAP while TME 419 had the highest at 18 MAP on stainless steel and galvanized sheet irrespective of the moisture content of the samples. TME 7 however had the highest COF at 12 and 18 (Table 4.3). This suggests that the frictional behaviour of cassava has a strong genetic component with some characteristics inherent to each of the cassava varieties as reported by Ngeve, (1995) for cassava tubers and Sriroth *et al.*, (1999) for cassava starch, which by extension may affect the granule structure and granule size distribution which interact with the granules of the surfaces (wood, stainless steel and galvanized sheet) that resulted in the observed behaviour.

4.2.2. Coefficient of Internal Friction of Cassava

The values of the coefficient internal friction (CIF) of TMS 30572, TME 419, and TME 7 are presented in Appendices C1 to C9 while a summary of the results are shown in Tables 4.4.

Table 4.4: Mean Values of Coefficient of Internal Friction of Cassava with Age

	TMS 30572			TME 419			TME 7		
MC (%)	**12 mths**	**15 mths**	**18 mths**	**12 mths**	**15 mths**	**18 mths**	**12 mths**	**15 mths**	**18 mths**
40	0.57	0.64	0.59	0.69	0.67	0.64	0.58	0.61	0.56
45	0.56	0.62	0.56	0.68	0.66	0.54	0.57	0.60	0.54
50	0.56	0.56	0.54	0.63	0.64	0.53	0.54	0.59	0.54
55	0.46	0.52	0.53	0.60	0.63	0.51	0.41	0.58	0.52
60	0.44	0.51	0.51	0.58	0.60	0.49	0.40	0.56	0.50

4.2.2.1 Coefficient of Internal Friction of TMS 30572 at Different Ages

The coefficient of internal friction of TMS 30572 ranged from 0.57 – 0.44 at 12 MAP, the corresponding values at 15 MAP ranged from 0.64 to 0.51, while the values at 18 MAP ranged from 0.59 to 0.51 respectively over the same range of moisture content (Table 4.4). Generally, the highest CIF were obtained at the age of 15MAP while the lowest were obtained at 12 months old. However, as the moisture content approached 60%, the 18 months old samples gave the highest CIF (Figure 4.14). The 18 months old samples shared the same CIF with the 12 and 15 months old sample when the moisture content was about 42% and 58% respectively. This suggests that moisture contents of 42 and 58% (wb) are critical to the influence that age could have on the internal coefficient of friction of the TMS 30572 cassava cultivar. The plot of the relationships between the CIF and moisture content is presented in Figure 4.14 with the regression equations and the R^2 values. It shows that a negative relationship exists between moisture content and coefficient of internal friction irrespective of the age of the tubers. The linear negative relationship between the coefficient of internal friction and moisture content as exhibited by the crop may be due to the ability of moisture to reduce the friction between two surfaces such that every increase in moisture is accompanied by a reduction in the CIF, hence, as the moisture content increased the friction between the surfaces of the cassava samples decreased.

The age 15 months at which the highest coefficient of internal friction was obtained could be due to the level of starch available at the two contacting surfaces which was expected to be at the peak at 15 MAP this age and the lowest values which were obtained from the 12 months old samples may be due to the tenderness of the fibers of the two contacting surfaces at that early age coupled with the relatively low starch content of the tubers at this developmental stage. The results of the ANOVA across ages showed that the influence of age on the coefficient of internal friction was very significant ($P < 0.05$).

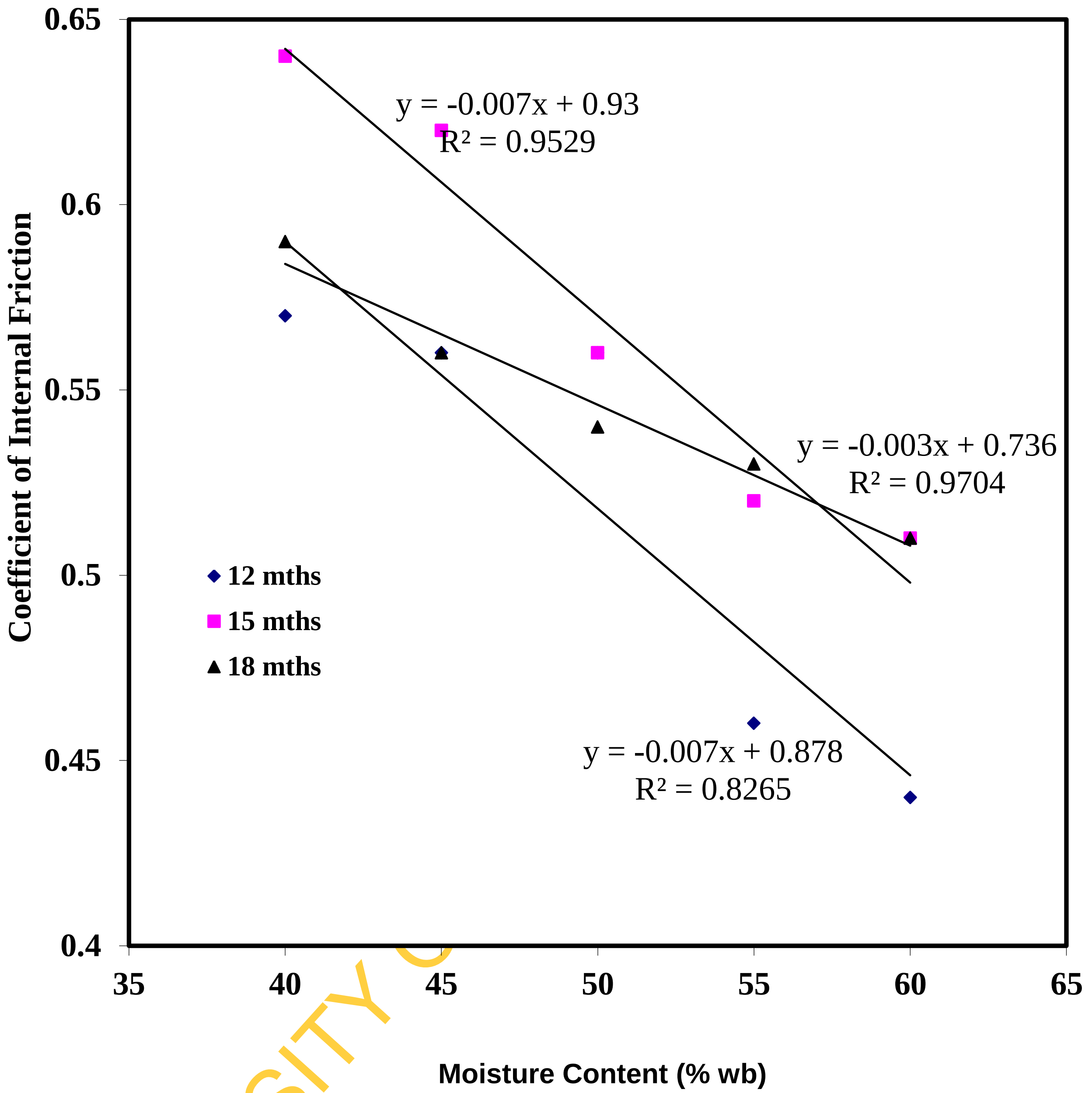

Figure 4.14: Relationship between Coefficient of Internal Friction and Moisture Content for TMS 30572 at different Ages.

4.2.2.2 Coefficient of Internal Friction of TME 419

The coefficient of internal friction of the TME 419 cassava cultivar ranged from 0.69 to 0.58 at 12MAP, the corresponding CIF at 15 MAP ranged from 0.67 to 0.60 while the values ranged from 0.64 to 0.49 at 18 MAP respectively over the same range of moisture content of 40-60% (Table 4.4). The relationship which exists between the CIF and moisture content is shown in Figure 5.15 together with the regression equation and the R^2. The CIF were observed to reduce with increase in age at low moisture contents, but later at moisture contents beyond 48% (wb), the trend changed as the CIF increased from 12MAP up to 15 MAP and then declined, expectedly, towards 18 MAP. The reduction in CIF at lower moisture contents may be peculiar to this cultivar.

The variation in the behaviour of this cassava cultivar compared to that of TMS 30572 whose CIF values peaked at 15 MAP may be due to the characteristics inherent in a cultivar of crop which differentiates it from another (Ngeve, 1995). The results of the ANOVA showed that age of TME 419 cassava cultivar has a strong influence on its coefficient of internal friction.

4.2.2.3 Coefficient of internal friction of TME 7 cultivar

The coefficient of internal friction of the TME 7 cultivar ranged from 0.40 to 0.58 at 12 MAP, the corresponding CIF at 15 MAP ranged from 0.56 to 0.61 while the range was 0.50 to 0.56 at 18 MAP respectively (Table 4.4). The variation of the CIF across ages is presented in Figure 4.16. It shows that the CIF values peaked at the age of 15 months beyond which it declined as the tubers grew older. This trend is similar to that observed with TMS 30572. The same reasons adduced for 30572 sufficed for this. The plot of CIF against moisture content shows that the CIF was highest at 15 months and lowest at 12 months at moisture contents above 45% (wb), while the 18 months old samples had the least coefficient of friction at moisture contents below 45% (Fig. 4.16 and Fig. 4.17). The ANOVA results showed that the influence of age of the TME 7 cultivar was very significant.

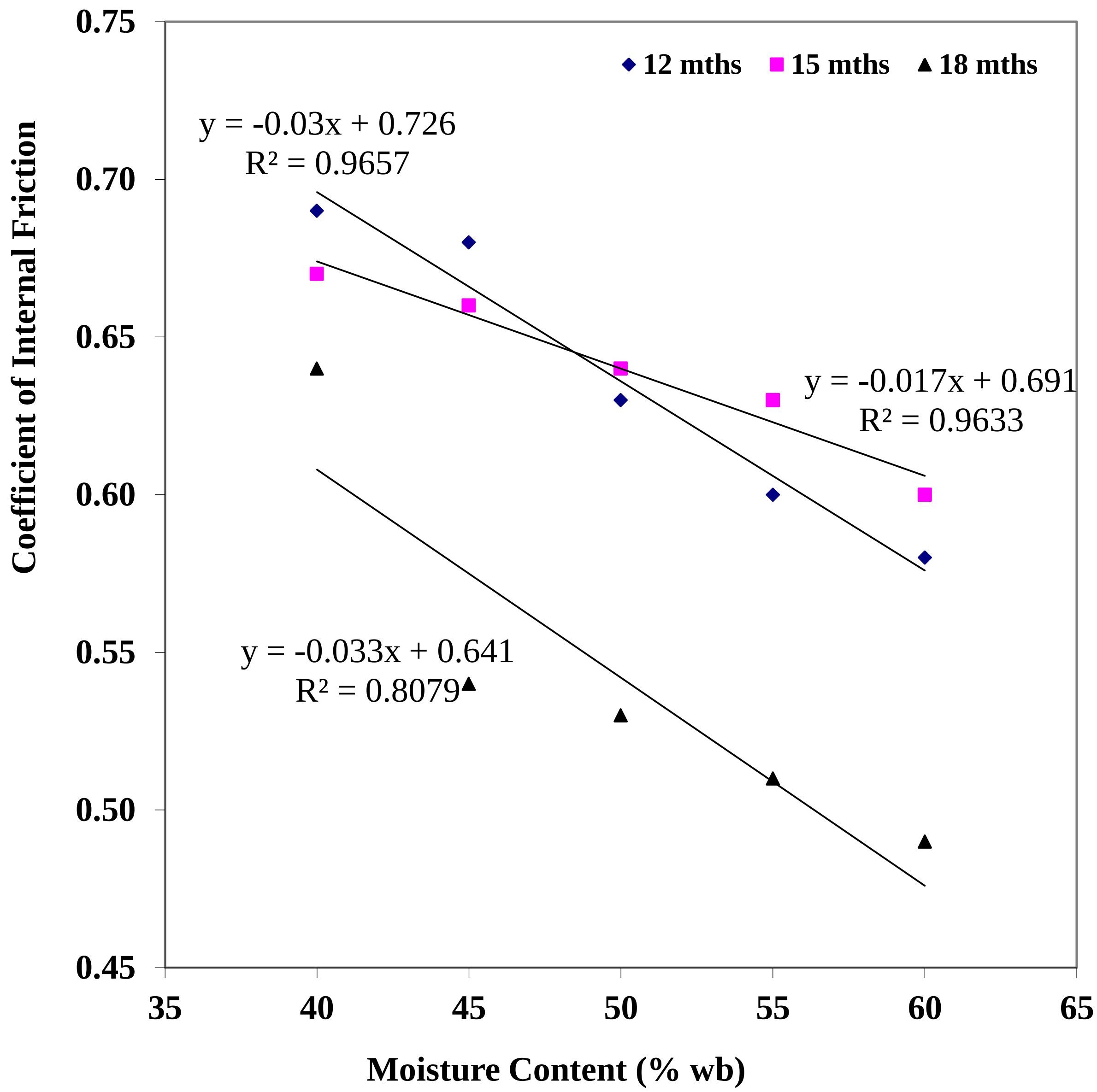

Figure 4.15: Relationship between Coefficient of Internal Friction and Moisture Content for TME 419 at different Ages

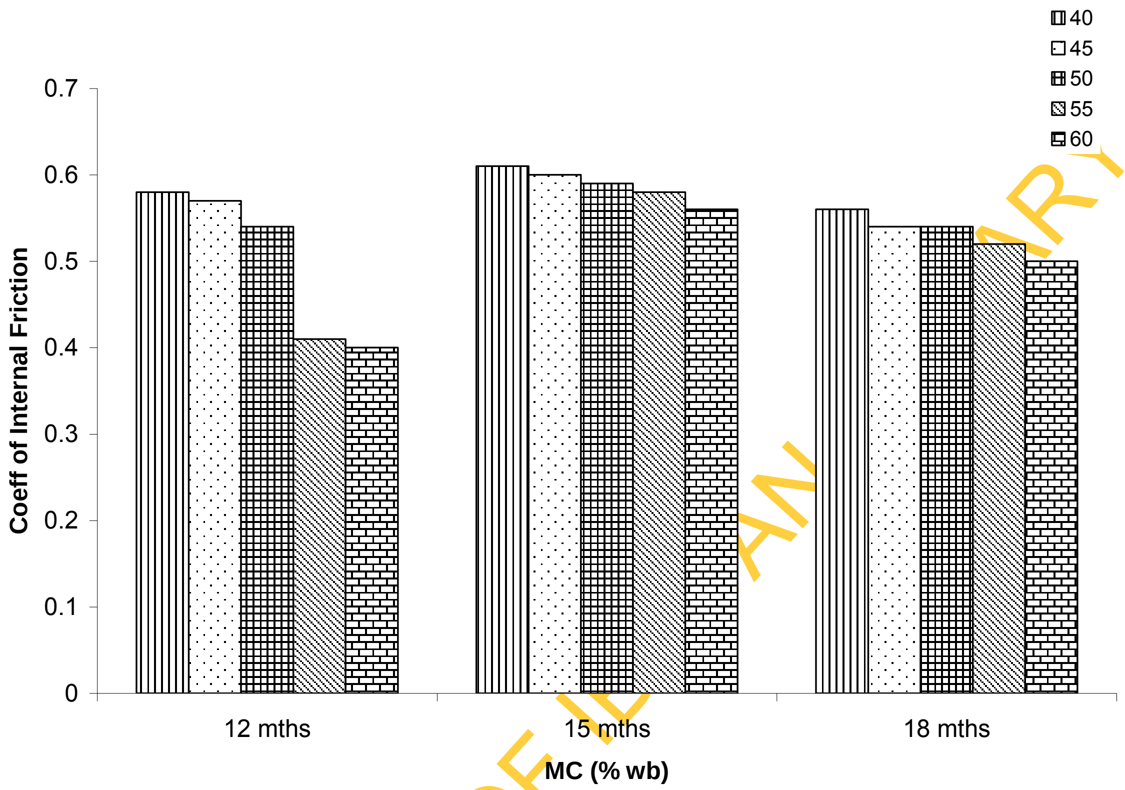

Figure 4.16: Coefficient of Internal Friction of TME 7 at different Ages.

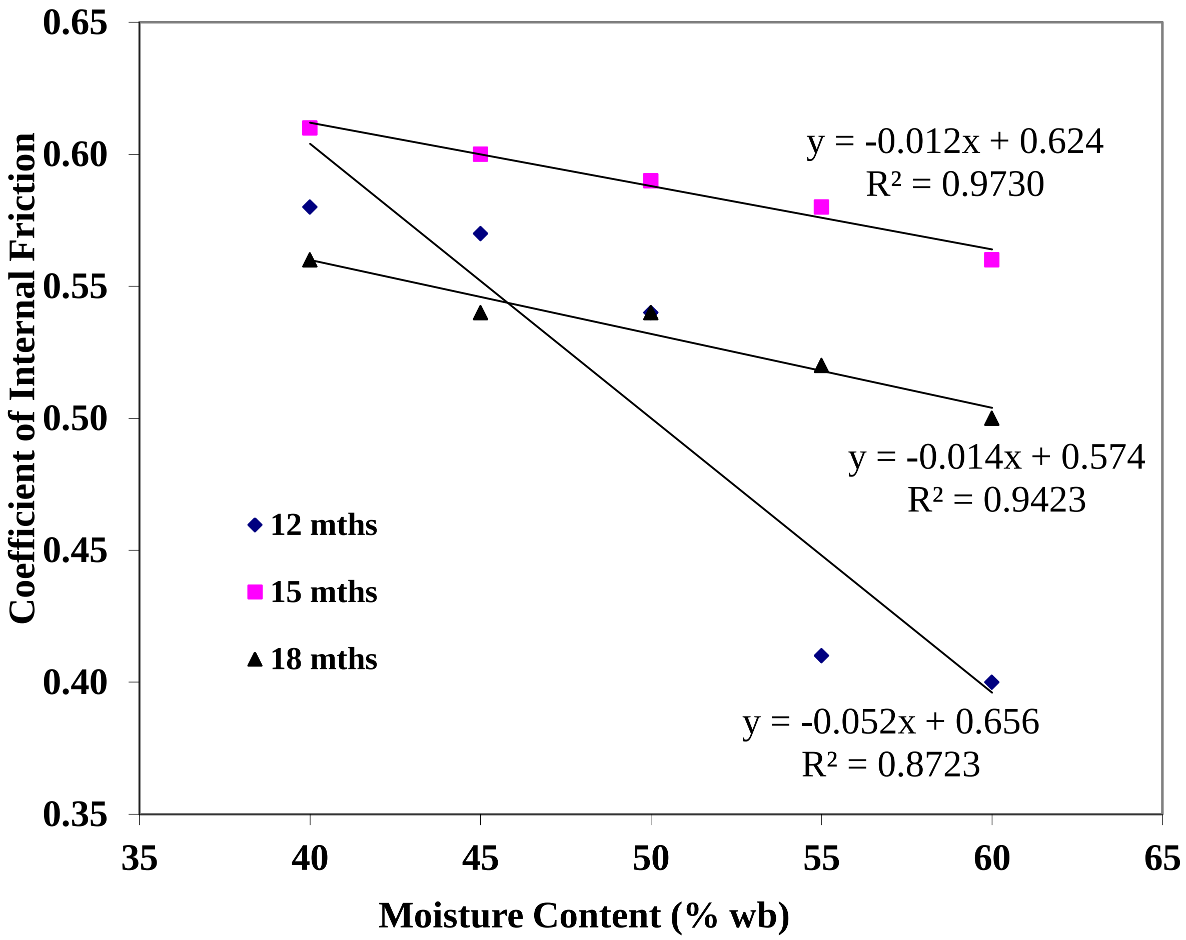

Figure 4.17: Relationship between Coefficient of Internal Friction and Moisture Content for TME 7 across Ages.

4.2.3 Coefficient of Rolling Resistance

The values of the coefficient of rolling resistance (CRR) of TMS 30572, TME 419 and TME 7 cultivars used in this study are presented in Appendix D1 to D27 while a summary of the results of the CRR of these cultivars on stainless steel, galvanized sheet and wood at different ages using the periderm, cortex and flesh of the tubers are as presented in Tables 4.5.

4.2.3.1 Coefficient of Rolling Resistance of TMS 30572

The coefficients of rolling resistance (CRR) of TMS 30572 on the three surfaces used in this study are as present in Table 4.5. Generally, the highest CRR were obtained with the periderm on all the three surfaces at each stage of development while the flesh of the tubers gave the least CRR. Also, the CRR were highest when the periderm was used on wood and least with the flesh on stainless steel surfaces. This is in strong support of the report of Ejovo *et al*. (1988). It is due to the high degree of roughness of the periderm compared to the cortex and the flesh, likewise the high degree of roughness of the wood compared to the other two surfaces. In addition, the CRR values vary with the age of the tubers as it increased from 12 MAP to reach the peak at 15 MAP before declining to values that were lower than those of 12 months old samples, especially on galvanized sheet and wood. Expectedly, the highest value of the CRR (0.41) was obtained on wood at the tuber age of 15 MAP while the least value (0.08) was obtained on stainless steel surface at both 12 and 18 MAP (Figure 4.18). This may not be unconnected with the size of the tuber at each stage of development of the crop as the results of the CRR tends to follow the same trend as that of the physical properties tests which showed that the sizes of the tubers were highest at 15MAP and, expectedly, the inertial of the tubers would vary with size.

Table 4.5: Average Coefficient of Rolling Resistance of Cassava on Different Surfaces

	12 months			15 months			18 months		
Covering	**Stainless**	**Galvanized**	**Wood**	**Stainless**	**Galvanized**	**Wood**	**Stainless**	**Galvanized**	**Wood**
TMS 30572									
Periderm	0.14	0.22	0.25	0.24	0.33	0.41	0.14	0.18	0.20
Cortex	0.10	0.16	0.20	0.22	0.27	0.36	0.11	0.14	0.17
Flesh	0.08	0.12	0.15	0.17	0.23	0.26	0.08	0.11	0.12
TME 419									
Periderm	0.14	0.20	0.25	0.16	0.20	0.25	0.18	0.23	0.33
Cortex	0.12	0.18	0.20	0.15	0.16	0.18	0.15	0.20	0.29
Flesh	0.09	0.13	0.17	0.07	0.11	0.14	0.09	0.14	0.19
TME 7									
Periderm	0.15	0.26	0.30	0.15	0.23	0.29	0.17	0.19	0.29
Cortex	0.13	0.19	0.26	0.12	0.20	0.24	0.14	0.15	0.25
Flesh	0.08	0.14	0.19	0.07	0.13	0.18	0.09	0.12	0.21

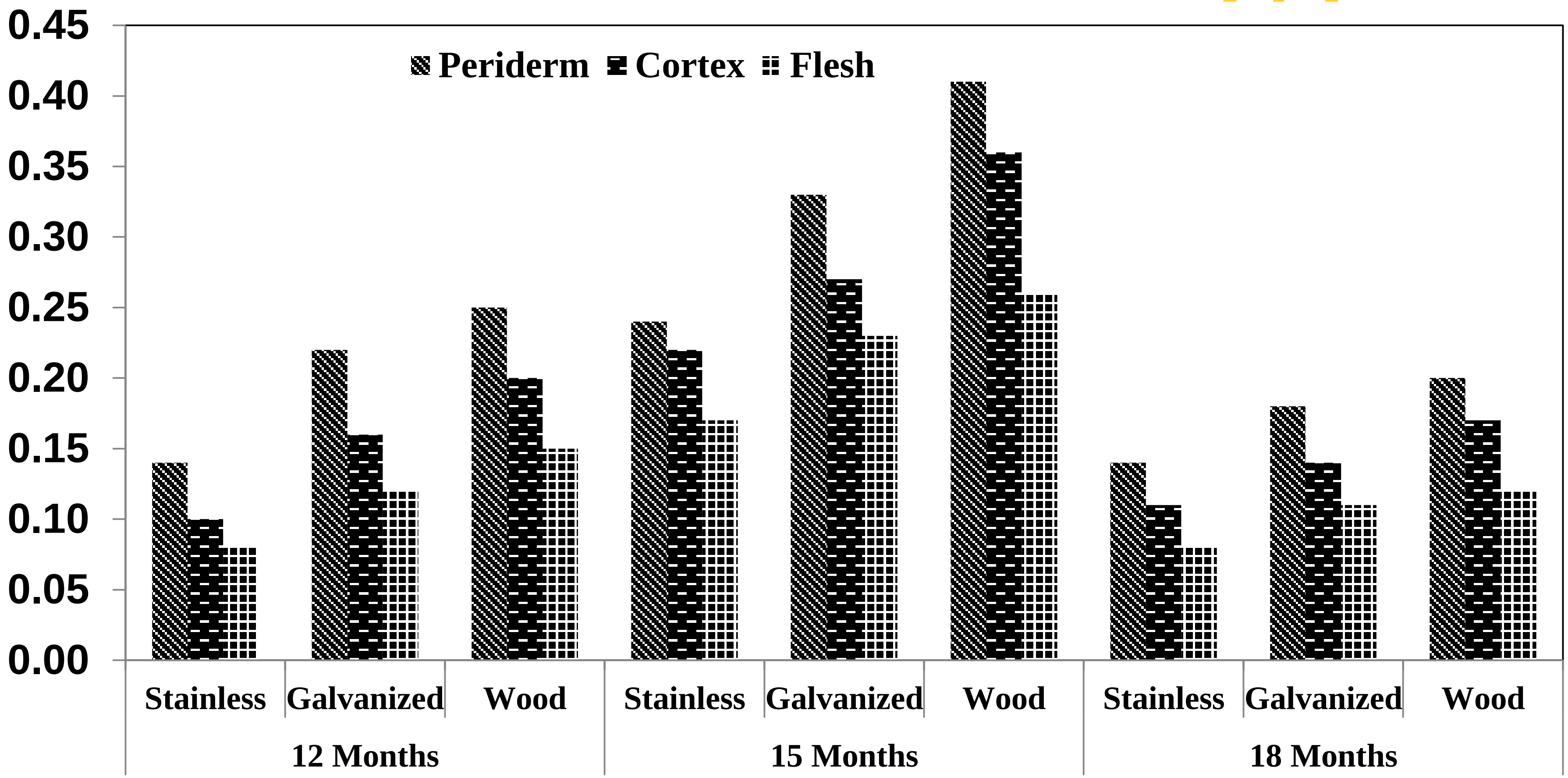

Figure 4.18: Variation of Coefficient of Rolling Resistance of TMS 30572 with Root Age on different Surfaces

These values of CRR as presented in Table 4.5 are, however, quite low to those reported by Ejovo *et al*., (1988) which ranged from 6.00 to 8.73 and averaged 7.66 on wood. Varietal differences coupled with environmental conditions at the time of harvest may be responsible for this. The ANOVA results of the coefficient of rolling resistance of TMS 30572 using the periderm, cortex and flesh on the three surfaces of stainless, galvanized sheet and wood showed that the influence of age was highly significant.

4.2.3.2 Coefficient of Rolling Resistance of TME 419

The coefficients of rolling resistance of TME 419 cultivar were as presented in Table 4.5. The CRR values were highest with the periderm on all the surfaces while the lowest were obtained with the flesh just like that of the TMS 30572. Also, wood gave the highest CRR and stainless steel gave the least. Expectedly, the combination of the periderm and the wood gave the highest CRR but, at the age of 18 months (Figure 4.19). This tends to suggests that the degree of roughness of the periderm of the tubers varies with age, and the interaction of this factor and tuber size has a considerable influence on the CRR of cassava as the high CRR of the 18 months old samples, in spite of the relatively low average size of the tubers (Table 4.1), points to the fact that tuber size alone could hardly explain the behavior in relation to age, of course, not in isolation of the influence of the degree of roughness of the structural surfaces as indicated by the increase in the values of the CRR with age on stainless steel surface especially for periderm and cortex (Table 4.5).

The results of the analysis of variance over the period of the study showed that the influence of age of tubers of the TME 419 cassava cultivar on the CRR of the periderm on wood was highly significant ($P < 0.05$) but not significant on stainless steel and galvanized sheet surfaces ($P > 0.05$).

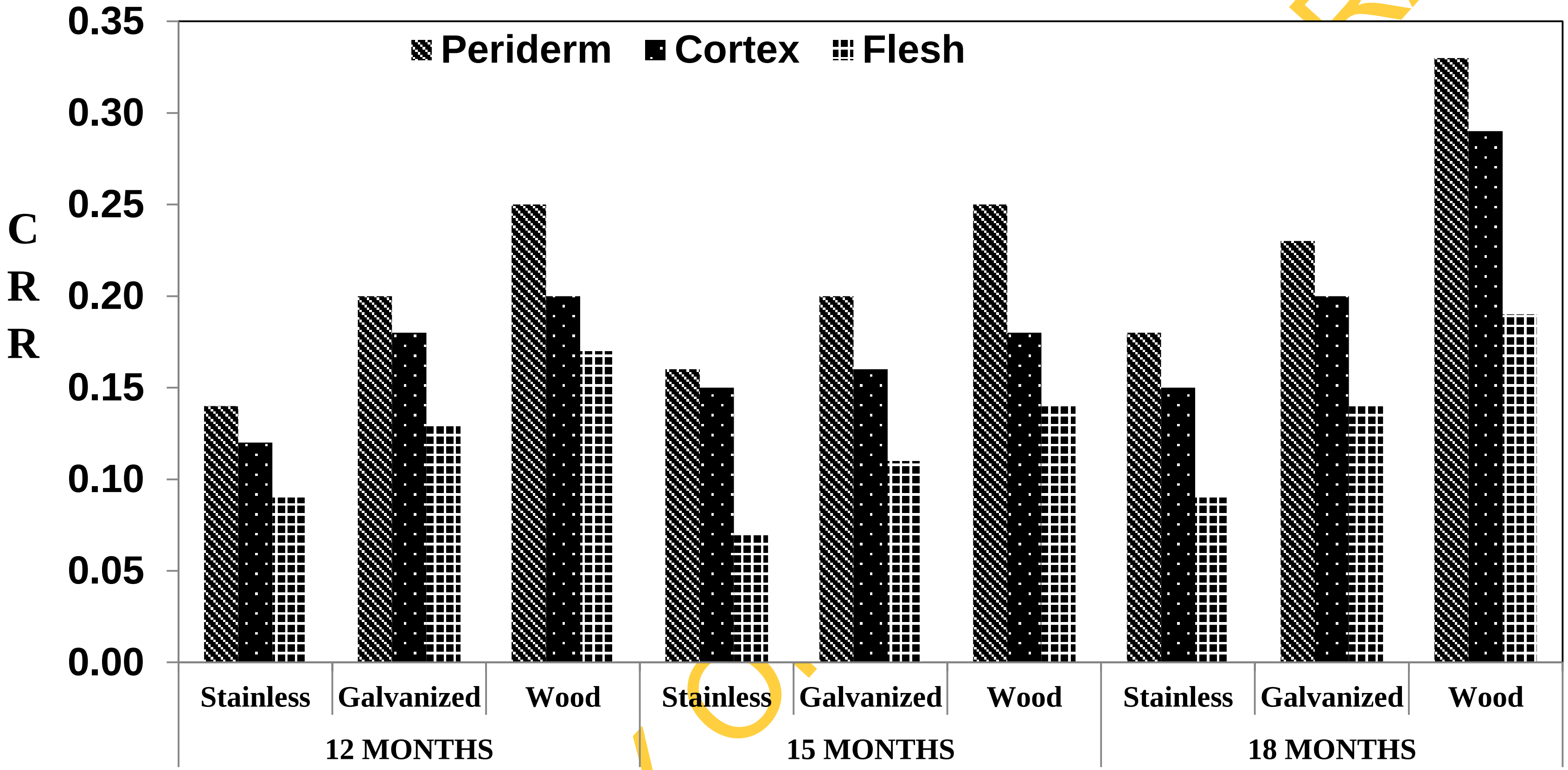

Figure 4.19: Variation of Coefficient of Rolling Resistance of TME 419 with Root Age on different Surfaces

4.2.3.3 Coefficient of Rolling Resistance of TME 7

The mean coefficient of rolling resistance (CRR) of TME 7 cultivar on the three surfaces used in this study are as present in Table 4.5. The mean coefficient of rolling resistance of the periderm on stainless steel increased from the age of 12 months old up till 18 months ranging from 0.15 at 12 months to 0.17 at 18 months old. The values however, decreased steadily with age on galvanized sheet and wood but with higher CRR values (0.26-0.19) on galvanized sheet and (0.30-0.29) on wood (Figure 4.20). The variations in the behaviour as noticed in this cultivar compared to the others could be the due to the influence of characteristics inherent to this variety. The CRR value of the cortex of the tubers against stainless steel surface was highest at 18 months and least at 15 months old. It however, peaked at the age of 15 months and least at 18 months on galvanized sheet surface.

The CRR of the flesh on stainless steel were also least at 15 months and highest at 18 months. The CRR of the flesh on galvanized sheet, however, declined steadily with age while it was least at 15 months and highest at 18 months on wood. Again, the influence of interactions of the size and size distribution of the starch granules of cassava on one hand, and the interaction of its micro-structure and that of the grains (micro structure) of the structural surfaces on the other is suspected to be responsible for the undefined frictional behavioral pattern observed. Results of the analysis of variance showed that the influence of age on the coefficient of rolling resistance of this cassava cultivar is not statistically significant on any of the three surfaces. However, results of the ANOVA test for the effects of tuber coverings (periderm, cortex and flesh) on CRR of TME 7 on the three surfaces showed that it has a strong influence on all the surfaces but with the CRR on flesh and cortex being homogeneous on galvanized sheet and wood surfaces. Age does not, however, significantly influence the CRR of the flesh on any of the three surfaces ($P > 0.05$) for this cassava.

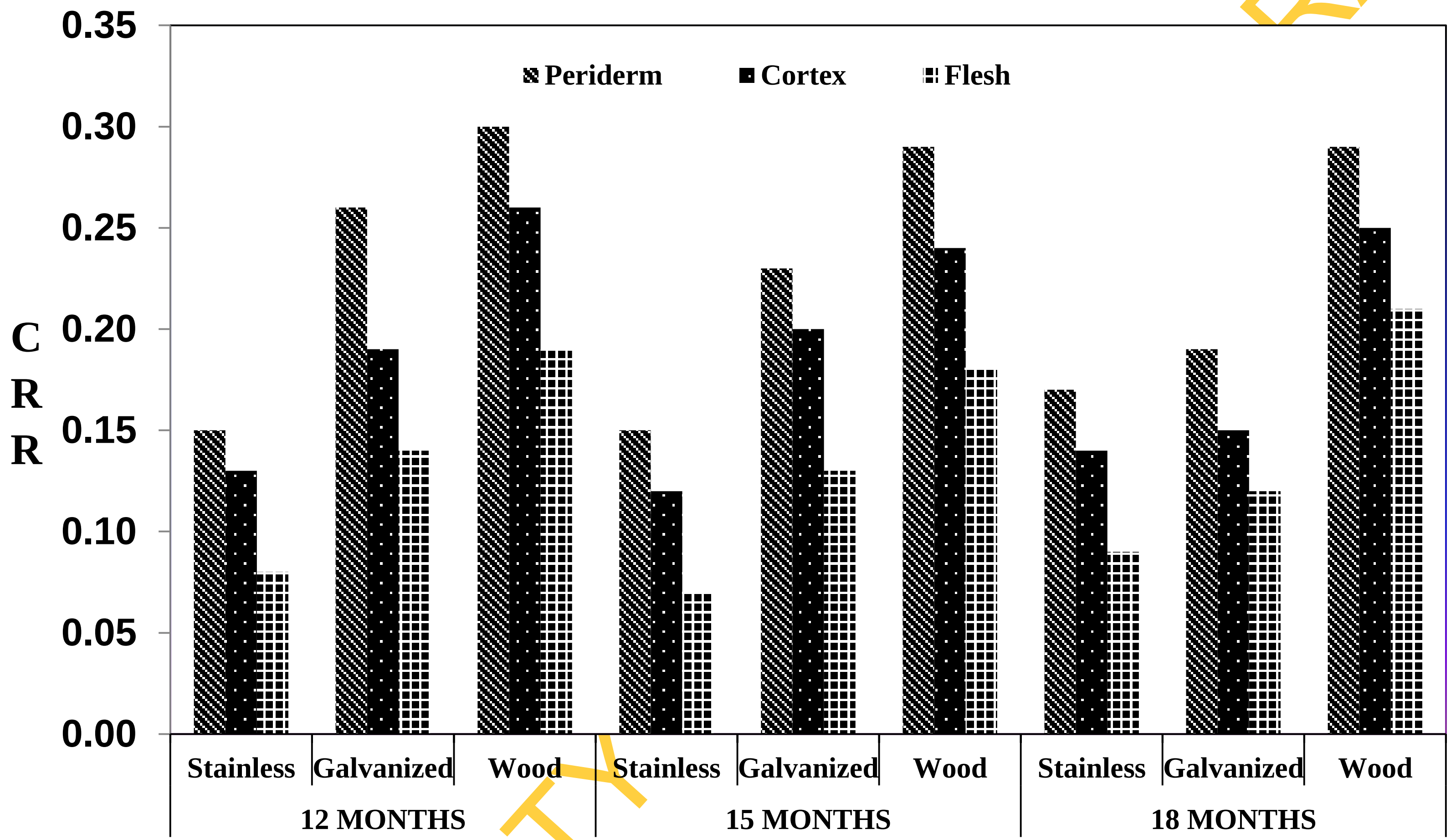

Figure 4.20: Variation of Coefficient of Rolling Resistance of TME 7 with Root Age on different Surface

4.2.4 Compressive Strength Properties of Cassava

Results of the compressive strength properties of the three cassava varieties used in this study are as presented in Table 4.6 while the individual values are presented in Appendix E1 to E9.

A typical (sample) compression curve as recorded in force-deformation coordinate system for the studied cassava varieties irrespective of their ages is shown in Figure 4.21. The curves generally have two major parts, the linear part which corresponds with the limit of elasticity, and the curved part, the crest of which depicts the peak force, from where its corresponding deformation at peak could be determined. The lower part of the curve (to the right) extends, occasionally, irregularly, indicating a yield, and eventually ended with failure. This pattern of deformation has been reported for different crops (Rebouillat and Peleg, 1988; Maduako and Faborode, 1994; Nwangugu and Okonkwo, 2009; Ozumba and Obiakor, 2011). The stress-strain curve of the compressive strength tests reported by Kolawole *et al*., (2007b) also gave this shape, a linear portion with a downward facing curve that ended with failure.

However, a critical observation made during the tests revealed that the UTM was made to stop automatically when the test samples break suddenly by snapping off as in metallic materials. However, cassava being an agricultural material which was not strong enough to snap off when it ruptures placed the burden of stopping the machine on the operator, who often found it difficult to know the exact time that the sample ruptures especially from sides away from his view. In some other cases, the rupture would start internally and proceeds outwardly, such that the cassava samples may have ruptured internally but this would manifest to the operator only when it extend to the outer part of the sample before stopping the machine. This problem thus made the values of the deformation at break to be exaggerated in most cases if the UTM was not stopped on time.

Table 4.6: Mean Compressive Strength Parameters of Cassava with Tuber Age

Parameter	MC	TMS 30572 12mth	TMS 30572 15mths	TMS 30572 18mths	TME 419 12mth	TME 419 15mths	TME 419 18mths	TME 7 12mth	TME 7 15mths	TME 7 18mths
Force @ Peak (N)	50	428.34	701.36	609.06	414.76	741.86	837.24	290.16	697.86	813.06
	55	551.68	627.32	649.76	483.28	806.46	805.84	359.36	811.40	833.20
	60	518.30	696.74	594.92	550.16	791.18	824.86	746.32	670.22	757.64
	65	571.34	660.34	559.05	544.52	809.14	755.10	665.84	798.36	916.80
	70	624.68	797.64	558.34	731.80	702.84	874.10	643.96	763.10	864.14
Force @ Break (N)	50	207.72	518.08	475.95	213.60	645.30	690.00	163.04	519.20	655.10
	55	140.92	446.92	544.42	189.88	634.86	631.58	164.16	684.22	792.40
	60	238.82	530.42	513.16	157.14	674.20	701.86	292.52	542.06	682.14
	65	321.82	448.50	496.85	148.44	609.56	624.80	380.64	659.48	762.86
	70	230.38	606.94	436.84	390.74	474.18	659.44	551.22	606.96	733.50
Energy @ Peak (N.m)	50	2.98	5.88	3.97	2.79	5.68	8.39	2.02	4.59	5.72
	55	4.28	4.78	4.18	3.83	6.86	6.73	2.26	6.53	5.99
	60	3.42	5.04	4.28	3.30	6.22	7.86	5.71	4.68	4.70
	65	3.87	5.34	3.82	3.89	7.49	6.57	4.73	5.60	6.66
	70	4.12	6.68	3.86	5.90	5.53	7.95	3.91	6.33	6.24
Energy to Break (N.m)	50	4.80	7.54	5.09	4.45	6.95	9.82	3.23	5.99	7.18
	55	6.37	5.99	5.11	6.10	9.80	8.69	3.81	8.05	6.99
	60	4.91	7.47	5.10	5.88	8.04	9.06	8.18	5.70	5.56
	65	5.65	7.00	4.55	6.00	9.71	8.33	6.95	7.72	8.04
	70	6.67	9.21	4.80	8.61	7.60	9.56	4.81	8.37	7.56
Stress @ Break (N/mm^2)	50	0.29	0.77	0.67	0.30	0.91	0.98	0.23	0.74	0.93
	55	0.20	0.63	0.77	0.27	0.90	0.89	0.24	1.02	1.12
	60	0.34	0.75	0.73	0.22	0.95	0.99	0.41	0.77	0.97
	65	0.46	0.64	0.70	0.21	0.86	0.88	0.54	0.93	1.08
	70	0.33	0.86	0.62	0.55	0.67	0.93	0.78	0.86	1.04
Stress @ Peak (N/mm^2)	50	0.61	0.99	0.86	0.59	1.05	1.19	0.41	0.99	1.15
	55	0.78	0.89	0.92	0.68	1.14	1.14	0.51	1.15	1.18
	60	0.73	0.99	0.84	0.78	1.12	1.17	1.06	0.95	1.07
	65	0.81	0.93	0.79	0.77	1.15	1.07	0.94	1.13	1.30
	70	0.88	1.13	0.79	1.04	0.99	1.24	0.91	1.08	1.22
Young's Modulus (N/mm^2)	50	4.81	5.57	8.03	3.58	4.85	7.11	3.22	4.72	7.41
	55	5.74	5.77	8.84	4.90	5.56	6.85	3.83	4.25	6.85
	60	6.24	5.73	8.05	6.60	5.17	7.65	6.96	4.44	7.46
	65	9.28	5.27	6.28	5.42	5.81	5.89	5.46	5.58	6.69
	70	8.13	5.76	5.68	7.25	5.99	7.38	6.33	4.30	8.38
Deformation @ Peak (mm)	50	10.10	13.17	11.08	11.86	12.78	16.44	11.82	11.49	12.68
	55	11.94	11.75	11.02	12.39	13.47	14.35	10.45	13.61	13.30
	60	9.08	12.02	12.21	9.79	12.81	15.47	12.56	12.16	11.15
	65	10.03	12.99	11.71	11.50	14.51	14.20	12.08	11.81	13.32
	70	10.37	13.01	11.39	13.30	12.53	15.22	9.77	13.85	12.58
Deformation @ Break (mm)	50	15.86	15.78	13.21	17.46	14.67	18.30	16.72	13.81	14.60
	55	17.62	13.98	12.57	19.54	17.43	17.06	16.21	15.53	14.63
	60	13.27	15.85	13.70	17.15	15.15	17.21	17.02	13.87	12.27
	65	14.14	16.10	13.09	18.36	17.60	16.71	16.02	14.68	14.83
	70	15.95	16.58	13.25	18.77	16.07	17.46	11.21	16.80	14.22

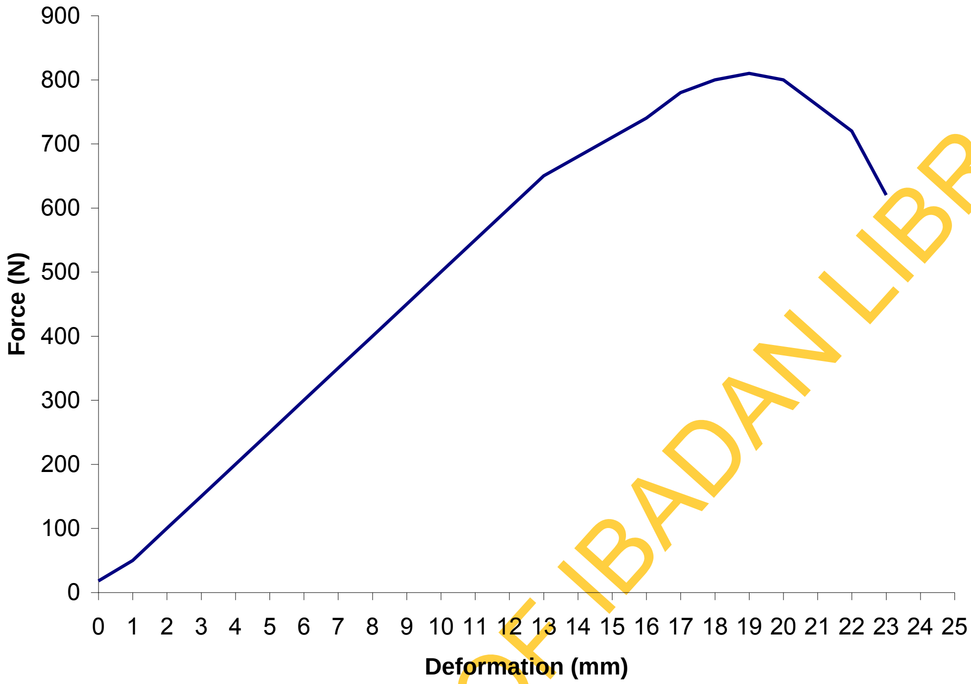

Figure 4.21: A Typical Compression Curve of Cassava Tubers

4.2.4.1 Compressive Strength of TMS 30572 Cassava Cultivar

The mean of the stress at peak for the TMS 30572 cultivar ranged from 0.61 – 0.88, 0.89 – 1.13, and 0.84 – 0.92N/mm^2 at 12, 15 and 18 MAP respectively. The mean of the force at peak for the TMS 30572 cassava cultivar ranged from 428.34 - 624.68, 627.32 - 797.23, and 558.34 – 649.76.14N at 12, 15 and 18 MAP respectively (Table 4.6). It was noted that the strength of material could be described correctly using either the force or stress (Kolawole *et al*., 2007b; Nwangugu and Okonkwo, 2009).

Generally, the peak stress of the tubers of the TMS 30572 cassava cultivar was found to be highest at 15 MAP while the moisture content determines the stronger between the 12months and the 18 months old samples. For instance, the 18months old samples were stronger than those of 12 months old at moisture contents between 50 and 60% (wb) beyond which a reversed trend was observed (Figure 4.22). Analysis of the data was done by response surface (RSM) regression for a second order polynomial model containing linear, quadratic and interaction terms for the two factors based on its R^2 value on one hand, and, production of response surface and significant level of confidence obtained from analysis of variance on the other. The cubic model (with the highest R^2), in contrast to the second order polynomial model, did not produce any response surface and its overall level of confidence was not significant. The representation of the response surface obtained from the second order polynomial model with interaction terms is given in Figure 4.23 as generated from equation 5.1 while the Analysis of Variance of the model for peak stress of TMS 30572 cassava variety is given in Table 5.17.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \varepsilon. \qquad \text{(Eqn. 4.1)}$$

Where;

Y = value of the considered response variable

X_1 and X_2 = values of age and moisture content respectively

β_0 = constant value

β_1 and β_2 = linear coefficients

β_{11} and β_{22} = quadratic coefficients

β_{12} = interaction coefficient

$\mathcal{E}$ = random error

It is evident from Figure 4.23 that the peak stress increased non-linearly from 0.61N/mm^2 to 0.88 N/mm^2 when the moisture content was increased between 50 – 70% (wb) at the age of 12 MAP. A similar trend was observed up to 16 MAP where the increase in strength was even sharper when the moisture content was increased from 60 to 70% (wb). A directly opposite trend was observed at 18 MAP where the strength of the tubers decline non-linearly from 0.9 to 08N/mm^2. Analysis of Variance of the model showed that the effect of age, moisture content and the interactions of these two variables did not significantly influence the strength of the tubers of the TMS 30572. The regression equation obtained for the model is of the form:

$$Y = -\ 0.184 - 0.08574M + 0.08386A + 0.000410M^2 + 0.00968MA + 0.00211A^2 - 9.524 \times 10^{-6}AM^2 - 0.000378MA^2 \qquad \text{(Eqn. 4.2)}$$

Where:

Y = Peak stress (N/mm^2)

M = Moisture content (% wb)

A = Tuber age (Months after planting)

The increase in tuber strength with age up to 16 MAP before declining was in line with the report of Opara (1999) who reported that root and starch production increase rapidly to their maximum value and then decline afterwards during cassava growth season. Amoah *et al.* (2009) also reported a similar trend for gari yield with increase in tuber age from 10 to 14 MAP and attributed this to higher dry matter in the older root. The opposing trend of peak stress of the 18 months old tuber to increase in moisture content, coupled with the statistically insignificant ($p > 0.05$) influence of age and moisture content of the tubers on the peak stress suggest that more factors other than age and moisture content may influence the strength of the tubers. This behavior may not be unconnected with the complexities of the combination of the influence of the changes in the internal structure, chemical composition and size distribution of the particle of the starch of the tubers with age on one hand, and that of the influence of the prevailing environmental conditions around the tubers just before they were harvested as suggested by Sriroth *et al.* (1999).

There is, however, a sharp difference between the strength values being reported in this study and those reported by Kolawole *et al.* (2007b) whose values of compressive stress ranged from 0.047 – 0.080N/mm^2 with a positive linear relationship between strength and moisture content. Also, Nwangugu and Okonkwo (2009) reported a maximum peak compressive force of 558N, 499N and 374N for the head, middle and tail parts respectively corresponding to moisture contents of 67.46, 68.72 and 71.19% using cassava tubers of the sweet variety, thereby suggesting a negative relationship between moisture content and compressive strength of cassava tubers. These values were, however, only close to the least values of peak compressive force of cassava being reported in this present study. These variations in their reported strength properties is apparently due to the improvised equipment used in their various studies which may also be responsible for the conflicting trend of the relationship between moisture content and compressive strength of cassava tubers reported.

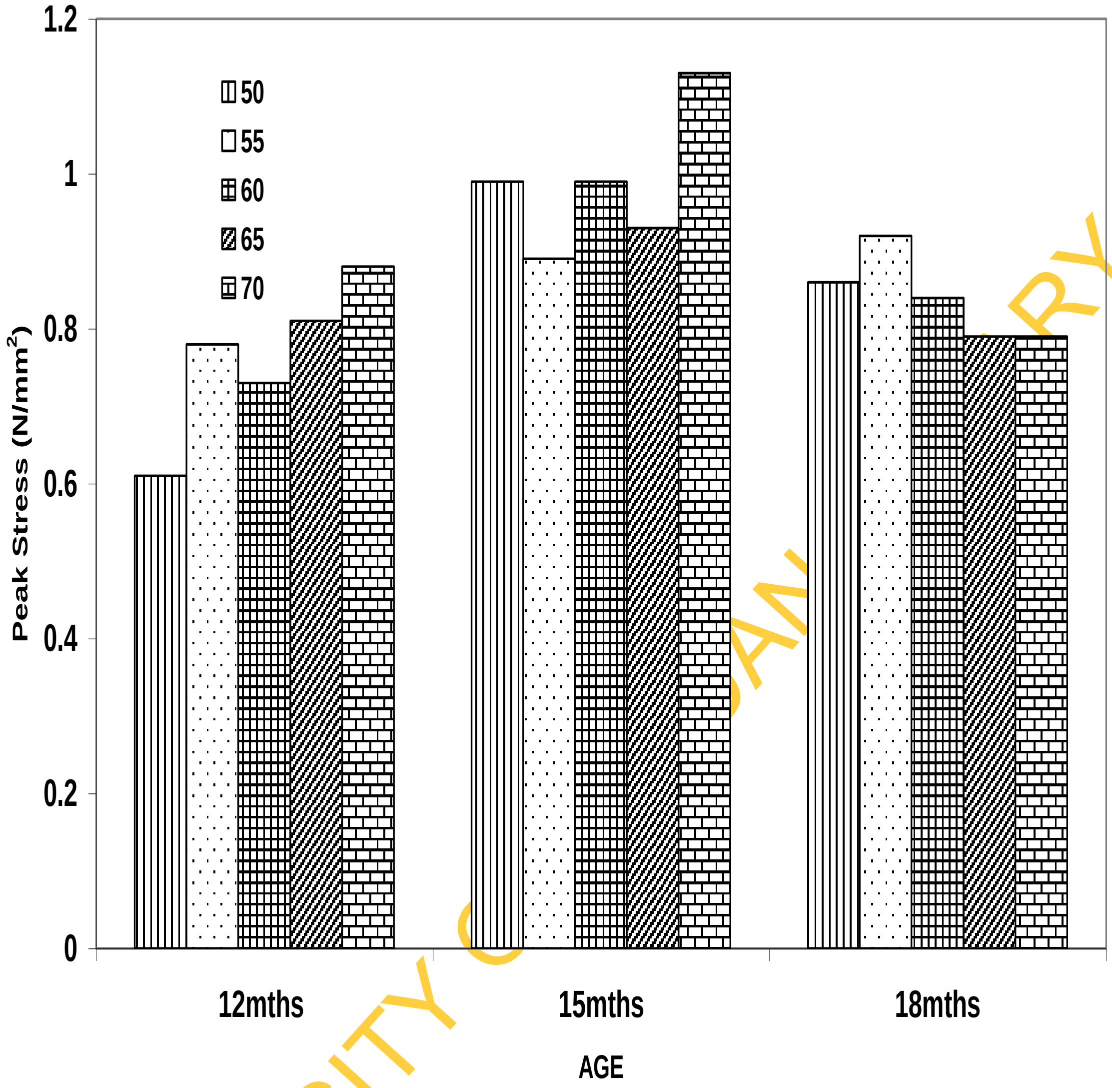

Figure 4.22: Peak Stress of TMS 30572 with Age

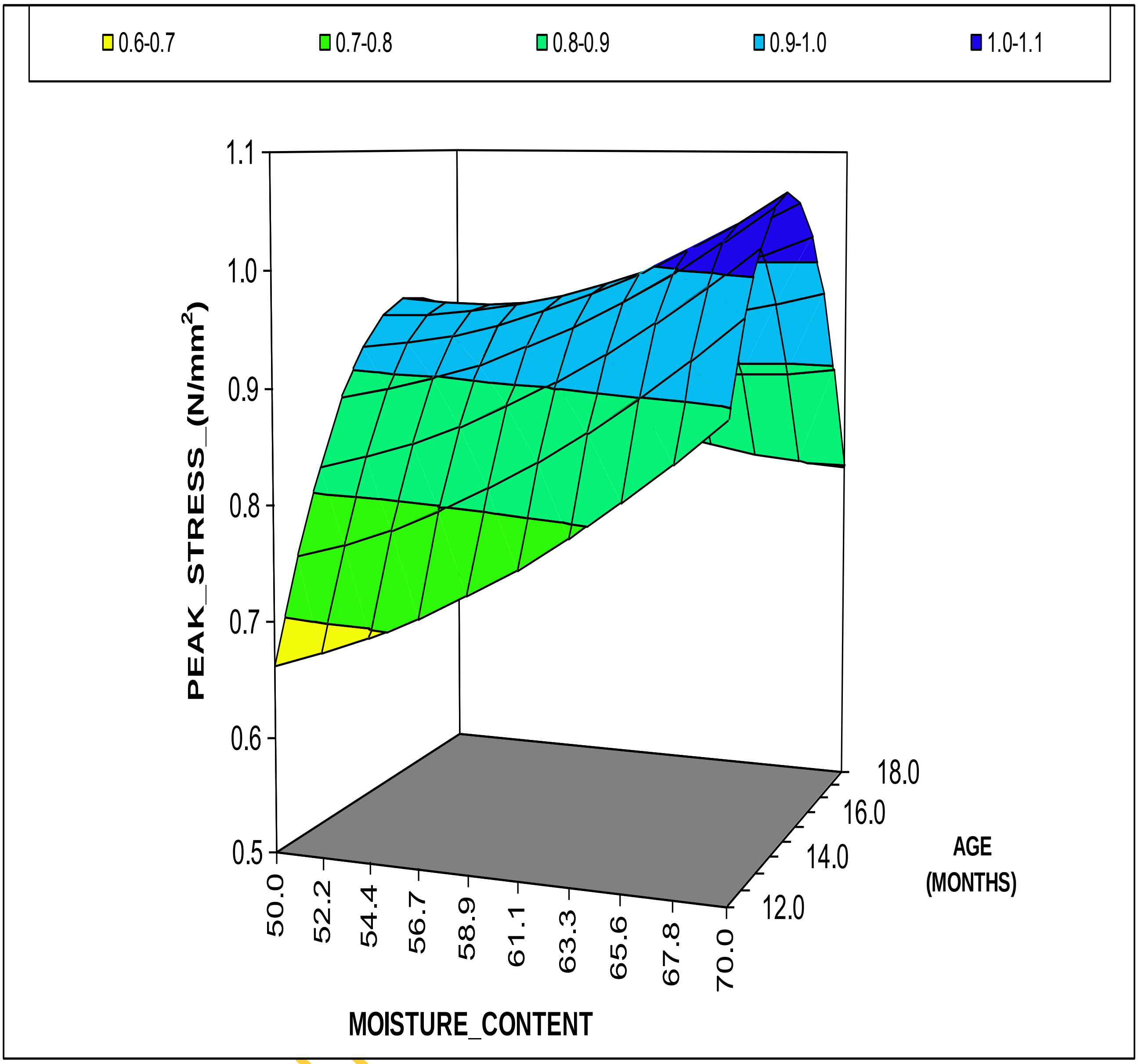

Figure 4.23: Response Surface for Peak Stress of TMS 30572

The toughness of this cassava cultivar, represented by the values of energy to break, perfectly followed the same trend like the strength property as it was observed to be toughest at 15 MAP where the least value of toughness (5.99N.m) was even higher than the toughest at 18 MAP (5.11 N.m). Coincidentally, these values were obtained at the same moisture content of 55%. The tubers were very brittle at 18 MAP irrespective of the moisture content (Figure 4.24). This could be as a result of the decrease in starch and dry matter content of the tubers at this age coupled with the increase in fibre content as reported by Safo-Kantanka and Osei-Minta (1996). Amoah *et al*. (2009) reported a similar result for a cassava cultivar (UCC 506) which gave a lower gari yield at 14 months old compared to those of 12months old. They however adduced the reasons postulated by Opara (1999) which indicated that during growth season, root and starch production increased rapidly to their peak value and then decline afterwards.

Second order polynomial was also fitted to the energy-to-break data even though the cubic model gave the highest R^2 value of 0.840 but its overall F-value was insignificant at 95% confidence level and its adjusted R^2 was undefined which makes its predictions unstable. The response surface is shown in Figure 4.25. It shows that the energy-to-break decreased between the moisture contents of 50 and 60% indicating that the tubers only exhibited better toughness at elevated moisture content from 60 up to 70% (wb). Also, the toughness of the tubers was greatest at the age of 15 MAP and the toughness increased sharply when the moisture content was increased from 60 and 70% (wb). Beyond 15 MAP the toughness declined with age and became very poor at 18 MAP. Unlike the trend obtained with the peak stress, the energy to break maintained the same trend with moisture content at all ages. Analysis of variance showed that the individual influence of age and moisture content on the toughness of the TMS 30572 was not statistically significant. The overall interaction of the two variables using the second order polynomial was, however, statistically significant ($P < 0.05$). The regression equation obtained for toughness is of the form:

$$\text{Energy to Break (N.m)} = 92.96 - 7.804A - 3.175M + 0.217A^2 + 0.281AM + 0.01479M^2 - 0.00758A^2M - 0.000562AM^2 \qquad \text{(Eqn. 4.3)}$$

Samples of this cassava specie (TMS 30572) were found to exhibit a poor ability to resist deformation at 15MAP irrespective of the moisture content (Figure 4.26), unlike the cases of strength and toughness whose values were at the peak at the age of 15 MAP.

This suggests that the stiffness of the tubers is inversely related to toughness and dependent on the interactions between the moisture content of the tubers and age which may not be completely explained by starch and dry matter contents alone but by other factors such as the physiological and biochemical structure, and more importantly, change in granule size distribution as affected by the prevailing environmental conditions around the plant before harvest as argued by Sriroth *et al.* (1999) .

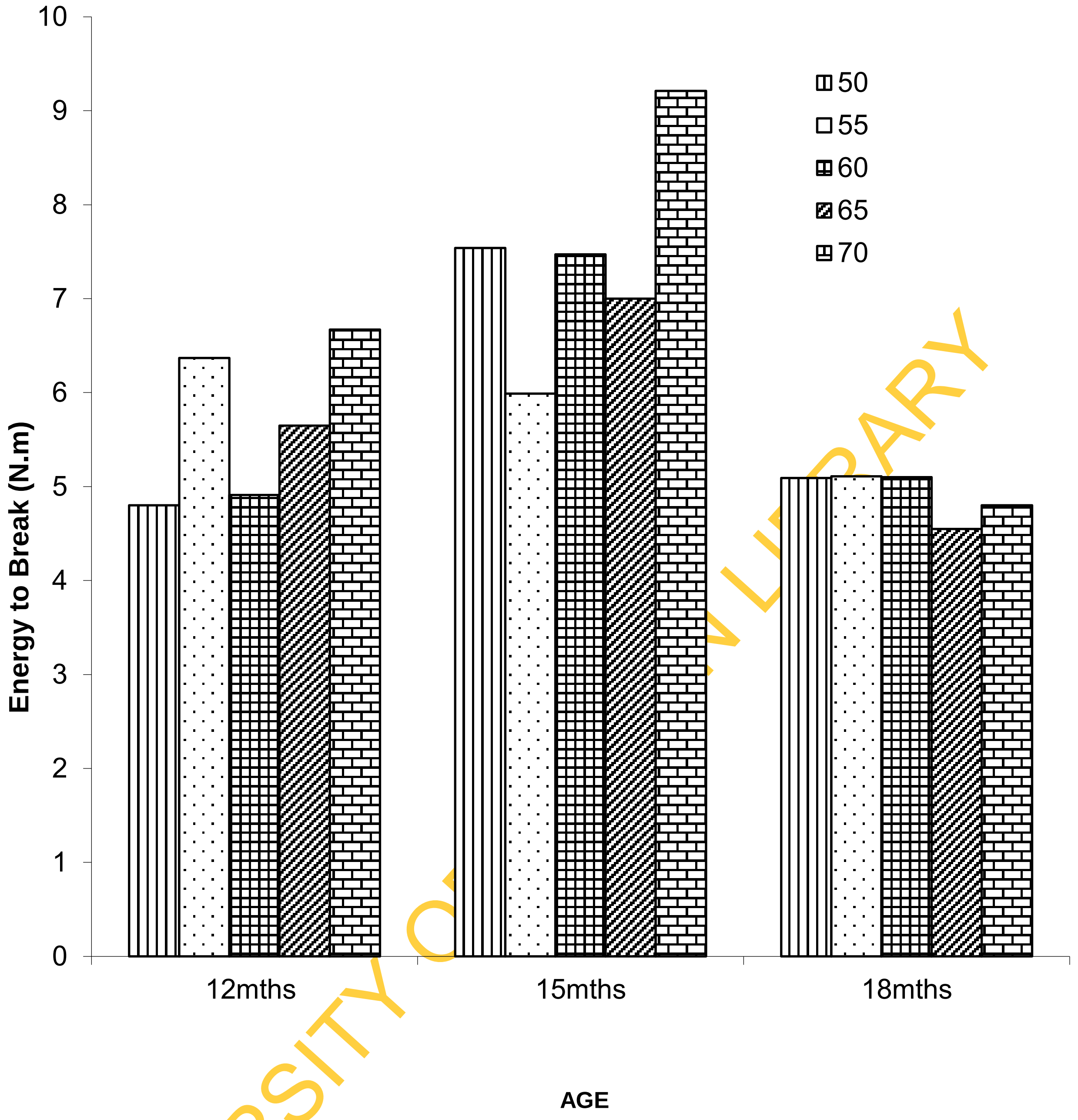

Figure 4.24: Toughness of TMS 30572 against Moisture Content at different Ages

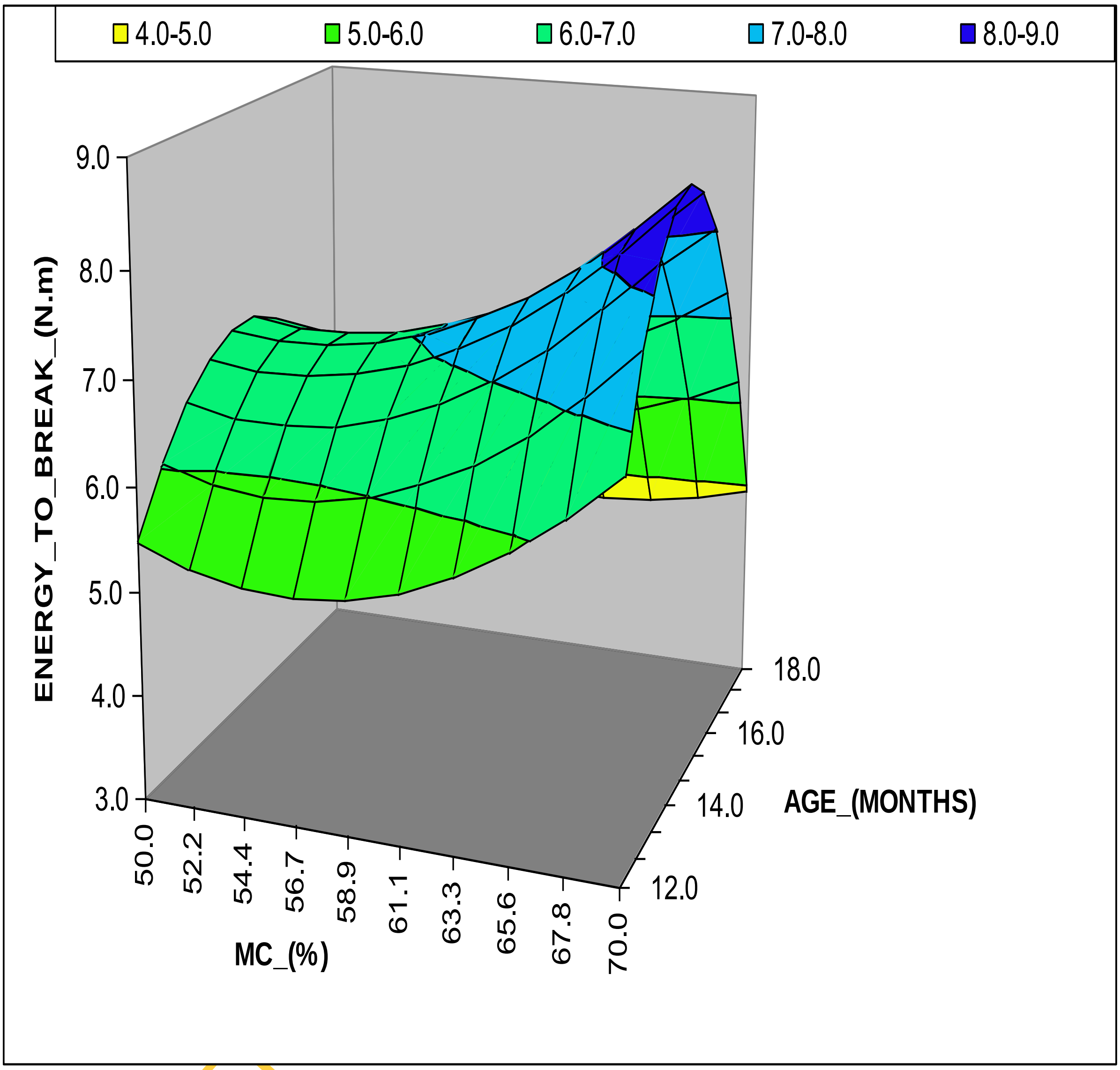

Figure 4.25: Response Surface of Toughness of TMS 30572 Cultivar

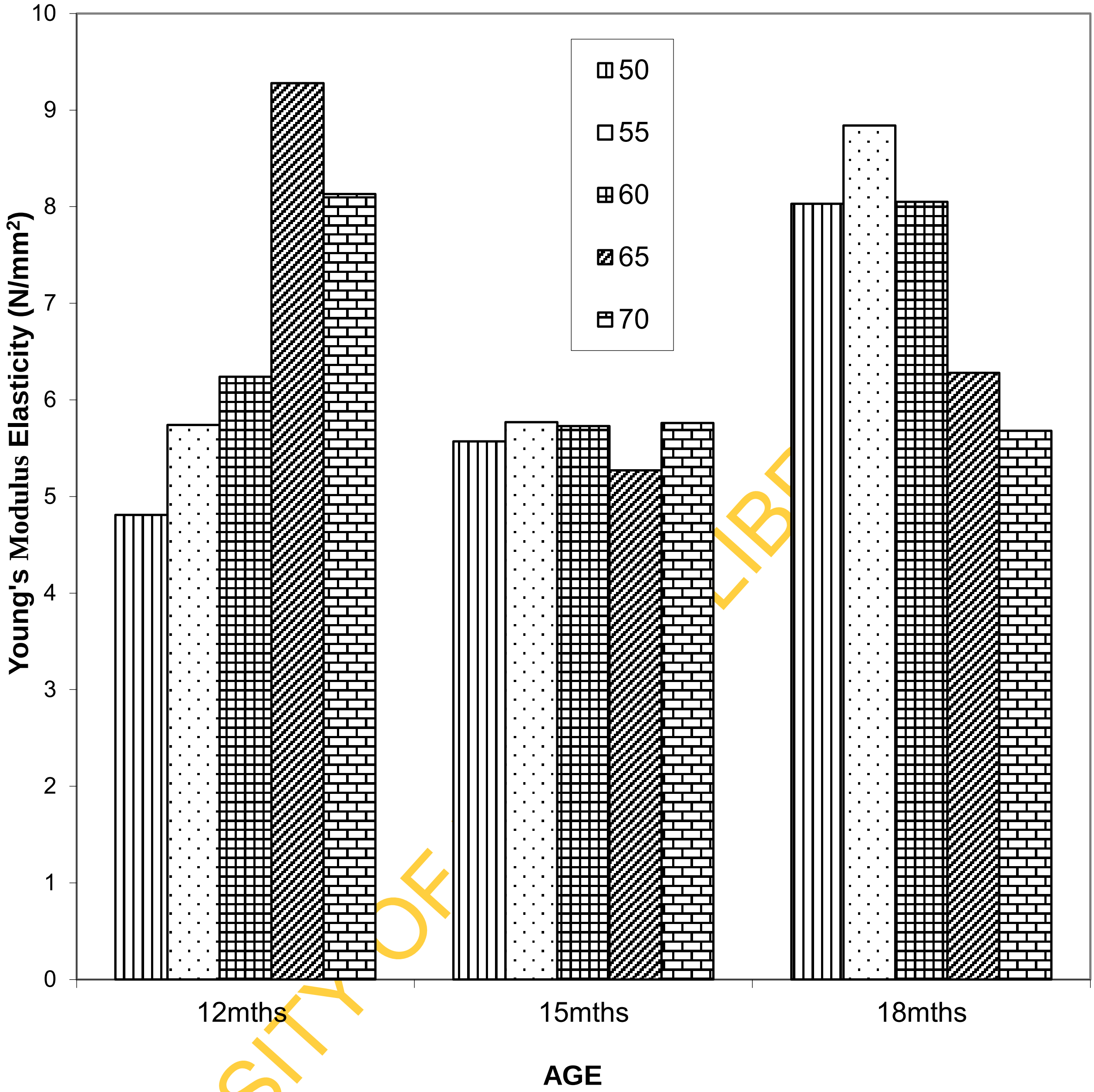

Fig. 4.26: Stiffness of TMS 30572 against Moisture Content at different Tuber Ages

A second order polynomial (as above) was similarly fitted for the young's modulus data of this cassava cultivar for the same reason as explained earlier. The regression equation obtained for stiffness is of the form:

$$\text{Young's Modulus} = -20.60 + 1.252A + 0.392M - 0.045233A^2 - 0.03890AM + 0.01056M^2 + 0.00351A^2M - 0.00104AM^2 \qquad \text{(Eqn. 4.4)}$$

The response surface is presented in Figure 4.27. It shows that the stiffness of the tubers increased sharply from 4.81 to 8.80 N/mm^2 at 12 MAP between the moisture content of 50 – 70% whereas, it decreased sharply from 8.30 to 5.68 N/mm^2 at 18 MAP. Also, the ability of the tubers to resist deformation at low moisture content (50% wb) increased exceptionally with increase in tuber age. The variation in stiffness with age at higher moisture content (70%) is shown in Figure 4.28 to reduce from 8.13 N.m at 12 MAP to 4.80 N.m at 16MAP thereafter it increased to 5.68 as the age increased to 18MAP. Again, the individual influence of age and/or moisture content was found to be insignificant, however, the ANOVA for the overall second order polynomial model was found to be significant, thereby suggesting that the influence of age and moisture content on the stiffness of TMS 30572 is better described by a second order polynomial model containing linear, quadratic and interaction terms.

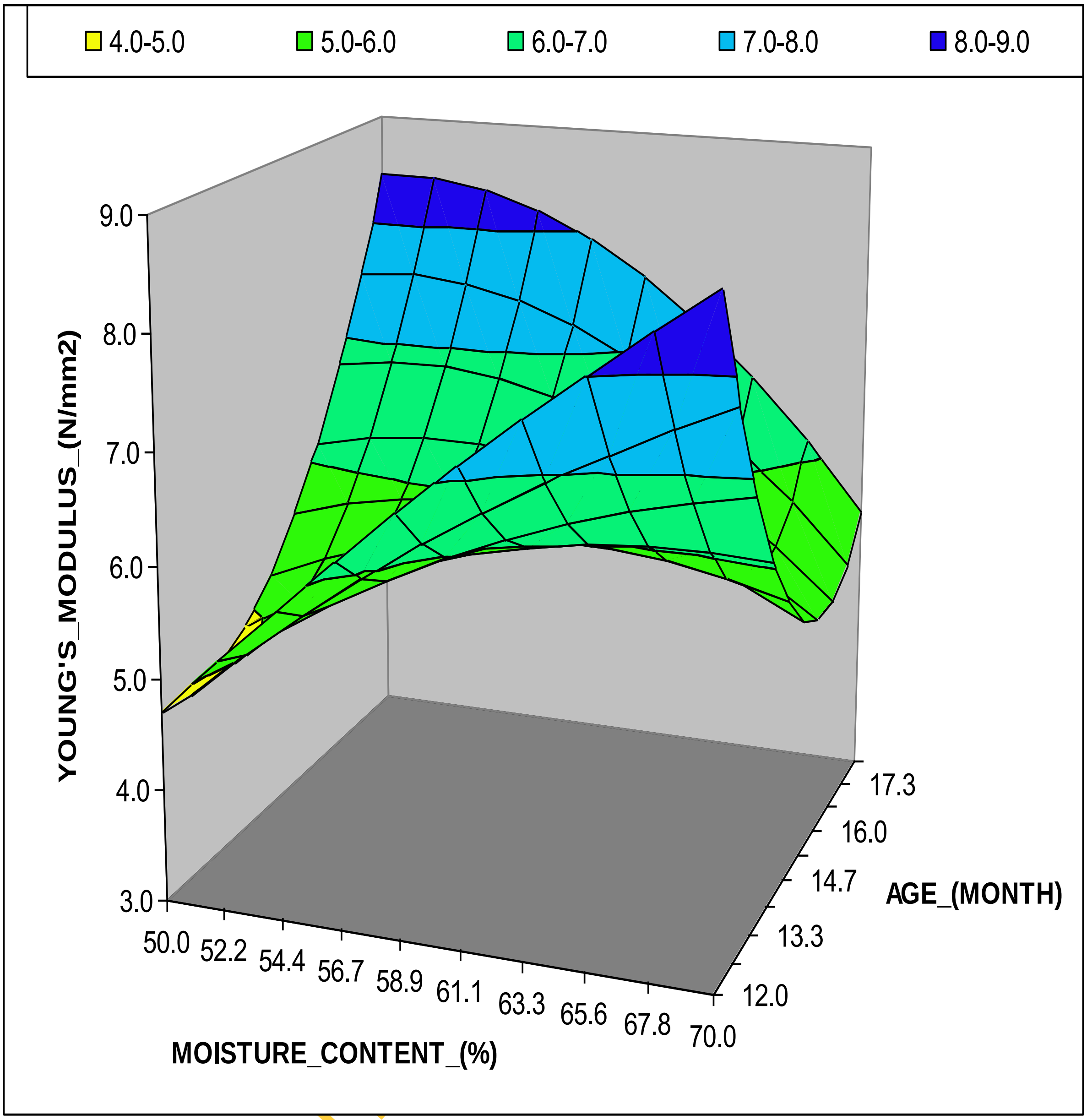

Figure 4.27: Response Surface for Stiffness of TMS 30572 Tubers

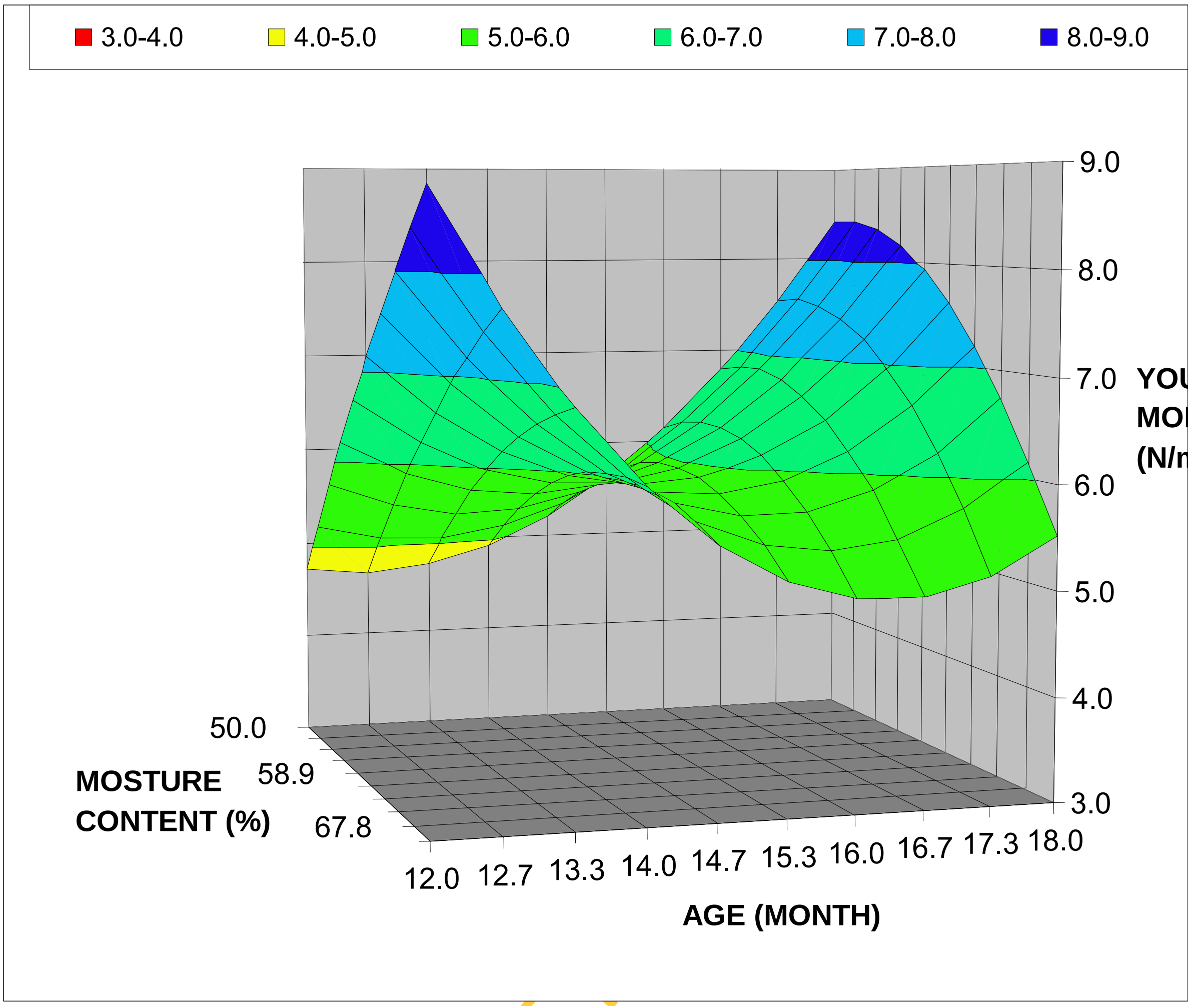

Figure 4.28: Response Surface Emphasizing Stiffness of TME 30572 at 18 MAP

4.2.4.2 Compressive Strength of TME 419 Cassava Cultivar

The mean stress at peak for the TME 419 cultivar ranged from 0.59 – 1.04; 0.99 – 1.15, and 1.07 – 1.24 N/mm^2 at 12, 15 and 18 MAP respectively. The mean force at peak also ranged from 414.76 – 731.80, 702.84 - 809.14 and 755.10 – 874.10 N at 12, 15 and 18 MAP respectively. Expectedly this trend is in line with that of the stress at peak (Table 4.6).

Figure 5.22 shows that the 12 months old tubers of this cassava cultivar were generally the weakest. The strength of the tubers increased non-linearly with increase in moisture content except at 12 MAP, thus not in complete agreement with the result of Kolawole *et al*. (2007b) who reported a linear relationship between cassava tuber strength and moisture content despite that they used 15months old tubers in their study. Also, the values of the peak force and peak stress for this cassava specie were greater than those reported by Nwangugu and Okonkwo (2009) and Kolawole *et al.* (2007b) who reported maximum values of 558N for peak force and 0.080N/mm^2 for peak stress respectively.

The peak stress appear, from Figure 4.29, to be slightly higher at 18 MAP than 15MAP, but after fitting a second order polynomial model (when the cubic model with the highest R^2 (0.925) had an undefined adjusted R^2), the response surface obtained shows that the strength increased from 12 MAP, attained its peak value (1.24 N/mm^2) at 16 months and declined thereafter to 1.2 N/mm^2 (Figure 4.30). Analysis of variance showed that tuber age, the interaction of age and moisture content, as well as the overall quadratic interaction of these two variables have a significant influence on the strength of the tubers of TME 419 while the influence of moisture alone was statistically insignificant ($P > 0.05$). This suggests that the age at harvest only partly explains the behavior of the tubers, different biochemical characteristic of the tubers at different ages which differs from one variety of cassava to another may be responsible for this as Moorhty and Ramanujam (1986) have observed that the proximate composition of cassava starch varied with the variety, season and/or age of the tuber at harvest. Also, the influence of the variations in properties such as fibre and amylose content with age has been reported by Safo-Kantanka and Acquistucci (1996) to affect the rheological properties of the paste produced from pounded cassava tubers. They further explained that none of the components of the proximate composition on its own could explain all the observed differences in quality between the varieties they studied. The regression equation obtained is in the form;

$$\text{Peak Stress} = -25.465 + 3.248A + 0.395M - 0.09633A^2 - 0.04796AM - 0.000324M^2 + 0.00138A^2M + 2.857 \times 10^{-5}AM^2 \qquad \text{(Eqn. 4.5)}$$

The toughness of the tubers of the TME 419 cultivar increased with increase in age as depicted by Figure 4.31. The energy to break almost follows the same trend as obtained for the stress at peak by exhibiting the least toughness at 12 MAP and highest at 18 MAP especially at moisture contents of 50, 60 and 70%. This suggests that the older the tubers of this cassava cultivar the better is its ability to dissipate energy before rupture under compressive load. A second order polynomial response surface model fitted to the data showed that the toughness increased non-linearly with increase in moisture between 50 and 70% (wb) at 12 MAP with values of energy to break between 4.45 and 8.61 N.m. Its toughness increased with age but had a negative non-linear relationship with moisture content at the age of 18 MAP (Figure 4.32). The regression equation obtained is in form;

$$\text{Energy to Break} = -157.14 + 17.01A + 2.945M - 0.414A^2 - 0.272AM - 0.01030M^2 + 0.00547A^2M + 0.000648AM^2 \qquad \text{(Eqn. 4.6)}$$

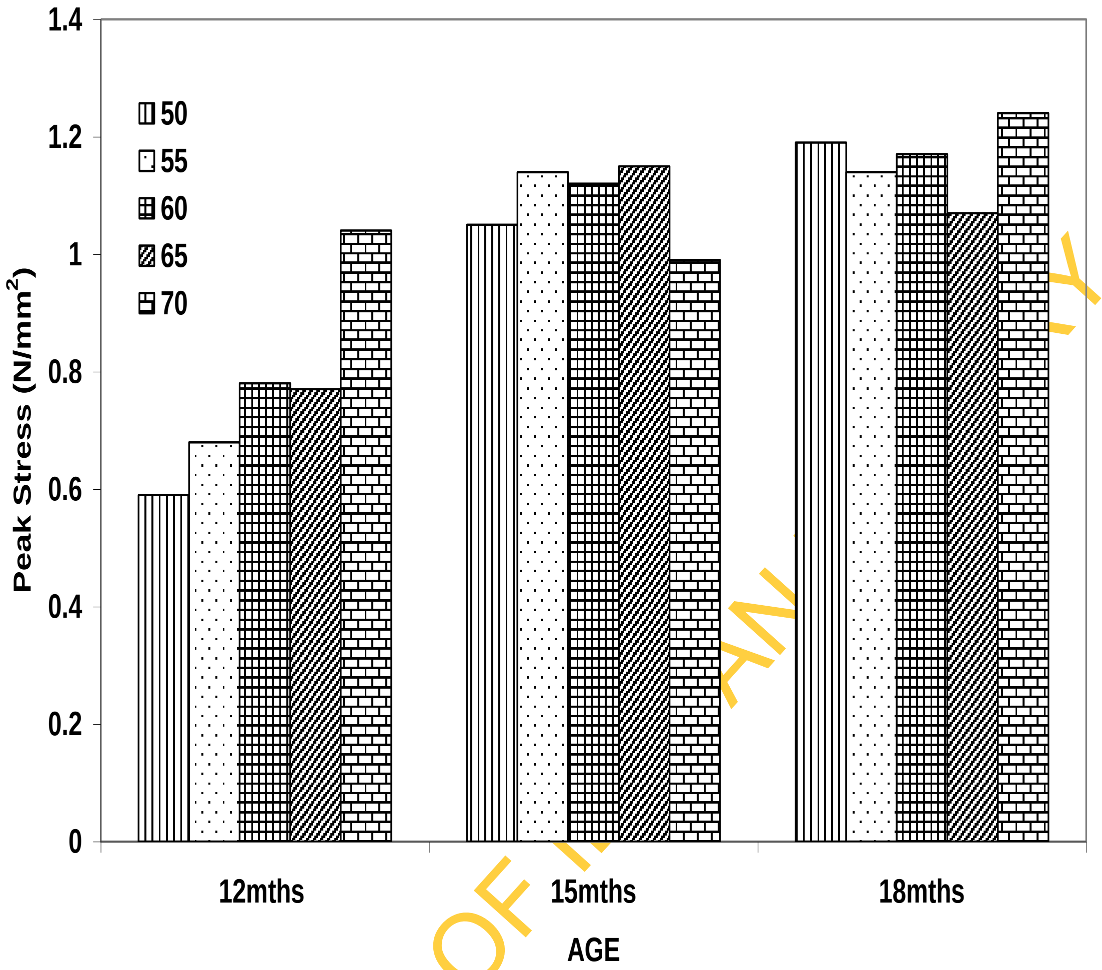

Figure 4.29: Peak Stress of TME 419 at different Ages

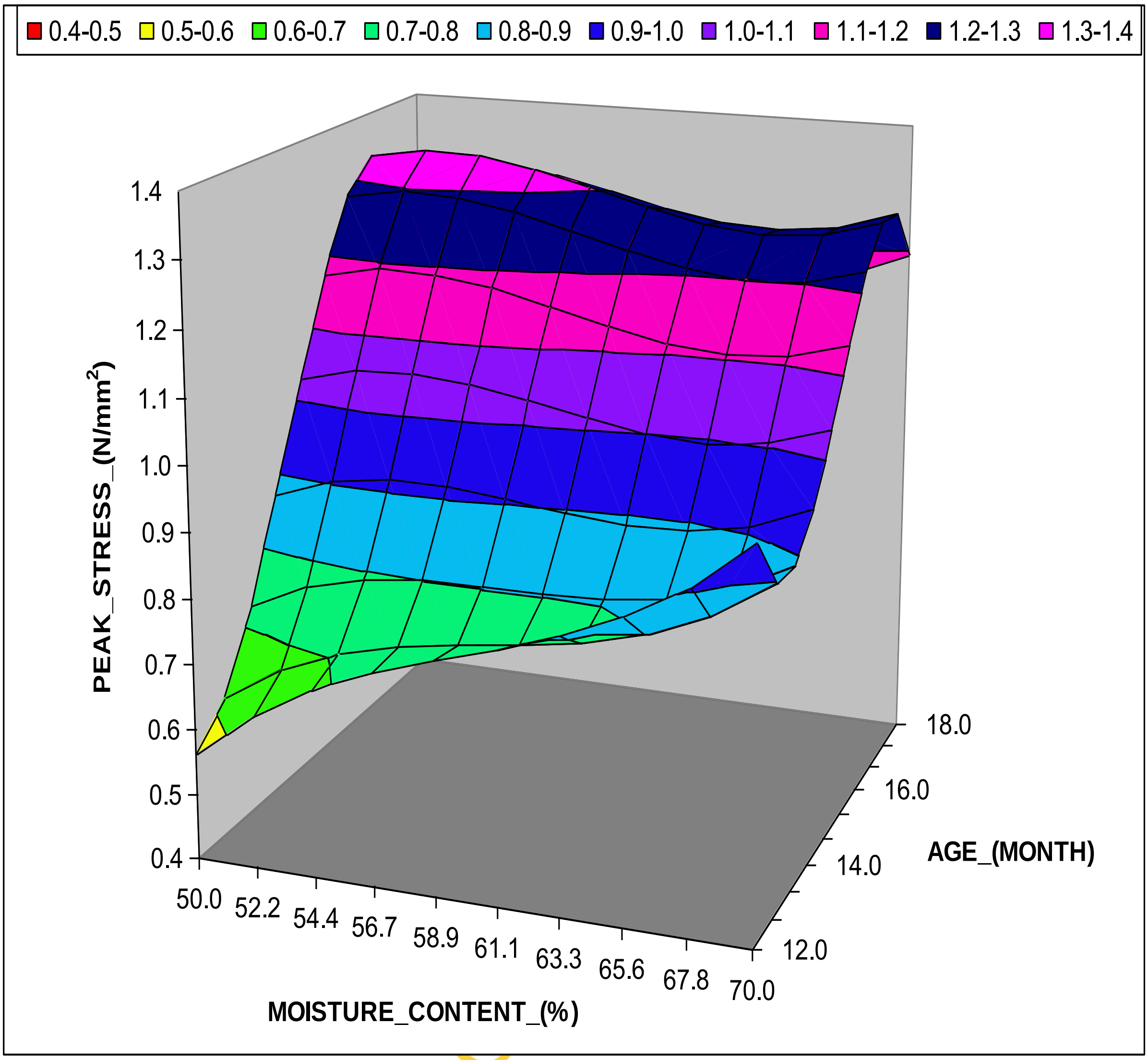

Fig 4.30: Response Surface for Peak Stress of TME 419

The 12 months old tubers were therefore relatively brittle but the tubers became tougher with time hence delayed harvest would reduce breakage during harvesting and postharvest handling operations. This may be a piece of useful information that could assist in solving the problem of tuber breakage reported in literature when attempting to design cassava harvesting machines (Agbetoye, 1998). The toughness of the tubers was observed to improve with increase in moisture content. Results of the analysis of variance showed that age and the interaction of age and moisture content significantly influence the toughness of the tubers of this cassava cultivar ($P < 0.05$).

The stiffness of the tubers of the TME 419 cultivar were found to increase with increase in age, especially when the moisture contents were less than 60% (wb). Fitting a second order polynomial model to the data gave a response surface as presented in Figure 4.33 and equation 5.7.

$$\text{Stiffness (N/mm}^2\text{)} = -116 + 8.764A + 3.568M - 0.07122A^2 - 0.267AM - 0.0209M^2 + 0.00164A^2M + 0.00133AM^2 \qquad \text{(Eqn. 4.7)}$$

Figure 4.33 shows that the stiffness reduced as the tuber age increased from 12 to 15 MAP where it had the least stiffness when the moisture was 70% although higher than that at 12 MAP when the tuber moisture was 50%. Beyond 15 MAP, the stiffness became even better than it was at 12 MAP (70%) where the value was 6.33 N/mm^2. It however continued to rise sharply with age at 50% moisture content until it attained the best stiffness at 18 MAP. The stiffness, at this age, reduced with increased tuber moisture. This is an indication that harvesting and postharvest handling operations involving the TME 419 are better carried out at 12 MAP if elevated moisture could be obtained, or delayed, if possible, beyond 15 MAP in order to reduce losses arising from breakage and crumbling as presently witnessed with the cassava washing machines.

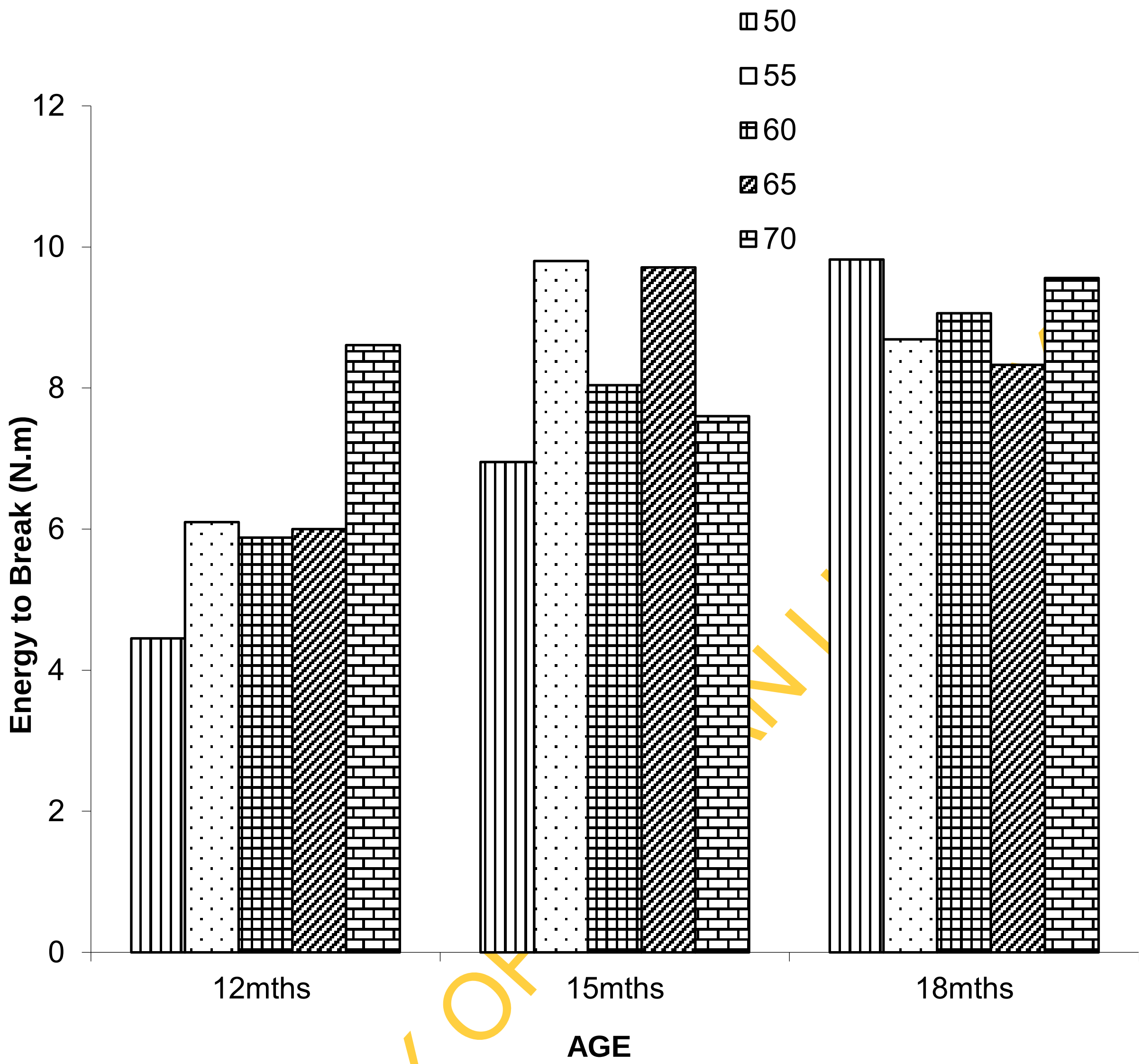

Figure 4.31: Toughness of TME 419 at different Ages

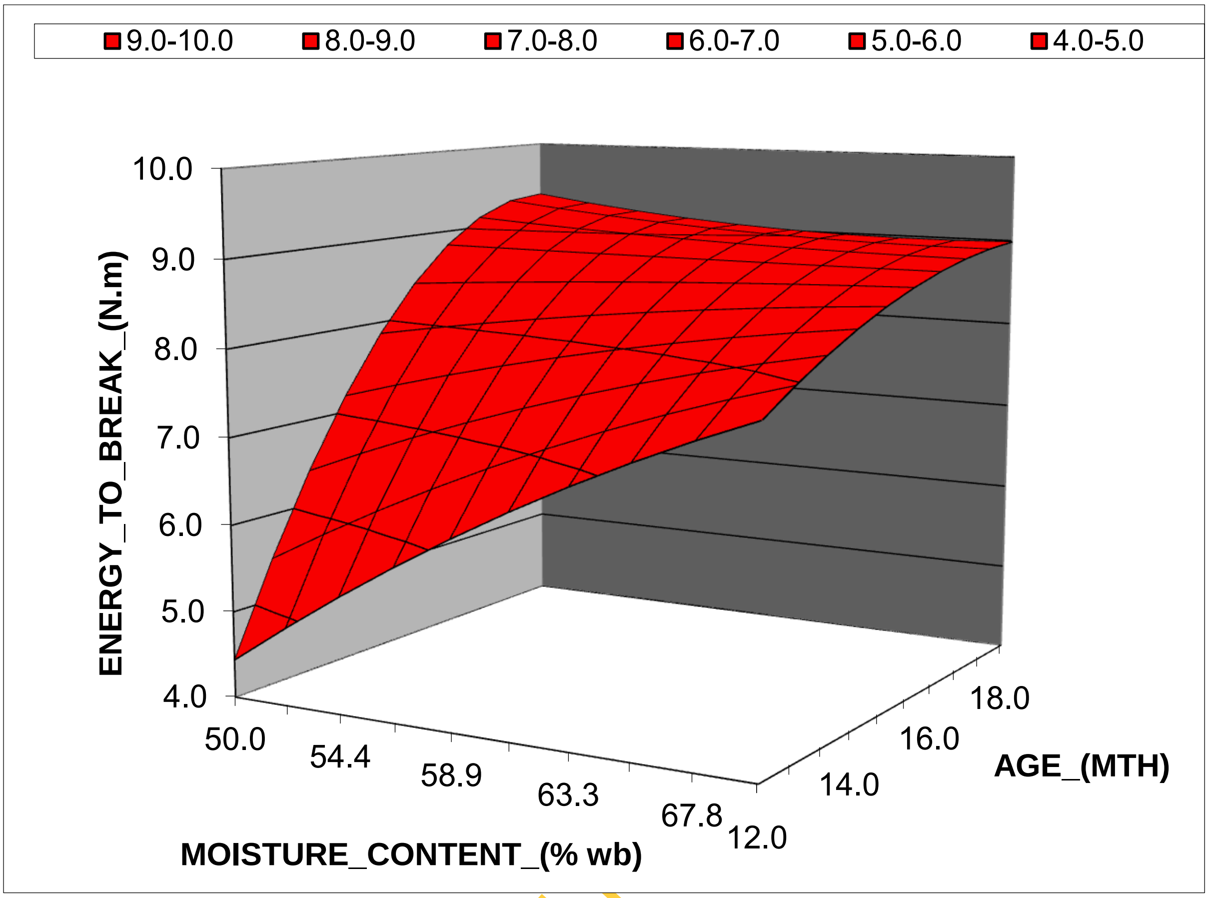

Figure 4.32: Response Surface for Toughness of TME 419

Results of the analysis of variance for the stiffness of this cassava cultivar showed that the influence of moisture content was not statistically significant ($p > 0.05$) whereas the influence of age as well as the interaction of age and moisture on the stiffness of the tubers was found to be statistically significant. Again, the mean values of the Young's Modulus were considerably higher than those reported by Kolawole *et al*. (2007b).

4.2.4.3 Compressive Strength of TME 7 Cassava Cultivar

The mean peak force of the TME 7 cultivar ranged from 290.16 – 746.32 N at 12 MAP. Corresponding values at 15MAP ranged from 670.22 – 811.40 N while it ranged from 757.64 – 916.80 N at 18 MAP respectively. Also, the mean values of the stress at peak for this local variety ranged from 0.41 – 1.06 N/mm^2 at 12 MAP. Corresponding values at 15 MAP ranged from 0.95 – 1.15N/mm^2 while it ranged from 1.07 – 1.30N/mm^2 at 18 MAP (Table 4.6).

Tubers of this cassava specie were found to grow stronger and stronger with age as the values of the peak stress continue to rise with time (Fig. 4.34). Its strength at 12 MAP increased non-linearly with increase in moisture content from 0.41 N/mm^2 at 50% (wb) up to a peak value of 1.06 N/mm^2 at 60% where it exhibited the greatest strength before growing weaker as its moisture level approached 70% (Table 4.6). The trend at 15 MAP was such that the strength improved from 0.99 N/mm^2 at 50% moisture content (wb) to 1.15 N/mm^2 at 55% moisture after which the strength continued to fluctuate with no definite trend as the tuber moisture approached 70% (wb). Fitting a second order polynomial model produced the response surface in Figure 4.35 and equation 5.8.

$$\text{Peak Stress (N/mm}^2) = -55.86 + 5.102A + 1.401M - 0.101A^2 - 0.110AM - 0.00831M^2 + 0.00152A^2M + 0.0005AM^2 \quad \text{(Eqn. 4.8)}$$

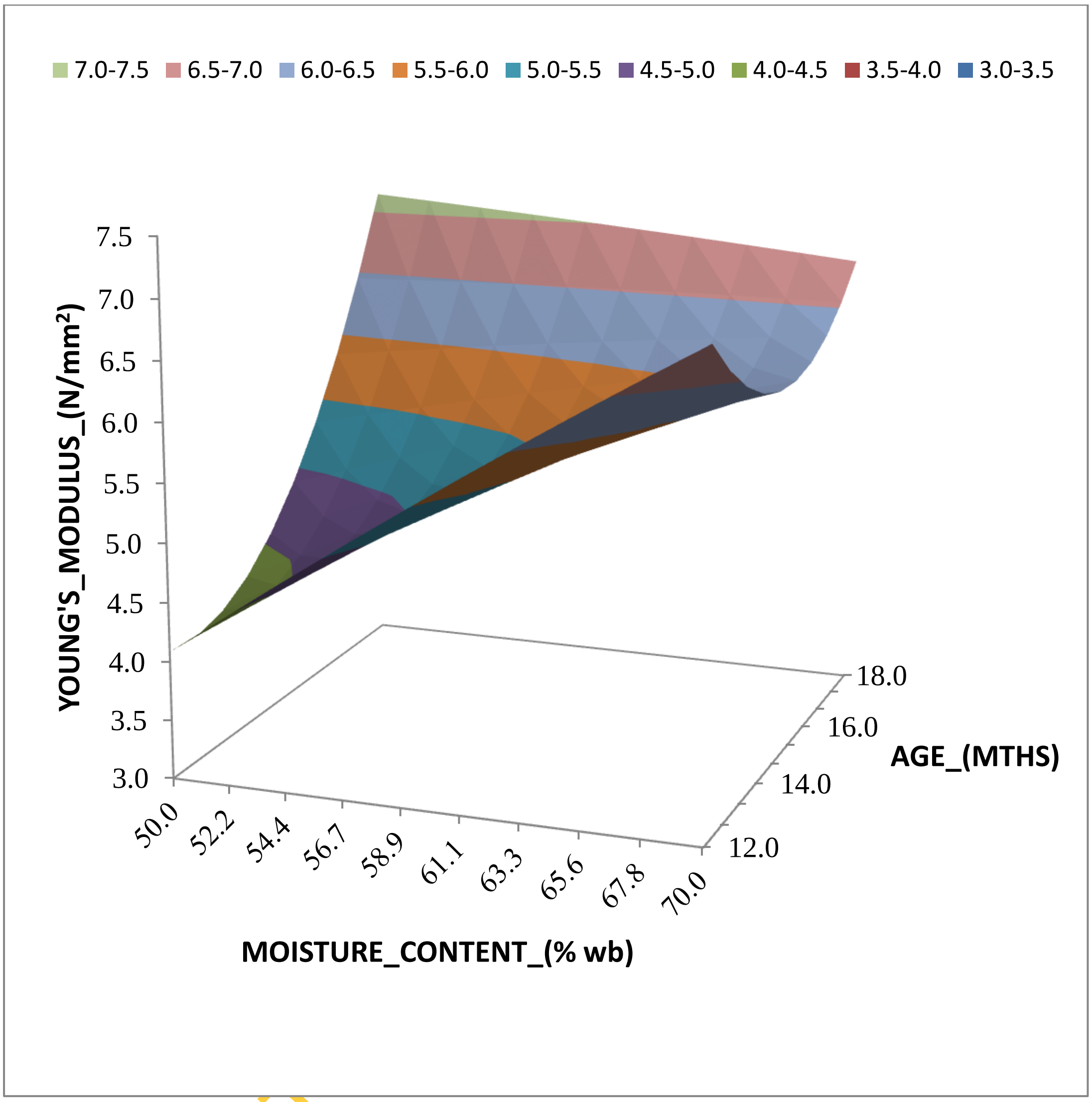

Figure 4.33: Response Surface of Stiffness of TME 419

The response surface shows that the peak stress of TME 7 varies non-linearly with both age and moisture content. For instance, the peak stress of the 12months old tubers increased from 0.39 N/mm^2 at 55% moisture content (wb) to a peak value of 0.94 at 65% and declined afterwards. As it grew older, its strength rose steadily but non-linearly to 1.2N/mm^2 when the moisture content was maintained at 50%. The combination of increased age and moisture content resulted in tubers with better strength characteristics exhibiting peak stress as high as 1.22 N/mm^2 at 18 MAP and 70% moisture content. The increase in strength was sharp between the ages of 15 and 18 MAP at elevated moisture. Results of the ANOVA show that the influence of age but not moisture content was significant at 95%. The influence of the interaction of both age and moisture content was also significant.

The energy to break (toughness) of the tubers of the TME 7 cultivar ranged from 3.22 – 6.96, 4.25 – 5.58, and 5.85 – 8.38 N.m at 12, 15, and 18 MAP respectively. The toughness at the age of 12months increased with increased moisture content up to 60% (wb) and then declined steadily afterwards up to 70% moisture content (Figure 4.36).

A marked behavior was also observed in the toughness of the tubers at 60% moisture content in that the 12 month old tubers were found to be toughest at this moisture level whereas the older tubers (15 and 18 MAP) had the least toughness at the same moisture level of 60% (wb). The same trend as observed for the strength of the tubers above. Besides, the values were very close (Table 4.6). A second order polynomial model was fitted to the energy to break data based on R^2 of different models tested but the cubic model with the highest R^2 value failed due to lack of adjusted R^2. However, neither the influence of age, moisture content nor their interactions was significant ($p > 0.05$) thereby suggesting that no definite relationship exists between the toughness of the tubers of TME 7 cassava cultivar and these variables. Variation in the biochemical characteristics of the tubers at different ages may account for this observed behavior.

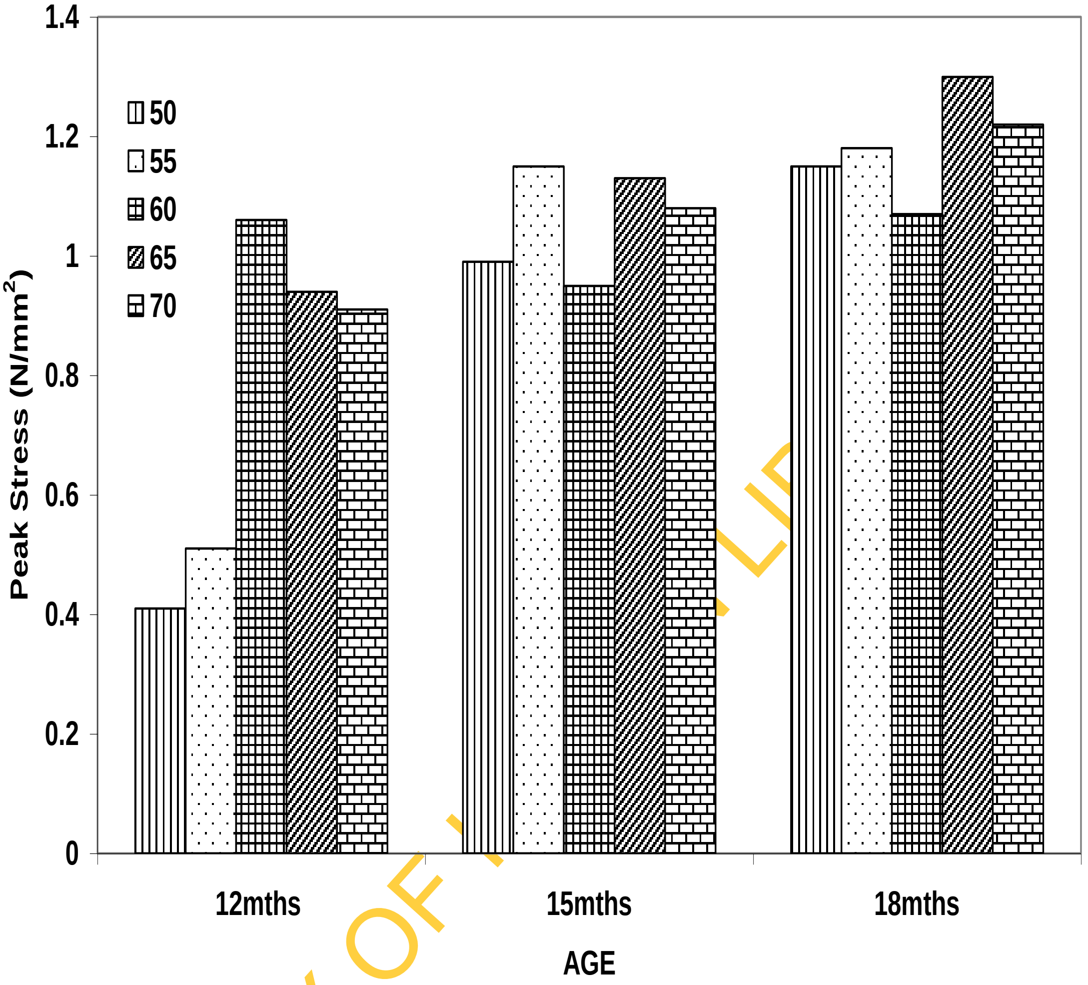

Figure 4.34: Peak Stress of TME 7 at different Ages

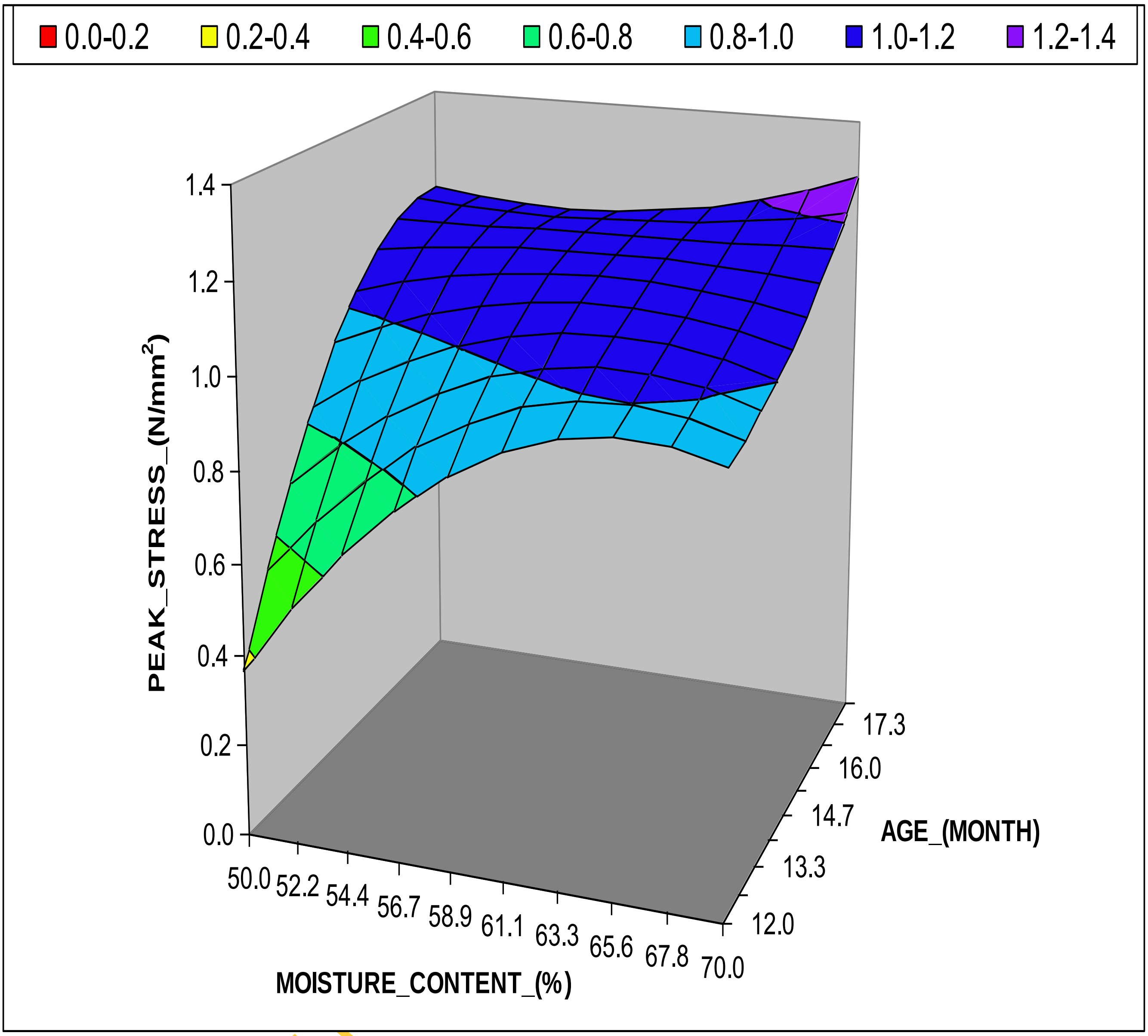

Figure 4.35: Response Surface of Peak Stress of TME 7 Cultivar at different Ages

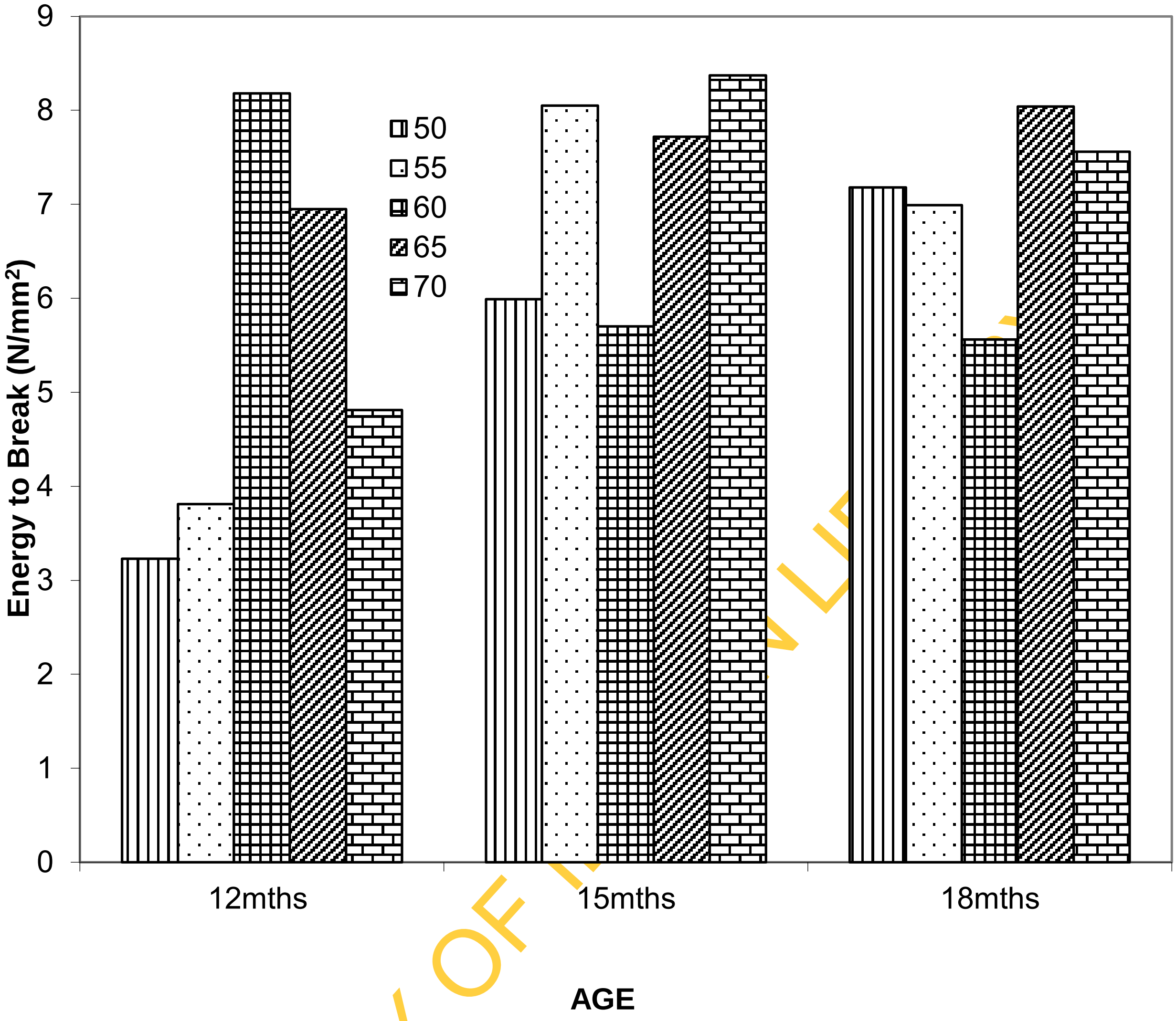

Figure 4.36: Toughness of TME 7 at different Moisture Content

The ability of the tubers of TME 7 to resist deformation (stiffness) was also fitted with a second order polynomial model to generate a response surface and an equation relating the stiffness of the tubers to age and moisture content. The response surface (Figure 4.37) shows that the stiffness improved with increased moisture content from 3.0 N/mm^2 (at 50% moisture content) at 12 MAP to a peak value of 6.7 N/mm^2 at 65% moisture and then declined to 6.33N/mm^2 as the moisture was increased to 70% (wb). The stiffness also increased gently (at low moisture) as the tuber aged towards 15 MAP, thereafter it rose sharply to 7.41 N/mm^2 in a manner similar to that at elevated moisture content (70% wb) where it also rose sharply after 15 MAP to the peak value of 8.38 N/mm^2. Also, at 18 MAP the stiffness initially reduced with increased moisture content up to 60% beyond which it improved considerably to 8.38 N/mm^2. The stiffness of the tubers was found not to be statistically influenced by neither age nor moisture content, not even by the interactions of age and moisture content ($p > 0.05$).

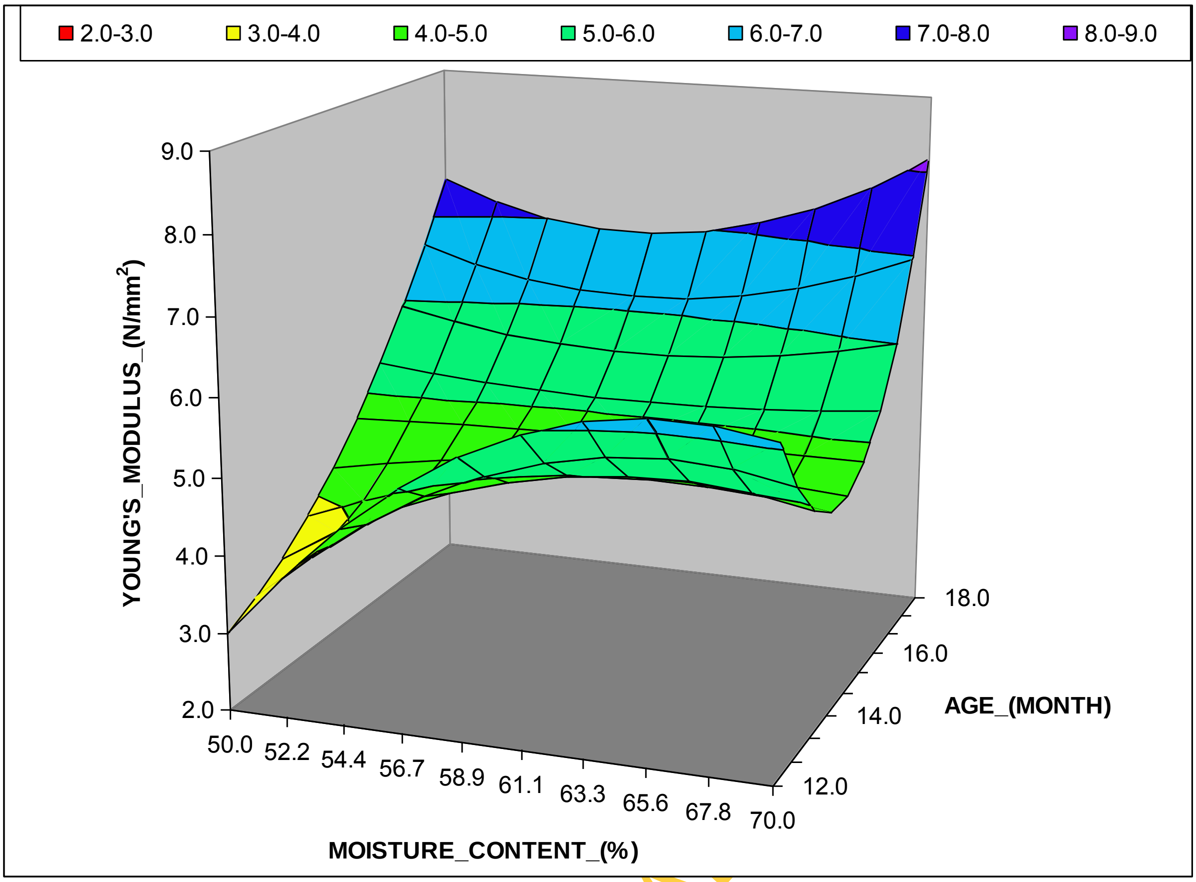

Figure 4.37: Response Surface of the Stiffness of TME 7.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the findings of this study it can be concluded that;

- Root age significantly influenced most of the engineering properties studied.
- 15MAP is the optimum age for these cassava varieties as most of the engineering properties peaked at this age.
- Length and diameters of the improved cultivars reduced after 15MAP while peel thicknesses increased with age for all varieties.
- A positive linear relationship exists between the COF and moisture content while a reverse trend occurred with the coefficient of internal friction (CIF).
- The high COF especially on wood surface suggested a high angle of inclination in wooden container design and storage structures.
- A second order polynomial model described the relationship between age, moisture content and the strength properties of the roots.
- The improved cassava varieties are better suited for mechanized harvesting and postharvest handling operations for they had a combination of good strength, toughness and stiffness for the periods after planting studied.
- Generally low values of peak stress, toughness and stiffness indicated that the roots require low power during processing

5.2 RECOMMENDATIONS FOR FURTHER STUDY

It is recommended that further studies on related topics should focus on the following area;

- Designers of cassava processing and handling machines need to consider the properties of cassava roots across ages and variety for effective mechanical processing operations.

- Different cassava varieties should be handled and processed separately due to wide variations in their engineering properties

- The influence of environmental factors, in conjunction with age, on the engineering properties of cassava tubers.
- Collaborative research work with biochemist and agronomist is highly recommended for further better understanding
- Possible application of fractal analysis to gain better insight into the frictional behaviour of the tubers on different structural surfaces as well as the strength properties under compressive load.

5.3 CONTRIBUTION TO KNOWLEDGE

It is expected that a comprehensive understanding of the features, properties, and behaviour of cassava tuber and some of its product, such as cassava chips, under various processing conditions would have been gained at the end of this study such that would form a base line technical data or data bank for cassava generally and the studied varieties in particular. It is hoped that results of this study would go a long way in reducing the level of scarcity of technical information on cassava, and eventually assist designers enormously to overcome the problems currently being faced in mechanizing cassava processing operations, as well as improve on the efficiencies of the already mechanized operations, the performance of which are generally unsatisfactory.

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APPENDIX A

Table A1: Physical Properties of TMS 30572 Cassava Cultivars at 12 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	300	247	14.17	250	40.6	38.6	25.9	2.39	1.21	1.18	0.48	0.99
2	321	303	14.85	277	36.9	38.5	34.3	1.26	1.26	1.14	0.39	1.09
3	295	302	12.91	320	41.5	40.6	32.7	1.28	2.27	1.21	0.43	0.94
4	280	381	14.96	335	45.8	46.7	40.8	1.23	2.02	1.28	0.13	1.14
5	445	678	16.08	538	41.3	46.6	29.7	2.04	3.30	2.24	0.12	1.26
6	283	212	19.81	200	34.7	31.7	21.8	1.29	1.06	1.19	0.11	1.06
7	272	468	32.91	458	43.4	52.5	46.8	1.89	2.24	1.22	0.45	1.02
8	463	470	18.09	312	36.1	39.7	28.2	1.31	1.26	1.24	0.77	1.51
9	441	722	19.95	640	49.5	51.2	41.7	1.06	1.29	1.15	0.29	1.13
10	450	518	11.97	442	36.7	44.3	38.5	1.02	1.49	1.26	0.99	1.17
11	421	513	5.07	415	42.7	47.2	36.0	1.31	1.26	1.29	0.31	1.24
12	248	227	13.22	237	34.3	41.9	30.1	1.17	1.22	1.17	0.52	0.96
13	378	452	19.91	482	48.1	38.6	30.1	2.03	2.24	1.11	0.35	0.94
14	234	280	18.93	220	42.3	36.1	38.0	1.03	1.18	1.06	0.51	1.27
15	217	140	20.00	162	31.7	32.9	30.2	1.32	1.24	1.21	0.60	0.86
16	460	389	17.99	265	33.4	36.7	28.3	1.06	1.03	1.24	0.54	1.47
17	364	311	19.94	220	35.6	36.2	28.2	1.33	1.24	1.24	0.32	1.41
18	264	277	21.30	235	40.5	35.7	33.1	1.35	1.06	1.00	0.47	1.18
19	271	412	20.87	510	44.3	48.7	38.9	1.24	1.17	1.13	0.47	0.81
20	232	221	19.91	147	38.7	35.1	29.2	2.73	1.36	1.12	0.55	1.50
21	500	115	15.65	940	60.8	57.0	42.0	2.33	1.27	1.04	0.71	0.12
22	247	230	18.26	240	46.4	45.1	29.1	1.22	1.03	1.06	0.85	0.96
23	255	215	19.07	218	40.6	37.7	26.8	1.27	1.32	1.38	0.13	0.99
24	332	371	19.14	370	39.0	41.0	36.3	1.19	1.12	1.09	0.36	1.00
25	152	93	16.13	123	31.9	26.3	24.2	1.28	1.18	1.11	0.18	0.76
26	171	59	18.64	92	25.1	24.0	17.0	1.43	1.39	1.35	0.66	0.64

27	218	332	18.07	228	52.2	48.7	39.2	1.16	1.05	1.04	0.73	1.46
28	254	235	16.17	170	39.2	35.9	25.7	1.23	1.10	1.22	0.45	1.38
29	370	455	19.12	440	47.2	46.3	33.7	1.13	1.23	1.27	0.33	1.03
30	349	562	19.40	546	44.5	44.8	34.1	1.07	1.24	1.06	0.32	1.03
31	297	188	16.49	180	31.0	30.1	23.0	1.47	1.28	1.18	0.44	1.04
32	130	81	18.52	110	32.9	23.0	20.8	1.02	0.94	1.81	0.19	0.74
33	90	331	19.03	378	44.2	40.4	26.4	1.07	1.29	1.19	0.16	0.88
34	352	143	17.48	175	30.1	16.1	15.0	1.23	1.38	1.19	0.14	0.82
35	316	338	19.23	300	44.7	40.5	36.0	1.26	1.18	1.23	0.42	1.13
36	294	234	18.38	140	33.1	32.7	26.8	1.70	1.80	1.80	0.13	1.67
37	210	201	19.90	205	37.6	41.8	34.1	1.13	0.90	1.20	0.15	0.98
38	207	160	15.63	170	35.0	30.9	25.1	1.13	0.90	1.60	0.16	0.94
39	180	254	18.11	270	50.1	39.8	36.1	1.26	1.33	1.24	0.76	0.94
40	278	216	18.98	200	20.8	31.1	25.8	1.27	1.19	1.09	0.36	1.08
41	346	420	19.05	283	35.3	45.4	25.5	1.32	1.18	1.22	0.10	1.48
42	350	313	19.81	236	25.6	37.6	27.4	1.14	0.90	1.20	0.35	1.33
43	435	377	18.57	355	35.9	40.2	31.9	1.22	1.28	1.16	0.25	1.06
44	303	304	20.07	270	34.8	37.5	29.9	1.23	1.09	1.27	0.12	1.13
45	383	341	19.94	280	34.4	37.6	25.1	1.36	1.46	1.17	0.15	1.22
46	228	161	13.67	140	31.5	33.0	31.8	1.23	1.26	1.21	0.55	1.15
47	298	229	20.96	220	32.9	30.4	25.5	1.31	1.26	1.13	0.48	1.04
48	210	153	13.07	290	33.9	29.9	27.1	1.23	1.19	1.13	0.15	0.53
49	195	82	18.29	100	29.4	23.9	21.7	1.10	1.19	0.60	0.35	0.82
50	193	190	16.84	198	38.2	34.6	28.4	1.40	1.20	1.30	0.18	0.96
Mean	**295.64**	**298.12**	**17.89**	**290.64**	**38.33**	**38.06**	**30.28**	**1.36**	**1.33**	**1.22**	**0.38**	**1.07**
S.D	**93.31**	**148.34**	**3.65**	**155.59**	**7.44**	**8.10**	**6.57**	**0.36**	**0.42**	**0.23**	**0.22**	**0.27**

Table A2: Physical Properties of TMS 30572 Cassava Cultivars at 15 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	215	371	33.99	520	48.5	48.0	40.1	2.3	2.1	1.4	0.61	0.71
2	285	382	23.01	305	44.5	42.1	41.9	3.5	2.9	2.7	0.75	1.25
3	255	195	21.47	167	27.3	33.4	30.6	2.9	4.0	1.9	0.56	1.17
4	316	372	20.24	382	34.7	42.2	37.4	3.1	2.6	1.9	0.58	0.97
5	325	367	15.64	410	47.6	42.8	22.8	2.5	2.4	2.1	0.92	0.90
6	140	129	18.94	135	34.0	38.2	35.2	2.1	1.5	1.1	0.37	0.95
7	265	317	20.10	316	49.4	48.3	25.2	3.4	3.1	1.9	0.75	1.00
8	338	501	13.53	508	31.2	55.1	24.3	2.5	2.0	1.3	0.99	0.99
9	227	179	24.44	228	36.8	40.9	19.2	3.1	3.2	1.7	0.41	0.78
10	284	274	12.29	181	30.2	38.2	31.3	3.6	4.2	3.0	0.56	1.51
11	276	202	14.68	180	24.5	34.8	18.3	4.0	3.0	2.9	0.73	1.12
12	476	606	13.65	651	29.3	47.3	25.1	4.0	2.8	1.9	0.47	0.93
13	484	410	26.73	310	29.1	28.5	23.5	3.1	3.4	2.6	0.60	1.32
14	312	556	19.43	636	50.2	52.0	40.2	1.5	1.8	1.2	0.87	0.87
15	218	284	11.97	650	40.0	41.2	38.5	3.8	4.2	3.4	0.73	0.44
16	337	207	14.58	156	24.6	28.4	23.4	2.1	2.9	1.9	0.54	1.32
17	403	642	7.56	700	31.8	50.5	42.3	3.1	2.1	2.0	0.61	0.92
18	418	329	26.11	259	34.2	31.9	18.5	2.9	3.8	2.2	0.82	1.27
19	262	291	18.66	430	38.5	41.6	29.7	3.6	2.5	1.8	0.56	0.68
20	494	470	15.95	850	42.5	44.9	40.5	3.0	2.8	2.1	0.75	0.55
21	396	487	17.70	520	36.5	46.1	24.2	3.1	2.2	2.1	0.66	0.94
22	312	501	13.86	610	40.5	42.3	29.3	4.5	2.3	1.9	0.57	0.82
23	368	599	19.60	610	53.6	49.2	25.5	4.0	3.1	1.5	0.81	0.98
24	295	499	20.71	564	47.4	50.0	32.8	3.5	2.5	2.1	0.78	0.89
25	235	299	13.70	262	44.2	52.1	43.3	4.0	3.9	3.1	0.85	1.14
26	390	445	18.83	430	36.0	36.8	36.2	3.5	2.8	2.6	0.93	1.03
27	520	781	14.02	835	31.5	52.7	40.4	3.4	3.1	1.4	0.65	0.94

28	354	483	23.75	610	47.5	50.4	40.1	3.0	3.3	1.9	0.71	0.79
29	143	247	18.58	210	40.1	52.1	35.0	3.2	2.5	1.7	0.74	1.17
30	311	920	21.51	820	53.4	59.5	34.3	3.0	2.4	2.0	0.63	1.12
31	338	379	14.84	200	39.4	40.1	27.2	2.3	3.1	2.1	0.51	1.89
32	392	545	11.69	450	41.6	43.1	33.4	1.7	1.7	1.2	0.61	1.21
33	194	426	17.61	450	48.2	55.4	44.2	3.5	3.2	2.1	0.34	0.95
34	416	499	20.24	700	44.3	48.3	43.1	2.5	2.2	1.3	0.44	0.71
35	414	691	27.49	910	56.1	49.2	30.2	3.4	3.2	2.4	0.62	0.76
36	303	610	21.51	430	51.4	48.5	44.8	4.2	3.1	2.9	0.21	1.42
37	239	421	20.41	482	46.9	55.0	33.9	2.9	2.7	2.1	0.54	0.87
38	282	406	13.95	320	50.1	54.2	45.5	2.9	3.1	2.5	0.43	1.27
39	288	521	11.30	550	58.5	52.8	34.1	3.5	3.3	2.3	0.65	0.95
40	276	902	13.48	750	51.4	57.4	34.3	3.4	2.7	1.8	0.72	1.20
41	334	511	14.49	511	50.9	44.1	36.1	3.7	2.4	1.9	0.48	0.99
42	426	693	24.53	629	45.6	46.2	43.9	3.2	3.5	2.0	0.46	1.10
43	375	477	23.22	380	28.5	40.8	36.2	3.3	3.3	1.3	0.25	1.26
44	255	501	15.78	480	53.1	52.5	42.1	2.1	3.3	1.7	0.45	1.04
45	316	979	11.28	610	53.4	41.5	41.8	3.5	2.5	2.3	0.84	1.61
46	434	570	12.82	556	55.2	33.4	20.2	4.1	4.0	2.6	0.92	1.03
47	290	971	8.13	700	44.8	58.6	41.7	2.7	2.7	2.1	0.65	1.39
48	291	691	14.33	660	48.9	52.4	43.3	3.1	2.7	2.0	0.70	1.05
49	339	449	15.20	480	30.1	44.1	30.3	2.3	2.1	1.9	0.94	0.94
50	362	767	19.51	779	42.0	40.0	38.2	2.8	3.4	1.5	0.87	0.98
Mean	**324.36**	**486.99**	**17.74**	**483.50**	**42.00**	**45.58**	**33.87**	**3.13**	**2.87**	**2.03**	**0.64**	**1.04**
S.D	**85.12**	**203.99**	**5.28**	**200.98**	**9.19**	**7.68**	**7.93**	**0.66**	**0.64**	**0.52**	**0.18**	**0.26**

Table A3: Physical Properties of TMS 30572 Cassava Cultivars at 18 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	201	391	23.57	530	45.0	47.4	41.2	2.9	3.1	2.5	0.89	0.74
2	329	518	17.94	620	39.6	51.1	43.0	1.9	2.1	1.5	0.63	0.84
3	305	713	16.85	790	66.4	65.5	44.1	1.5	4.2	2.4	1.00	0.90
4	295	815	17.85	860	46.5	56.4	44.5	3.6	3.1	1.3	0.69	0.95
5	204	232	23.16	340	58.8	38.7	21.6	4.2	3.8	3.1	1.00	0.68
6	496	921	8.30	840	69.5	64.5	38.9	3.1	2.2	2.8	0.56	1.10
7	364	730	24.88	810	40.0	21.0	37.0	5.3	4.2	3.1	0.54	0.90
8	496	801	18.25	920	38.5	54.5	36.1	3.5	2.3	2.1	0.49	0.87
9	421	602	17.22	710	40.7	44.1	29.0	2.7	2.4	2.5	0.49	0.85
10	329	805	13.37	820	62.3	67.1	55.5	5.0	4.5	3.1	0.58	0.98
11	156	329	20.10	470	50.0	50.2	47.0	3.6	2.5	1.8	0.73	0.70
12	264	267	14.67	390	28.3	32.1	21.4	4.0	3.1	2.5	0.46	0.69
13	245	325	27.11	460	68.9	57.4	39.0	4.0	3.7	3.2	0.44	0.71
14	255	581	16.63	690	52.5	68.5	46.2	5.2	3.6	2.6	0.34	0.84
15	331	823	18.68	870	36.0	24.9	39.3	4.8	3.5	3.2	0.56	0.95
16	120	153	21.38	280	23.2	36.5	28.0	3.5	4.1	3.2	0.80	0.55
17	234	910	9.41	1,020	29.1	34.9	37.3	5.1	4.8	3.5	0.54	0.89
18	286	435	16.92	560	34.0	29.8	24.9	5.0	4.3	3.3	0.67	0.78
19	319	870	14.81	970	28.5	34.7	23.0	2.6	2.2	2.1	0.56	0.90
20	331	363	18.46	510	33.4	33.6	24.6	3.5	5.0	2.5	0.35	0.71
21	245	146	20.11	213	41.2	31.9	21.1	2.1	2.2	1.8	0.37	0.69
22	285	179	23.98	215	43.4	31.4	19.3	3.0	2.6	2.1	0.50	0.83
23	300	383	18.30	540	40.3	42.1	24.0	4.1	3.2	2.8	0.26	0.71
24	200	477	18.56	570	45.5	49.0	42.5	2.6	2.2	1.9	0.54	0.84
25	237	473	15.95	580	44.0	57.5	48.7	3.4	2.6	2.4	0.45	0.82
26	253	273	23.87	410	50.1	37.4	37.2	3.2	2.1	1.9	0.71	0.67
27	243	132	26.54	210	17.9	23.1	13.3	3.4	2.4	1.9	0.60	0.63

28	267	165	16.94	320	26.6	30.5	22.6	3.5	2.9	2.3	0.62	0.52
29	349	406	21.02	510	30.1	37.3	38.0	4.0	3.0	2.3	0.81	0.80
30	221	219	18.57	370	42.5	36.0	19.1	3.2	2.2	1.8	0.42	0.59
31	351	741	23.05	870	48.3	58.1	39.0	4.1	4.2	3.2	0.59	0.85
32	229	334	16.15	480	33.7	45.3	35.7	5.0	4.5	3.3	0.70	0.70
33	346	364	21.61	510	33.3	36.0	22.2	4.0	3.3	2.4	0.44	0.71
34	244	286	14.05	380	41.4	33.2	30.5	3.6	4.0	3.0	0.37	0.75
35	239	344	17.69	490	37.1	44.5	28.4	3.1	2.2	2.1	0.44	0.70
36	191	211	17.66	360	29.5	30.0	25.0	4.8	4.0	3.4	0.61	0.59
37	273	197	18.22	196	28.9	31.1	30.5	4.0	4.2	3.1	0.69	1.01
38	307	445	24.01	570	39.1	30.4	40.3	3.7	4.1	3.3	1.00	0.78
39	186	305	15.06	340	39.5	39.0	20.0	3.5	3.2	2.1	0.60	0.90
40	254	427	19.89	550	38.4	43.5	44.5	3.1	2.4	2.4	0.79	0.78
41	283	519	13.21	525	62.6	64.0	38.6	3.5	2.8	2.6	0.51	0.99
42	227	464	22.46	510	42.6	36.3	34.1	4.0	3.1	2.1	0.71	0.91
43	644	764	25.55	570	47.5	54.1	50.4	3.1	3.0	2.4	0.52	1.34
44	286	440	19.43	420	53.4	52.1	39.0	3.5	3.6	3.3	0.67	1.05
45	415	731	13.42	880	36.1	41.4	32.5	4.2	3.1	2.9	0.41	0.83
46	195	271	14.22	321	34.4	43.3	24.3	3.7	2.4	1.9	0.61	0.85
47	336	790	22.78	870	42.0	70.0	55.1	4.4	2.7	3.2	0.61	0.91
48	304	721	17.87	825	55.5	58.8	39.5	3.1	3.5	2.7	0.90	0.87
49	229	272	19.21	370	24.0	29.4	20.3	3.6	4.3	3.1	0.44	0.74
50	281	840	8.07	1,020	53.5	60.2	36.4	5.2	4.8	2.8	0.43	0.82
Mean	**288.02**	**478.11**	**18.54**	**572.40**	**41.87**	**43.80**	**33.87**	**3.69**	**3.27**	**2.58**	**0.59**	**0.81**
S.D	**91.18**	**239.41**	**4.37**	**227.75**	**11.94**	**13.10**	**10.30**	**0.89**	**0.85**	**0.56**	**0.18**	**0.15**

Table A4: Physical Properties of TME 419 Cassava Cultivars at 12 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	272	200	14.22	225	36.0	37.7	30.2	1.22	1.18	1.08	0.37	0.90
2	195	180	20.74	230	35.7	43.8	32.6	2.20	2.18	1.22	0.14	0.78
3	317	321	14.91	401	48.1	47.4	26.4	1.38	1.26	1.30	0.14	0.80
4	228	220	29.24	289	44.9	46.1	43.2	2.20	1.32	1.22	0.52	0.76
5	300	312	23.50	358	40.7	39.8	34.4	1.22	1.26	1.32	0.18	0.87
6	187	190	23.44	224	30.9	39.6	37.7	1.18	1.26	1.28	0.49	0.85
7	218	253	16.80	300	34.1	45.3	31.8	1.22	1.30	1.10	0.40	0.84
8	252	92	12.60	121	24.9	28.5	22.0	1.50	1.60	1.36	0.31	0.76
9	217	81	9.75	102	25.0	26.1	18.8	1.14	1.22	1.10	0.35	0.79
10	252	264	13.76	279	47.4	43.1	20.9	1.82	1.98	1.12	0.67	0.95
11	187	50	17.86	71	20.6	19.4	16.4	1.36	1.42	1.12	0.42	0.71
12	178	202	16.66	239	47.2	52.3	24.7	1.28	1.34	1.16	0.76	0.84
13	181	100	3.36	101	30.6	24.2	22.2	2.18	1.38	1.18	0.16	1.01
14	295	121	11.82	148	37.0	31.2	14.4	1.20	1.24	1.12	0.22	0.81
15	221	373	14.69	400	55.3	53.1	36.4	2.10	1.42	1.22	0.94	0.93
16	162	81	9.56	63	20.2	27.3	25.2	2.04	1.32	1.18	0.68	1.29
17	292	269	30.62	297	41.2	31.0	22.2	1.36	1.28	1.14	0.62	0.91
18	304	252	12.95	303	37.0	35.8	28.3	1.18	1.22	1.06	0.48	0.83
19	147	120	18.88	120	28.8	37.8	28.9	1.12	1.28	1.40	0.37	1.01
20	341	202	19.42	220	36.0	36.6	26.9	1.36	1.38	1.34	0.81	0.92
21	342	310	17.77	341	38.2	41.7	33.3	1.18	2.10	1.06	0.48	0.91
22	328	271	15.23	306	29.8	35.0	24.4	1.10	1.28	1.32	0.45	0.89
23	374	420	16.11	460	41.3	41.7	33.9	1.36	1.30	1.08	0.29	0.91
24	350	381	9.02	402	40.8	44.4	37.8	1.32	1.28	1.10	0.14	0.95
25	252	319	18.38	400	46.6	46.0	47.6	1.42	1.34	1.22	0.36	0.80
26	279	330	14.06	372	43.4	43.3	31.6	1.34	1.34	1.14	0.27	0.89
27	321	169	17.37	210	32.7	35.8	25.0	1.30	2.14	1.18	0.20	0.80

28	272	351	17.99	377	43.4	47.0	43.5	1.06	1.22	1.02	0.39	0.93
29	363	670	27.09	495	32.7	34.4	25.2	1.18	1.24	1.08	0.20	1.35
30	380	293	19.44	316	32.8	36.4	29.9	1.46	1.48	1.09	0.32	0.93
31	367	331	16.89	198	40.3	35.3	39.7	1.32	1.08	1.14	0.26	1.67
32	390	488	16.43	560	35.6	45.2	34.9	1.10	1.24	1.08	0.33	0.87
33	378	220	24.26	259	31.9	32.3	20.4	1.10	2.16	1.32	0.15	0.85
34	382	301	12.85	335	28.8	38.8	31.0	1.20	1.20	1.04	0.35	0.90
35	420	391	18.88	402	38.6	32.5	29.0	1.22	1.36	1.14	0.32	0.97
36	412	400	16.83	395	39.6	40.9	25.5	1.26	1.18	1.14	0.22	1.01
37	358	131	17.95	149	34.2	21.3	18.5	1.18	1.20	1.16	0.67	0.88
38	441	250	19.13	221	24.8	31.5	21.3	1.20	1.22	1.08	0.35	1.13
39	344	511	22.75	604	49.1	44.8	33.5	1.34	2.18	1.20	0.54	0.85
40	346	321	18.93	378	39.0	38.6	31.4	1.14	1.36	1.26	0.63	0.85
41	464	549	21.38	510	45.5	49.3	29.5	1.20	1.24	1.32	0.34	1.08
42	208	300	17.04	338	32.1	49.5	48.8	1.30	1.28	1.34	0.33	0.89
43	421	450	37.35	412	41.0	40.9	32.2	1.16	1.02	1.00	0.30	1.09
44	201	291	17.33	340	49.8	36.0	22.6	2.26	1.32	2.08	0.33	0.86
45	415	81	19.09	142	32.8	59.2	48.0	1.16	1.28	1.10	0.26	0.44
46	520	449	26.12	563	37.8	53.8	29.6	1.18	1.22	1.14	0.61	0.80
47	175	20	42.28	36	18.4	17.7	15.6	1.34	1.26	1.36	0.44	0.56
48	405	101	22.32	117	44.7	50.3	34.1	1.42	1.24	1.10	0.58	0.86
49	180	130	14.92	158	49.4	31.8	31.0	1.18	1.22	1.16	0.34	0.82
50	170	20	30.62	25	16.8	14.4	11.0	1.40	1.22	1.20	0.20	0.81
Mean	**300.08**	**262.65**	**18.81**	**286.24**	**36.67**	**38.32**	**29.27**	**1.37**	**1.38**	**1.19**	**0.39**	**0.90**
S.D	**93.07**	**143.44**	**6.92**	**141.56**	**8.76**	**9.67**	**8.59**	**0.32**	**0.29**	**0.16**	**0.19**	**0.18**

Table A5: Physical Properties of TME 419 Cassava Cultivars at 15 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	300	458	30.09	300	28.3	31.1	18.7	3.0	2.8	2.5	0.89	1.53
2	323	650	28.65	410	50.3	37.6	42.3	2.5	2.1	2.4	0.81	1.59
3	367	548	26.72	530	36.9	25.6	19.9	3.1	2.3	2.0	0.52	1.03
4	305	900	18.40	700	59.2	58.2	39.8	3.5	2.3	2.1	0.54	1.29
5	325	1,000	23.45	700	59.2	66.0	46.7	2.1	2.9	2.1	0.61	1.43
6	418	490	19.80	410	36.4	38.9	37.6	2.1	2.2	2.0	0.44	1.20
7	522	1,100	25.46	980	66.8	60.4	39.7	1.8	2.0	1.7	0.37	1.12
8	357	410	24.51	310	45.2	38.7	24.3	2.3	2.5	2.1	0.49	1.32
9	363	1,500	21.25	910	52.0	54.8	38.4	1.9	2.6	1.9	0.50	1.65
10	422	327	20.21	255	33.6	32.1	21.4	2.4	2.5	1.8	0.45	1.28
11	378	980	21.20	1,200	35.3	36.1	36.6	3.0	2.6	2.4	0.70	0.82
12	471	800	25.89	821	49.6	41.6	27.2	3.2	2.8	2.2	0.62	0.97
13	459	600	20.62	734	45.9	44.5	21.6	3.5	3.0	3.0	0.54	0.82
14	270	426	18.70	424	50.6	46.6	29.2	3.2	3.1	2.8	0.57	1.00
15	470	582	27.34	690	40.9	55.4	23.8	2.9	3.1	2.4	0.72	0.84
16	306	650	24.71	740	53.5	40.8	30.1	2.8	3.3	2.8	0.67	0.88
17	190	465	32.49	510	59.3	61.2	41.0	3.6	3.7	3.2	0.52	0.91
18	640	500	27.12	452	58.8	45.7	29.4	3.2	2.1	1.9	0.65	1.11
19	248	247	26.40	248	41.2	34.5	21.1	3.0	2.4	2.1	0.71	0.99
20	408	407	21.30	620	34.6	37.1	27.1	3.1	2.2	2.1	0.48	0.66
21	272	450	19.47	310	51.1	44.0	28.5	3.2	3.0	2.3	0.37	1.45
22	389	150	25.73	280	40.6	28.9	30.9	3.1	2.8	2.1	0.51	0.54
23	431	150	31.20	189	30.3	28.3	18.3	2.7	2.4	2.9	0.34	0.79
24	269	400	23.75	700	37.2	34.5	39.5	2.6	2.2	2.0	0.74	0.57
25	241	320	19.81	360	54.1	57.7	34.6	3.1	3.5	2.8	0.45	0.89
26	270	368	27.61	480	43.7	45.2	39.0	2.2	2.5	2.1	0.35	0.77
27	430	369	21.65	426	40.3	31.8	19.0	2.8	2.5	2.4	0.46	0.87

28	250	413	19.67	540	31.1	23.9	19.7	3.1	2.8	2.7	0.37	0.76
29	265	379	24.70	520	32.9	29.8	16.7	2.6	2.4	2.2	0.53	0.73
30	358	350	26.34	470	33.4	38.4	24.6	3.1	3.2	2.8	0.78	0.74
31	372	495	26.21	610	33.5	29.3	21.3	2.6	2.5	2.1	0.48	0.81
32	264	231	19.44	256	32.2	34.0	27.6	2.8	2.5	1.8	0.75	0.90
33	436	292	21.64	370	33.7	29.8	19.7	3.0	2.6	2.3	0.35	0.79
34	441	408	20.31	580	37.2	32.9	24.1	3.3	3.0	2.7	0.72	0.70
35	249	423	24.50	470	43.4	45.0	46.7	1.6	1.5	1.4	0.59	0.90
36	286	272	20.58	350	23.2	29.4	19.6	2.5	2.6	2.4	0.64	0.78
37	264	349	18.85	357	48.3	35.9	31.3	2.0	2.1	1.8	0.88	0.98
38	437	404	23.86	530	31.5	30.5	28.3	2.8	2.6	2.2	0.59	0.76
39	353	459	28.45	379	27.8	29.6	22.5	3.0	2.8	2.3	0.32	1.21
40	276	235	21.40	310	33.7	28.1	21.7	1.9	2.1	1.7	0.53	0.76
41	254	180	31.56	240	32.9	33.8	14.4	4.0	3.6	3.5	0.86	0.75
42	299	214	20.28	280	35.9	31.5	19.8	3.2	3.0	3.0	0.91	0.76
43	371	472	20.80	465	40.6	43.1	23.7	1.9	1.5	1.3	0.32	1.01
44	324	278	20.74	410	33.8	34.9	24.9	2.6	2.3	1.8	0.72	0.68
45	356	278	58.34	285	28.1	30.0	22.5	2.4	2.3	1.7	0.54	0.98
46	258	655	9.56	680	43.4	45.0	46.7	2.5	2.4	1.8	0.66	0.96
47	272	326	4.02	300	23.2	29.4	19.6	2.8	2.4	2.0	0.71	1.09
48	279	66	37.39	50	48.3	35.9	31.3	2.5	2.2	1.9	0.63	1.32
49	471	420	23.48	400	41.2	41.5	39.8	2.7	2.5	1.8	0.58	1.05
50	230	120	28.76	125	49.3	51.0	41.0	2.3	1.9	1.8	0.76	0.96
Mean	**344.18**	**459.25**	**24.09**	**473.32**	**41.07**	**39.00**	**28.66**	**2.74**	**2.56**	**2.22**	**0.59**	**0.97**
S.D	**90.37**	**268.15**	**7.32**	**221.85**	**10.26**	**10.29**	**8.97**	**0.51**	**0.47**	**0.46**	**0.16**	**0.26**

Table A6: Physical Properties of TME 419 Cassava Cultivars at 18 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	358	857	19.03	520	49.9	60.7	52.0	3.2	3.0	2.5	0.53	1.65
2	412	983	25.76	730	51.1	59.8	30.6	3.0	2.6	2.5	0.31	1.35
3	255	445	20.09	460	45.5	49.5	44.0	2.1	2.3	1.9	1.00	0.97
4	255	391	29.00	960	37.2	19.4	19.2	2.9	2.8	2.4	0.52	0.41
5	318	486	20.03	340	47.5	45.6	35.7	1.6	1.5	1.4	0.55	1.43
6	342	961	22.47	720	53.5	65.5	51.5	3.1	3.1	2.8	1.00	1.33
7	501	781	21.99	690	54.0	58.4	50.1	3.1	2.7	2.5	0.44	1.13
8	299	541	22.00	710	43.4	31.5	19.8	3.0	2.9	2.3	0.48	0.76
9	478	505	17.99	440	24.6	42.3	17.4	3.5	3.0	2.3	0.54	1.15
10	520	593	17.99	770	45.0	42.7	19.1	3.2	2.6	2.4	0.70	0.77
11	345	405	28.00	280	43.0	41.5	20.5	2.3	2.5	2.2	0.56	1.45
12	415	283	28.99	410	26.5	30.9	22.0	2.0	2.1	1.6	0.80	0.69
13	349	740	21.99	470	40.5	51.5	24.3	3.2	3.2	3.1	0.59	1.57
14	351	961	18.99	490	50.5	56.5	46.0	3.3	2.7	2.5	0.67	1.96
15	279	502	18.00	680	19.7	28.2	14.6	1.6	1.6	1.2	0.83	0.74
16	341	721	30.99	510	57.0	53.0	30.0	3.8	3.9	3.4	0.68	1.41
17	489	514	23.99	710	33.6	41.6	29.4	3.4	3.1	2.7	0.38	0.72
18	427	416	20.00	380	41.0	36.8	26.1	3.6	3.9	3.0	0.37	1.09
19	403	542	18.99	610	37.2	36.2	19.8	2.9	2.6	2.2	0.61	0.89
20	413	327	16.99	520	23.5	31.5	20.5	2.6	2.6	2.3	0.43	0.63
21	397	349	18.99	490	42.5	41.6	33.3	3.3	3.1	2.7	0.63	0.71
22	481	488	19.90	540	37.1	28.1	25.1	3.6	3.9	3.1	0.71	0.90
23	319	345	20.06	280	39.5	35.5	23.8	2.9	2.4	2.2	0.72	1.23
24	428	353	22.98	390	36.5	30.7	22.0	2.5	2.2	2.0	0.55	0.91
25	182	543	18.99	590	51.0	49.3	36.5	2.4	2.7	2.4	0.94	0.92
26	120	278	25.99	410	40.4	34.6	30.3	2.6	2.5	2.1	0.47	0.68
27	376	174	21.02	260	25.0	28.5	21.2	2.0	1.6	1.4	0.54	0.67

28	244	807	15.99	520	43.5	64.2	38.0	2.5	3.5	2.2	0.79	1.55
29	343	802	17.99	680	34.6	27.1	32.3	2.7	2.9	1.4	0.56	1.18
30	447	787	20.99	500	65.0	37.7	20.5	3.2	2.1	1.9	0.52	1.57
31	431	865	21.99	880	46.5	34.3	26.0	2.9	3.0	2.3	0.54	0.98
32	339	213	13.99	250	17.0	22.0	16.2	3.2	2.9	2.2	0.44	0.85
33	164	296	17.02	460	49.5	52.0	36.6	3.8	4.2	3.4	0.59	0.64
34	176	452	18.99	453	42.5	44.5	33.5	3.0	2.1	1.9	0.71	0.99
35	195	168	20.98	158	29.5	34.0	24.0	3.3	2.0	2.2	0.72	1.07
36	215	254	17.99	390	31.9	36.1	18.1	2.9	3.8	2.5	0.52	0.65
37	418	240	23.00	235	28.5	33.0	27.0	2.0	3.0	1.8	0.53	1.02
38	182	860	18.43	920	36.1	33.1	27.2	1.5	1.9	1.2	0.68	0.94
39	415	800	21.69	990	58.2	33.3	14.2	1.9	2.7	1.9	1.00	0.81
40	225	336	23.99	410	47.0	46.6	33.6	4.5	4.1	3.4	1.00	0.82
41	276	281	26.98	310	33.0	38.4	25.1	1.8	1.8	1.4	0.74	0.91
42	304	450	16.02	413	39.5	47.2	37.3	3.2	3.0	2.7	0.53	1.09
43	332	420	20.00	430	37.2	34.9	19.0	2.7	2.1	1.6	0.45	0.98
44	228	253	18.97	300	27.0	37.0	23.4	2.1	3.2	1.9	0.61	0.84
45	198	146	23.90	400	34.0	31.5	20.5	3.0	2.1	1.8	0.86	0.36
46	120	189	21.99	180	36.0	46.1	22.3	2.3	2.2	1.6	0.59	1.05
47	254	293	19.97	220	40.5	33.6	28.0	2.8	2.1	1.5	0.61	1.33
48	296	230	24.70	240	21.5	26.3	21.2	2.7	2.2	1.3	0.72	0.96
49	141	84	16.05	90	19.0	28.0	12.0	1.6	2.3	1.7	0.96	0.93
50	249	466	19.89	530	39.0	52.5	23.5	2.6	2.5	2.1	0.51	0.88
Mean	**320.90**	**483.48**	**21.05**	**480.17**	**39.05**	**40.10**	**27.29**	**2.78**	**2.70**	**2.18**	**0.64**	**1.04**
S.D	**106.24**	**245.22**	**3.67**	**206.60**	**10.81**	**11.14**	**9.66**	**0.65**	**0.66**	**0.58**	**0.18**	**0.33**

Table A7: Physical Properties of TME 7 Cassava Cultivars at 12 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	145	131	16.03	160	42.2	37.6	33.8	1.27	1.26	1.13	0.27	0.82
2	296	379	15.57	339	44.4	37.2	27.0	1.16	1.17	1.38	0.36	1.12
3	230	113	15.93	140	35.8	35.2	20.6	1.18	1.14	1.11	0.17	0.81
4	235	227	18.06	251	44.5	36.6	31.9	1.24	1.21	1.14	0.13	0.90
5	145	140	17.14	175	42.8	43.4	43.0	1.19	1.22	1.03	0.90	0.80
6	145	100	21.00	102	33.5	33.5	31.6	1.20	1.18	1.15	0.20	0.98
7	148	133	16.54	130	37.2	41.8	31.0	1.21	1.19	1.24	0.29	1.02
8	135	157	15.92	72	34.5	31.6	16.0	1.18	1.24	1.08	0.25	2.18
9	289	285	16.14	280	37.6	42.7	29.9	1.24	1.16	1.31	0.15	1.02
10	335	355	14.93	340	50.2	34.4	24.9	1.17	1.12	1.13	0.15	1.04
11	276	117	16.24	141	33.0	28.2	18.0	1.33	1.04	1.19	0.30	0.83
12	345	613	14.36	560	50.6	61.9	32.4	1.15	1.32	1.06	0.15	1.10
13	196	339	14.45	340	61.4	53.5	38.2	1.32	1.16	1.16	0.30	0.99
14	272	161	18.63	179	33.5	31.4	23.7	1.02	1.17	1.31	0.15	0.90
15	185	230	19.13	278	41.4	46.4	41.0	1.18	1.12	1.17	0.96	0.83
16	182	242	19.84	263	52.9	43.1	39.3	2.03	1.24	1.90	0.95	0.92
17	138	368	14.13	141	53.1	53.4	28.0	1.33	1.24	1.19	0.47	2.61
18	249	152	16.45	176	30.6	36.4	23.8	1.90	1.22	1.17	0.13	0.86
19	312	378	16.14	322	39.1	43.2	34.1	1.24	1.13	1.09	0.15	1.17
20	312	177	19.21	178	28.1	31.7	23.1	1.23	1.28	1.16	0.12	0.99
21	221	323	12.07	310	46.6	47.0	37.4	1.05	1.01	1.00	0.60	1.04
22	201	130	17.69	158	37.2	36.4	21.8	1.11	1.14	1.23	0.18	0.82
23	165	59	22.03	50	23.2	23.0	12.5	1.80	1.27	1.19	0.18	1.18
24	107	62	20.97	60	30.4	30.1	26.0	1.41	1.33	1.39	0.46	1.03
25	154	164	16.46	160	43.1	45.2	31.9	1.39	1.07	1.02	0.34	1.03
26	260	366	15.30	406	63.5	54.1	30.3	1.16	2.14	1.01	0.19	0.90
27	191	233	19.31	270	45.2	47.2	33.6	1.04	1.06	1.39	0.56	0.86

28	145	221	18.10	250	50.4	49.6	35.7	1.26	1.18	1.08	0.34	0.88
29	250	238	19.75	239	42.0	39.2	28.7	1.28	1.11	1.24	0.83	0.99
30	227	152	15.13	162	21.0	38.7	24.6	1.07	1.22	1.00	0.18	0.94
31	170	109	21.10	159	34.2	35.2	26.4	1.27	1.19	1.06	0.19	0.69
32	185	79	16.46	70	26.9	25.5	23.2	2.24	1.33	1.39	0.69	1.13
33	295	222	18.02	241	33.7	36.2	31.3	1.33	1.23	1.42	0.17	0.92
34	138	148	15.54	128	39.8	40.6	34.3	1.16	1.21	1.38	0.94	1.16
35	400	453	14.57	458	41.8	44.4	28.5	1.42	1.08	1.24	0.64	0.99
36	338	671	15.05	615	60.3	53.4	37.1	1.37	1.19	1.28	0.18	1.09
37	312	143	21.68	138	21.5	29.7	22.4	1.90	1.24	1.22	0.12	1.04
38	382	354	15.54	398	41.7	32.2	27.1	1.36	1.18	1.23	0.11	0.89
39	288	62	22.58	83	14.9	22.6	16.4	1.16	1.22	1.14	0.65	0.75
40	190	154	16.23	170	42.6	41.2	23.2	1.26	1.12	1.04	0.20	0.91
41	355	227	19.38	205	29.8	31.4	23.5	1.31	1.09	1.19	0.90	1.11
42	360	560	13.04	502	46.7	55.0	33.3	1.12	1.42	1.23	0.14	1.12
43	40	270	17.04	225	27.6	37.4	20.3	1.31	1.06	1.14	0.15	1.20
44	193	102	21.57	105	39.7	22.0	24.0	1.06	1.11	1.41	0.11	0.97
45	170	41	24.39	52	26.8	26.3	10.9	1.23	1.12	1.19	0.17	0.79
46	435	481	14.55	380	47.4	39.8	27.6	1.26	1.02	1.05	0.73	1.27
47	314	328	12.81	341	40.5	47.5	26.9	1.29	1.33	1.25	0.15	0.96
48	195	133	18.80	158	38.9	34.1	23.8	1.12	1.28	1.26	0.22	0.84
49	174	127	18.11	159	41.6	38.4	30.3	1.13	2.33	2.61	0.22	0.80
50	224	80	18.75	82	23.5	26.3	25.2	1.21	1.29	2.56	0.79	0.98
Mean	**232.98**	**229.78**	**17.36**	**226.02**	**38.98**	**38.66**	**27.77**	**1.30**	**1.23**	**1.26**	**0.36**	**1.02**
S.D	**85.43**	**146.98**	**2.73**	**131.00**	**10.48**	**9.21**	**7.02**	**0.25**	**0.23**	**0.31**	**0.27**	**0.31**

Table A8: Physical Properties of TME 7 Cassava Cultivars at 15 Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	335	334	20.19	510	23.8	30.5	21.3	2.1	2.4	2.1	0.55	0.66
2	445	980	13.34	720	48.2	29.4	17.4	2.4	3.7	2.1	0.55	1.36
3	392	1,020	14.12	780	43.0	43.1	33.2	3.4	3.9	2.9	0.67	1.31
4	278	334	19.56	515	22.5	20.6	14.3	2.4	2.3	2.2	0.62	0.65
5	181	810	18.36	670	63.5	62.5	50.5	3.4	3.1	3.3	0.58	1.21
6	219	1,480	12.80	920	70.0	76.0	66.8	4.4	4.2	0.41	0.75	1.61
7	174	352	18.71	540	33.0	31.5	27.2	2.8	3.8	2.8	0.39	0.65
8	186	333	23.68	490	35.5	31.8	24.0	3.0	3.2	2.1	0.39	0.68
9	163	188	17.66	310	30.0	24.5	18.5	4.1	2.2	5.7	1.00	0.61
10	227	315	19.64	460	27.0	27.1	21.4	2.1	2.9	2.7	0.68	0.68
11	371	400	17.79	610	31.5	30.0	20.5	2.4	2.1	2.6	0.64	0.66
12	269	396	21.67	590	30.0	23.5	19.1	3.1	3.1	2.1	0.45	0.67
13	299	359	19.73	380	25.7	18.7	12.5	2.1	2.6	2.8	0.76	0.94
14	221	352	18.88	530	29.5	28.2	22.3	2.2	2.1	2.1	0.47	0.66
15	243	410	24.51	530	29.5	36.1	27.5	2.1	2.1	1.6	0.62	0.77
16	307	472	22.65	580	31.7	25.8	21.2	3.3	2.2	2.9	0.64	0.81
17	308	263	21.14	270	22.5	21.8	12.9	2.1	2.1	1.1	0.45	0.97
18	242	300	19.69	290	26.5	23.1	21.6	2.3	2.3	2.2	0.57	1.03
19	235	321	26.71	520	29.1	23.1	18.7	4.2	5.1	2.2	0.78	0.62
20	165	272	23.24	280	29.5	26.6	15.4	2.1	3.3	1.4	0.63	0.97
21	110	171	19.45	290	27.0	21.3	12.7	2.2	2.1	2.8	0.59	0.59
22	300	337	25.19	520	17.5	23.6	15.5	3.1	2.8	2.4	1.00	0.65
23	273	238	20.52	380	25.6	20.5	17.0	2.2	2.1	2.4	1.00	0.63
24	287	244	26.71	390	25.9	20.5	19.6	2.1	2.1	2.6	0.80	0.63
25	199	198	30.49	300	20.9	22.2	22.3	2.2	2.7	2.7	1.00	0.66
26	311	260	26.85	350	20.0	20.6	17.3	2.1	2.2	2.1	0.73	0.74
27	227	106	31.00	100	34.5	27.5	19.1	1.5	1.3	1.3	0.40	1.06

28	223	181	19.80	280	20.2	25.2	12.4	3.7	2.5	3.1	0.60	0.65
29	113	79	25.60	90	30.8	33.0	20.0	2.1	2.1	2.2	0.59	0.88
30	237	158	23.49	270	35.0	31.5	14.5	3.1	2.7	3.4	0.75	0.58
31	256	160	33.75	270	31.5	24.0	23.9	2.0	1.3	1.4	0.99	0.59
32	134	64	38.13	70	15.0	17.5	12.1	2.1	1.7	2.2	0.64	0.91
33	196	195	17.56	310	19.0	20.4	20.6	2.8	2.2	1.9	0.44	0.63
34	134	165	17.81	270	34.5	27.5	19.3	2.1	2.4	2.1	0.77	0.61
35	158	115	15.97	110	20.9	22.5	16.4	2.2	2.1	2.1	0.28	1.05
36	382	610	19.56	410	57.1	58.0	41.3	6.3	5.2	4.1	0.40	1.49
37	256	300	31.27	230	42.0	42.5	40.5	5.7	1.5	1.6	0.37	1.30
38	314	961	13.46	930	66.2	67.1	55.1	6.7	5.6	5.1	0.56	1.03
39	311	702	19.33	390	67.5	50.0	23.0	8.2	4.1	3.9	0.38	1.80
40	239	326	30.15	320	43.0	44.0	25.0	8.6	5.8	5.9	0.48	1.02
41	297	540	16.98	510	46.0	44.5	43.5	1.5	5.1	5.0	0.24	1.06
42	313	520	19.71	620	57.0	64.3	32.5	8.8	5.9	5.8	0.52	0.84
43	218	670	18.18	520	66.4	66.1	63.7	7.8	5.6	5.0	0.36	1.29
44	302	500	22.62	470	47.2	31.2	30.3	7.1	5.9	3.9	0.38	1.06
45	500	970	14.06	890	43.3	55.5	35.2	8.7	2.1	2.3	0.30	1.09
46	315	881	17.10	930	67.5	66.3	42.5	5.5	5.2	5.1	0.47	0.95
47	357	698	19.44	670	67.5	50.0	23.3	8.2	4.1	3.9	0.38	1.04
48	273	525	20.95	510	43.0	45.5	26.0	8.6	5.9	5.9	0.48	1.03
49	269	520	22.17	490	47.9	30.9	36.5	7.1	5.9	3.8	0.39	1.06
50	431	970	13.84	860	43.1	55.4	35.5	5.0	2.1	2.3	0.52	1.13
Mean	**263.90**	**441.10**	**21.30**	**464.90**	**37.30**	**35.26**	**26.06**	**3.91**	**3.22**	**2.91**	**0.58**	**0.91**
S.D	**84.35**	**302.82**	**5.50**	**217.37**	**15.51**	**15.77**	**12.94**	**2.33**	**1.43**	**1.34**	**0.20**	**0.29**

Table A9: Physical Properties of TME 7 Cassava Cultivars at 18Months after Planting

S/N	Length (mm)	Mass (g)	PPW (%)	Volume (cm^3)	D_H (mm)	D_M (mm)	D_T (mm)	P_H (mm)	P_M (mm)	P_T (mm)	Roundness	Density g/cm^3
1	337	908	13.80	550	50.5	37.0	32.8	5.2	5.2	3.0	0.98	1.65
2	223	192	25.63	170	35.0	36.0	23.2	3.1	4.1	4.2	0.85	1.13
3	235	366	18.58	300	45.5	44.0	39.0	5.1	4.9	4.0	0.89	1.22
4	265	387	17.27	420	32.5	44.0	39.7	5.2	5.2	5.2	0.52	0.92
5	234	159	16.24	120	29.5	31.0	22.3	5.2	5.1	5.1	0.77	1.32
6	290	279	18.77	250	30.0	37.5	30.5	3.4	3.3	3.2	0.69	1.12
7	379	427	16.57	430	48.5	48.5	19.0	2.4	2.5	2.3	0.71	0.99
8	401	531	21.45	560	41.5	43.0	27.0	3.5	2.8	1.5	0.46	0.95
9	334	462	22.60	450	65.0	59.0	44.4	3.2	2.3	2.5	0.83	1.03
10	336	807	22.99	560	33.0	46.0	44.6	5.3	5.2	5.1	0.51	1.44
11	333	271	19.29	260	30.3	47.5	24.3	3.0	5.0	4.0	1.00	1.04
12	427	296	23.21	300	30.0	33.0	17.7	4.2	4.1	4.0	0.57	0.99
13	231	176	26.47	280	34.0	33.0	19.0	3.3	5.2	5.1	0.91	0.63
14	311	266	16.71	210	35.0	37.0	17.5	5.4	5.3	5.0	0.94	1.27
15	273	336	20.21	420	39.0	40.5	38.5	5.0	4.9	4.7	0.58	0.80
16	297	971	15.63	450	63.0	57.5	40.5	4.4	4.3	4.1	0.51	2.16
17	278	223	25.74	200	30.5	36.0	20.1	5.5	5.0	3.8	1.00	1.12
18	254	258	22.64	210	34.5	38.0	26.1	5.2	5.1	5.0	1.00	1.23
19	242	291	20.42	298	35.5	46.0	34.5	5.7	5.6	5.3	0.55	0.98
20	251	349	19.21	390	39.5	47.5	37.0	5.2	4.9	4.7	0.68	0.90
21	348	501	17.62	320	42.5	43.0	19.3	5.2	5.1	4.8	0.54	1.56
22	362	467	18.95	470	39.0	40.0	32.5	5.7	5.7	4.7	0.21	0.99
23	388	526	21.51	390	47.0	41.5	40.0	3.5	3.6	3.4	0.66	1.35
24	462	721	12.98	410	49.5	38.5	41.0	5.0	5.5	5.0	0.48	1.76
25	395	446	18.75	520	31.0	40.5	39.2	4.2	4.1	4.0	0.36	0.86
26	349	820	17.62	700	44.0	46.5	45.0	3.3	3.4	3.2	0.68	1.17
27	286	451	23.09	380	40.5	50.7	42.0	5.0	5.1	5.0	0.49	1.19

28	260	709	15.67	410	43.5	56.5	51.6	5.2	5.0	5.1	0.56	1.73
29	347	484	18.38	370	44.0	41.5	36.7	5.3	5.0	4.1	0.62	1.31
30	423	620	16.29	630	45.0	50.5	34.2	2.1	2.4	3.1	0.43	0.98
31	214	394	23.81	230	43.5	51.5	47.5	1.5	1.6	1.8	0.57	1.71
32	316	881	16.41	930	67.5	66.0	42.3	5.2	5.1	4.7	0.55	0.95
33	310	702	19.33	390	67.5	50.0	23.2	4.1	3.9	3.8	0.82	1.80
34	294	533	19.77	510	43.0	45.5	26.0	5.9	5.9	4.8	0.86	1.05
35	263	520	22.64	500	47.5	31.0	36.8	5.9	3.8	3.9	0.71	1.04
36	437	970	13.84	860	43.5	55.5	35.7	2.1	2.3	2.0	0.50	1.13
37	328	520	19.71	820	57.0	64.5	32.3	5.9	5.8	4.7	0.88	0.63
38	282	525	17.48	450	46.0	44.5	43.2	5.1	5.0	2.4	1.00	1.17
39	424	610	19.56	380	57.5	59.0	41.5	5.2	4.1	4.0	0.63	1.61
40	206	670	18.18	480	64.5	67.0	65.5	5.8	5.0	4.8	0.55	1.40
41	324	516	23.50	600	41.5	43.5	38.9	5.2	5.1	4.9	0.48	0.86
42	336	513	21.62	600	50.5	71.5	22.6	3.7	2.5	1.3	0.52	0.85
43	525	121	28.69	130	50.5	37.0	29.2	4.5	4.4	4.3	0.46	0.93
44	522	68	35.38	72	57.5	62.5	59.3	5.0	5.5	4.1	0.34	0.95
45	620	158	31.14	150	25.5	37.5	41.1	5.2	5.1	5.1	1.00	1.05
46	326	424	21.45	455	64.0	59.5	36.0	5.5	5.2	5.1	1.00	0.93
47	264	1,561	12.86	1,250	46.5	51.0	45.1	5.9	5.2	5.1	0.72	1.25
48	209	480	23.63	460	32.5	27.5	19.4	5.0	5.7	4.2	0.84	1.04
49	156	86	36.74	570	28.0	21.5	12.6	5.2	5.1	3.8	0.76	0.15
50	100	506	23.20	710	23.5	23.0	12.5	5.1	4.9	4.0	0.94	0.71
Mean	**320.14**	**489.11**	**20.67**	**439.50**	**43.32**	**45.20**	**33.80**	**4.60**	**4.52**	**4.06**	**0.68**	**1.14**
S.D	**95.42**	**274.28**	**5.00**	**219.52**	**11.53**	**11.24**	**11.55**	**1.13**	**1.08**	**1.05**	**0.21**	**0.35**

APPENDIX B

Table B1: Coefficient of Friction for TMS 30572 on Stainless Steel at 12 Months

MC (%)	**60**		**55**		**50**		**45**		**40**	
1st trial	0.26	(14)	0.23	(13)	0.21	(12)	0.21	(12)	0.20	(11)
2nd trial	0.27	(15)	0.26	(14)	0.22	(13)	0.21	(12)	0.21	(12)
3rd trial	0.29	(16)	0.27	(15)	0.25	(14)	0.21	(12)	0.20	(11)
4th trial	0.27	(15)	0.26	(14)	0.22	(13)	0.21	(12)	0.21	(12)
5th trial	0.26	(14)	0.23	(13)	0.23	(13)	0.21	(12)	0.20	(11)
Average	0.27	(15)	0.26	(14)	0.23	(13)	0.21	(12)	0.20	(11)

Table B2: Coefficient of Friction for TMS 30572 on Galvanize Sheet at 12 Months

MC (%)	**60**		**55**		**50**		**45**		**40**	
1st trial	0.54	(29)	0.53	(27)	0.52	(26)	0.45	(24)	0.44	(23)
2nd trial	0.53	(27)	0.52	(26)	0.52	(26)	0.51	(25)	0.45	(24)
3rd trial	0.54	(28)	0.52	(26)	0.51	(25)	0.45	(24)	0.44	(23)
4th trial	0.53	(27)	0.51	(25)	0.44	(23)	0.44	(23)	0.42	(22)
5th trial	0.52	(26)	0.51	(25)	0.45	(24)	0.45	(24)	0.44	(23)
Average	0.53	(27)	0.52	(26)	0.46	(25)	0.45	(24)	0.44	(23)

Table B3: Coefficient of Friction for TMS 30572 on Wood at 12 Months

MC (%)	**60**		**55**		**50**		**45**		**40**	
1st trial	0.76	(37)	0.74	(36)	0.69	(34)	0.68	(36)	0.61	(35)
2nd trial	0.76	(37)	0.71	(35)	0.69	(34)	0.62	(34)	0.58	(33)
3rd trial	0.74	(36)	0.74	(35)	0.69	(34)	0.67	(36)	0.66	(35)
4th trial	0.76	(37)	0.74	(36)	0.71	(35)	0.62	(34)	0.58	(33)
5th trial	0.74	(36)	0.71	(35)	0.69	(34)	0.67	(37)	0.68	(36)
Average	0.76	(37)	0.74	(35)	0.69	(34)	0.67	(35)	0.61	(34)

<u>**N.B:**</u> Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B4: Coefficient of Friction for TME 419 on Stainless Steel at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.28	(16)	0.26	(15)	0.22	(13)	0.21	(12)	0.20	(11)
2nd trial	0.28	(16)	0.26	(15)	0.22	(13)	0.22	(13)	0.21	(12)
3rd trial	0.26	(15)	0.26	(15)	0.24	(14)	0.22	(13)	0.21	(12)
4th trial	0.28	(16)	0.25	(14)	0.22	(13)	0.22	(13)	0.21	(12)
5th trial	0.28	(16)	0.26	(15)	0.24	(14)	0.21	(12)	0.21	(12)
Average	0.28	(16)	0.26	(15)	0.24	(13)	0.22	(13)	0.21	(12)

Table B5: Coefficient of Friction for TME 419 on Galvanized at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.53	(28)	0.52	(27)	0.48	(25)	0.45	(24)	0.43	(23)
2nd trial	0.53	(28)	0.52	(27)	0.49	(26)	0.45	(24)	0.43	(23)
3rd trial	0.54	(29)	0.52	(27)	0.49	(26)	0.45	(24)	0.39	(21)
4th trial	0.53	(28)	0.52	(27)	0.53	(27)	0.43	(23)	0.44	(24)
5th trial	0.52	(27)	0.49	(26)	0.49	(26)	0.45	(24)	0.43	(23)
Average	0.53	(28)	0.52	(27)	0.49	(26)	0.45	(24)	0.43	(23)

Table B6: Coefficient of Friction for TME 419 on Wood at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.75	(37)	0.74	(36)	0.69	(35)	0.63	(32)	0.61	(31)
2nd trial	0.84	(38)	0.69	(35)	0.64	(34)	0.61	(31)	0.61	(31)
3rd trial	0.74	(36)	0.84	(38)	0.74	(36)	0.66	(33)	0.61	(31)
4th trial	0.69	(35)	0.69	(35)	0.69	(35)	0.63	(32)	0.57	(29)
5th trial	0.85	(39)	0.69	(35)	0.69	(35)	0.63	(32)	0.63	(32)
Average	0.75	(37)	0.73	(36)	0.69	(35)	0.63	(32)	0.61	(31)

N.B: Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B7: Coefficient of Friction for TME 7 on Stainless Steel at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.27	(14)	0.23	(13)	0.23	(13)	0.22	(12)	0.20	(11)
2nd trial	0.30	(17)	0.28	(15)	0.27	(14)	0.22	(12)	0.20	(11)
3rd trial	0.29	(16)	0.28	(15)	0.27	(14)	0.27	(14)	0.23	(13)
4th trial	0.27	(14)	0.23	(13)	0.23	(13)	0.22	(12)	0.20	(11)
5th trial	0.28	(15)	0.23	(14)	0.23	(13)	0.22	(12)	0.20	(11)
Average	0.28	(15)	0.23	(14)	0.23	(13)	0.22	(12)	0.21	(11)

Table B8: Coefficient of Friction for TME 7 on Galvanized at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.54	(28)	0.48	(26)	0.48	(26)	0.46	(25)	0.43	(23)
2nd trial	0.54	(28)	0.51	(27)	0.48	(26)	0.48	(26)	0.41	(22)
3rd trial	0.55	(28)	0.46	(25)	0.45	(24)	0.43	(23)	0.45	(24)
4th trial	0.55	(28)	0.55	(28)	0.51	(27)	0.48	(26)	0.45	(24)
5th trial	0.55	(28)	0.55	(28)	0.48	(26)	0.46	(25)	0.43	(23)
Average	0.55	(28)	0.53	(27)	0.49	(26)	0.47	(25)	0.43	(23)

Table B9: Coefficient of Friction for TME 7 on Wood at 12 Months

MC (%)	60		55		50		45		40	
1st trial	0.77	(37)	0.75	(36)	0.67	(34)	0.62	(32)	0.61	(31)
2nd trial	0.75	(36)	0.74	(35)	0.66	(33)	0.61	(31)	0.61	(31)
3rd trial	0.79	(38)	0.75	(36)	0.67	(34)	0.62	(32)	0.61	(31)
4th trial	0.77	(37)	0.74	(35)	0.67	(34)	0.63	(33)	0.61	(31)
5th trial	0.77	(37)	0.75	(36)	0.67	(34)	0.76	(37)	0.61	(31)
Average	0.78	(37)	0.75	(36)	0.67	(34)	0.62	(33)	0.61	(31)

<u>**N.B:**</u> Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B10: Coefficient of Friction for TMS 30572 on Stainless Steel at 15 Months

MC (%)	60	55	50	45	40
1st trial	0.30 (16)	0.29 (15)	0.28 (14)	0.25 (13)	0.25 (13)
2nd trial	0.29 (15)	0.28 (14)	0.28 (14)	0.25 (13)	0.22 (12)
3rd trial	0.29 (15)	0.28 (14)	0.28 (14)	0.23 (13)	0.23 (13)
4th trial	0.30 (16)	0.29 (15)	0.29 (15)	0.25 (13)	0.25 (13)
5th trial	0.29 (15)	0.29 (14)	0.25 (13)	0.23 (12)	0.22 (12)
Average	0.29 (15)	0.28 (14)	0.26 (14)	0.25 (13)	0.23 (13)

Table B11: Coefficient of Friction for TMS 30572 on Galvanized Sheet at 15 Months

MC (%)	60	55	50	45	40
1st trial	0.50 (26)	0.49 (25)	0.43 (23)	0.43 (23)	0.42 (22)
2nd trial	0.50 (26)	0.49 (25)	0.44 (24)	0.44 (24)	0.43 (23)
3rd trial	0.53 (27)	0.50 (26)	0.49 (25)	0.48 (25)	0.44 (24)
4th trial	0.49 (25)	0.47 (24)	0.43 (23)	0.43 (23)	0.42 (22)
5th trial	.53 (27)	0.29 (25)	0.49 (25)	0.44 (24)	0.43 (23)
Average	0.51 (26)	0.49 (25)	0.47 (24)	0.45 (24)	0.44 (23)

Table B12: Coefficient of Friction for TMS 30572 on Wood at 15 Months

MC (%)	60	55	50	45	40
1st trial	0.76 (36)	0.74 (35)	0.72 (34)	0.67 (33)	0.69 (33)
2nd trial	0.76 (36)	0.76 (36)	0.74 (35)	0.70 (34)	0.67 (32)
3rd trial	0.80 (39)	0.77 (37)	0.76 (36)	0.74 (35)	0.67 (33)
4th trial	0.80 (39)	0.79 (38)	0.77 (37)	0.72 (36)	0.74 (35)
5th trial	0.77 (37)	0.76 (36)	0.74 (35)	0.72 (34)	0.67 (31)
Average	0.79 (37)	0.78 (36)	0,74 (35)	071 (34)	0.68 (33)

N.B: Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B13: Coefficient of Friction for TME 419 on Stainless Steel at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.27	(15)	0.23	(13)	0.21	(13)	0.20	(12)	0.19	(11)
2nd trial	0.26	(14)	0.23	(13)	0.21	(13)	0.20	(12)	0.18	(10)
3rd trial	0.26	(14)	0.25	(15)	0.21	(13)	0.20	(12)	0.19	(11)
4th trial	0.26	(14)	0.23	(13)	0.21	(12)	0.20	(12)	0.18	(10)
5th trial	0.27	(15)	0.24	(14)	0.23	(14)	0.22	(13)	0.19	(11)
Average	0.26	(15)	0.23	(14)	0.21	(13)	0.22	(13)	0.19	(11)

Table B14: Coefficient of Friction for TME 419 on Galvanized Sheet at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.43	(23)	0.43	(23)	0.42	(22)	0.39	(21)	0.36	(20)
2nd trial	0.47	(25)	0.45	(24)	0.43	(23)	0.39	(22)	0.36	(20)
3rd trial	0.45	(24)	0.43	(23)	0.41	(22)	0.39	(21)	0.36	(20)
4th trial	0.45	(24)	0.43	(23)	0.41	(22)	0.36	(20)	0.35	(19)
5th trial	0.49	(26)	0.45	(24)	0.43	(23)	0.41	(22)	0.39	(21)
Average	0.46	(24)	0.43	(23)	0.41	(22)	0.38	(21)	0.36	(20)

Table B15: Coefficient of Friction for TME 419 on Wood at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.67	(35)	0.64	(33)	0.64	(33)	0.61	(32)	0.58	(30)
2nd trial	0.70	(36)	0.64	(33)	0.63	(32)	0.60	(31)	0.58	(30)
3rd trial	0.66	(34)	0.63	(32)	0.63	(32)	0.60	(31)	0.57	(29)
4th trial	0.70	(36)	0.66	(34)	0.64	(33)	0.61	(32)	0.60	(31)
5th trial	0.68	(34)	0.64	(33)	0.64	(33)	0.61	(32)	0.58	(30)
Average	0.70	(35)	0.65	(33)	0.64	(33)	0.61	(32)	0.58	(30)

N.B: Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B16: Coefficient of Friction for TME 7 on Stainless steel at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.24	(14)	0.23	(13)	0.21	(12)	0.19	(11)	0.18	(10)
2nd trial	0.24	(14)	0.23	(13)	0.21	(12)	0. 18	(10)	0.18	(10)
3rd trial	0.25	(15)	0.23	(13)	0.21	(12)	0.19	(11)	0.18	(10)
4th trial	0.24	(14)	0.23	(13)	0.21	(12)	0.18	(10)	0.17	(9)
5th trial	0.25	(15)	0.24	(14)	0.23	(13)	0.19	(11)	0.18	(10)
Average	0.24	(14)	0.23	(13.2)	0.21	(12.2)	0.19	(11)	0.18	(10)

Table B17: Coefficient of Friction for TME 7 on Galvanized Sheet at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.46	(24)	0.43	(23)	0.41	(22)	0.37	(20)	0.36	(20)
2nd trial	0.47	(25)	0.46	(25)	0.42	(23)	0.39	(22)	0.37	(21)
3rd trial	0.48	(26)	0.46	(25)	0.41	(24)	0.39	(22)	0.37	(21)
4th trial	0.48	(26)	0.46	(25)	0.43	(23)	0.39	(22)	0.37	(21)
5th trial	0.47	(25)	0.44	(24)	0.43	(23)	0.38	(21)	0.36	(20)
Average	0.48	(25)	0.46	(24)	0.42	(23)	0.39	(21)	0.37	(21)

Table B18: Coefficient of Friction for TME 7 on Wood at 15 Months

MC (%)	60		55		50		45		40	
1st trial	0.70	(35)	0.66	(34)	0.63	(33)	0.61	(32)	0.58	(31)
2nd trial	0.70	(35)	0.66	(34)	0.63	(33)	0.61	(32)	0.58	(31)
3rd trial	0.70	(35)	0.66	(34)	0.63	(33)	0.60	(31)	0.57	(30)
4th trial	0.70	(35)	0.65	(33)	0.62	(32)	0.60	(31)	0.56	(30)
5th trial	0.69	(33)	0.65	(33)	0.61	(31)	0.58	(30)	0.55	(28)
Average	0.70	(35)	0.66	(34)	0.63	(30)	0.60	(31)	0.58	(30)

N.B: Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B19: Coefficient of Friction for TMS 30572 on Stainless Steel at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.19	(11)	0.18	(10)	0.18	(10)	0.17	(9)	0.16	(9)
2nd trial	0.20	(12)	0.19	(11)	0.18	(10)	0.17	(9)	0.17	(9)
3rd trial	0.20	(12)	0.19	(11)	0.19	(11)	0.17	(9)	0.16	(9)
4th trial	0.19	(11)	0.18	(10)	0.18	(10)	0.18	(8)	0.16	(9)
5th trial	0.20	(12)	0.19	(11)	0.19	(11)	0.18	(9)	0.16	(8)
Average	0.20	(12)	0.19	(11)	018	(10)	0.17	(9)	0.16	(9)

Table B20: Coefficient of Friction for TMS 30572 on Galvanized at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.49	(24)	0.47	(23)	0.47	(25)	0.46	(27)	0.45	(26)
2nd trial	0.48	(23)	0.47	(23)	0.47	(24)	0.45	(26)	0.44	(25)
3rd trial	0.50	(25)	0.48	(24)	0.46	(24)	0.46	(27)	0.46	(26)
4th trial	0.50	(25)	0.48	(24)	0.46	(26)	0.46	(27)	0.45	(27)
5th trial	0.48	(24)	0.49	(26)	0.47	(27)	0.49	(28)	0.46	(27)
Average	0.50	(24)	0.48	(24)	0.47	(25)	0.46	(27)	0.45	(26)

Table B21: Co-efficient of Friction for TMS 30572 on Stainless Steel at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.70	(35)	0.67	(34)	0.67	(34)	0.66	(35)	0.65	(35)
2nd trial	0.71	(36)	0.67	(34)	0.67	(34)	0.64	(34)	0.64	(34)
3rd trial	0.72	(36)	0.68	(35)	0.67	(34)	0.66	(35)	0.65	(35)
4th trial	0.67	(34)	0.64	(32)	0.67	(34)	0.66	(35)	0.65	(35)
5th trial	0.68	(35)	0.66	(34)	0.67	(34)	0.64	(34)	0.64	(34)
Average	0.71	(35)	0.68	(34)	0.67	(34)	0.66	(37)	0.65	(35)

<u>**N.B:**</u> Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B22: Coefficient of Friction for TME 419 on Stainless Steel at 18 months

MC (%)	60		55		50		45		40	
1st trial	0.27	(14)	0.25	(13)	0.23	(12)	0.21	(12)	0.19	(11)
2nd trial	0.28	(15)	0.26	(14)	0.24	(13)	0.21	(12)	0.19	(11)
3rd trial	0.27	(14)	0.25	(13)	0.23	(12)	0.20	(11)	0.18	(10)
4th trial	0.28	(15)	0.26	(14)	0.24	(13)	0.21	(12)	0.19	(11)
5th trial	0.28	(15)	0.26	(14)	0.24	(13)	0.21	(12)	0.19	(11)
Average	0.28	(15)	0.26	(14)	0.24	(13)	0.21	(12)	0.19	(11)

Table B23: Coefficient of Friction for TME 419 on Galvanized at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.58	(28)	0.56	(26)	0.50	(25)	0.46	(24)	0.47	(24)
2nd trial	0.56	(26)	0.55	(25)	0.49	(24)	0.42	(23)	0.42	(23)
3rd trial	0.56	(26)	0.55	(25)	0.49	(24)	0.42	(23)	0.42	(23)
4th trial	0.28	(30)	0.60	(28)	0.51	(27)	0.48	(26)	0.48	(26)
5th trial	0.28	(28)	0.59	(27)	0.49	(25)	0.46	(24)	0.46	(24)
Average	0.58	(28)	0.56	(26)	0.49	(25)	0.46	(24)	0.45	(24)

Table B24: Coefficient of Friction for TME 419 on Wood at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.79	(39)	0.77	(37)	0.74	(36)	0.70	(35)	0.65	(34)
2nd trial	0.78	(39)	0.78	(38)	0.74	(36)	0.72	(36)	0.70	(35)
3rd trial	0.78	(38)	0.76	(36)	0.74	(36)	0.70	(35)	0.70	(35)
4th trial	0.79	(39)	0.77	(37)	0.74	(36)	0.70	(35)	0.65	(34)
5th trial	0.75	(35)	0.74	(34)	0.72	(34)	0.68	(34)	0.63	(33)
Average	0.79	(38)	0.78	(36)	0.74	(36)	0.70	(35)	0.67	(34)

N.B: Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

Table B25: Coefficient of Friction for TME 7 on Stainless Steel at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.23	(13)	0.21	(12)	0.21	(12)	0.21	(12)	0.18	(10)
2nd trial	0.23	(13)	0.21	(12)	0.21	(12)	0.20	(11)	0.20	(11)
3rd trial	0.24	(14)	0.21	(12)	0.21	(12)	0.20	(11)	0.18	(10)
4th trial	0.23	(13)	0.23	(13)	0.21	(12)	0.21	(12)	0.18	(10)
5th trial	0.23	(13)	0.21	(12)	0.21	(12)	0.21	(12)	0.29	(11)
Average	0.23	(14)	0.21	(12)	0.21	(12)	0.20	(12)	0.18	(10)

Table B26: Coefficient of Friction for TME 7 on Galvanized at 18 Months

MC (%)	60		55		50		45		40	
1st trial	0.49	(26)	0.47	(25)	0.45	(24)	0.43	(23)	0.39	(22)
2nd trial	0.49	(26)	0.47	(25)	0.45	(24)	0.43	(23)	0.39	(22)
3rd trial	0.48	(25)	0.46	(24)	0.45	(24)	0.43	(23)	0.38	(21)
4th trial	0.49	(26)	0.47	(25)	0.43	(23)	0.43	(23)	0.38	(21)
5th trial	0.49	(26)	0.47	(25)	0.46	(25)	0.45	(24)	0.39	(22)
Average	0.49	(26)	0.47	(25)	0.45	(24)	0. 43	(23)	0.39	(22)

Table B27: Coefficient of Friction for TME 7 on Wood at 18 Months

MC(%)	60		55		50		45		40	
1st trial	0.83	(40)	0.82	(39)	0.76	(37)	0.75	(36)	0.66	(34)
2nd trial	0.87	(42)	0.83	(40)	0.79	(38)	0.75	(36)	0.66	(34)
3rd trial	0.84	(41)	0.82	(39)	0.79	(38)	0.76	(37)	0.68	(35)
4th trial	0.88	(43)	0.84	(41)	0.82	(39)	0.79	(38)	0.68	(35)
5th trial	0.89	(45)	0.83	(40)	0.82	(39)	0.76	(37)	0.68	(35)
Average	0.89	(42)	0.83	(40)	0.79	(38)	0.75	(37)	0.68	(35)

<u>**N.B:**</u> Corresponding values of the angle of repose of the individual Coefficient of Friction are given in the bracket

APPENDIX C

Table C1: Coefficient of Internal Friction of TMS 30572 Varieties at 12 Months old

MC (%)	**60**	**55**	**50**	**45**	**40**
1st trial	0.44	0.45	0.54	0.56	0.56
2nd trial	0.43	0.46	0.56	0.54	0.57
3rd trial	0.45	0.46	0.55	0.56	0.57
4th trial	0.42	0.44	0.56	0.55	0.57
5th trial	0.45	0.47	0.56	0.56	0.56
Average	0.44	0.46	0.56	0.56	0.57

Table C2: Coefficient of Internal Friction of TME 419 Varieties at 12 Months old

MC (%)	**60**	**55**	**50**	**45**	**40**
1st trial	0.59	0.61	0.61	0.68	0.68
2nd trial	0.58	0.60	0.64	0.68	0.69
3rd trial	0.58	0.60	0.64	0.67	0.68
4th trial	0.57	0.59	0.63	0.67	0.68
5th trial	0.58	0.60	0.62	0.68	0.70
Average	0.58	0.60	0.63	0.68	0.69

Table C3: Coefficient of Internal Friction of TME 7 Varieties at 12 Months old

MC (%)	**60**	**55**	**50**	**45**	**40**
1st trial	0.39	0.40	0.55	0.57	0.57
2nd trial	0.39	0.40	0.54	0.56	0.58
3rd trial	0.41	0.41	0.54	0.57	0.58
4th trial	0.40	0.41	0.54	0.58	0.59
5th trial	0.30	0.41	0.52	0.56	0.58
Average	0.40	0.41	0.54	0.57	0.58

Table C4: Coefficient of Internal Friction of TMS 30572 Cultivar at 15 Months old

MC (%)	60	55	50	45	40
1st trial	0.40	0.40	0.54	0.56	0.58
2nd trial	0.39	0.41	0.54	0.57	0.59
3rd trial	0.39	0.42	0.54	0.57	0.58
4th trial	0.41	0.42	0.53	0.58	0.58
5th trial	0.41	0.41	0.55	0.56	0.57
Average	0.40	0.41	0.54	0.57	0.58

Table C5: Coefficient of Internal Friction of TME 419 Cultivar at 15 Months old

MC (%)	60	55	50	45	40
1st trial	0.58	0.63	0.64	0.61	0.65
2nd trial	0.62	0.60	0.62	0.65	0.67
3rd trial	0.60	0.65	0.66	0.67	0.69
4th trial	0.61	0.64	0.65	0.72	0.67
5th trial	0.59	0.63	0.63	0.65	0.67
Average	0.60	0.63	0.64	0.66	0.67

Table C6: Coefficient of Internal Friction of TME 7 at 15 Months old

MC (%)	60	55	50	45	40
1st trial	0.56	0.58	0.59	0.60	0.61
2nd trial	0.56	0.59	0.60	0.59	0.61
3rd trial	0.54	0.57	0.59	0.61	0.59
4th trial	0.58	0.58	0.59	0.60	0.61
5th trial	0.56	0.58	0.58	0.60	0.63
Average	**0.56**	**0.58**	**0.59**	**0.60**	**0.61**

Table C7: Coefficient of Internal Friction of TMS 30572 at 18 Months old

MC (%)	60	55	50	45	40
1st trial	0.51	0.51	0.55	0.56	0.58
2nd trial	0.48	0.55	0.55	0.59	0.61
3rd trial	0.49	0.51	0.55	0.58	0.61
4th trial	0.53	0.53	0.54	0.56	0.59
5th trial	0.51	0.55	0.56	0.56	0.58
Average	0.57	0.53	0.54	0.56	0.59

Table C8: Coefficient of Internal Friction of TME 419 Cultivar at 18 Months old

MC (%)	60	55	50	45	40
1st trial	0.49	0.52	0.53	0.54	0.65
2nd trial	0.31	0.57	0.53	0.54	0.64
3rd trial	0.49	0.57	0.55	0.56	0.67
4th trial	0.49	0.48	0.54	0.55	0.63
5th trial	0.48	0.53	0.54	0.55	0.64
Average	0.49	0.51	0.53	0.54	0.64

Table C9: Coefficient of Internal Friction of TME 7 Cultivar at 18 Months old

MC (%)	60	55	50	45	40
1st trial	0.5	0.52	0.54	0.54	0.51
2nd trial	0.5	0.52	0.54	0.54	0.56
3rd trial	0.5	0.53	0.54	0.54	0.58
4th trial	0.5	0.55	0.56	0.54	0.56
5th trial	0.5	0.52	0.52	0.55	0.55
Average	0.5	0.52	0.54	0.54	0.56

APPENDIX D

Table D1: Coefficient of Rolling Resistance of TMS 30572 with Periderm (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.3	0.12	(3^0)	0.20	(5^0)	0.24	(6^0)
2nd trial	3.0	0.16	(3^0)	0.21	(4^0)	0.26	(5^0)
3rd trial	2.5	0.17	(4^0)	0.26	(6^0)	0.31	(7^0)
4th trial	2.5	0.13	(3^0)	0.31	(5^0)	0.26	(6^0)
5th trial	2.0	0.10	(3^0)	0.14	(4^0)	0.17	(5^0)
Average		**0.14**	**(3^0)**	**0.22**	**(5^0)**	**0.25**	**(6^0)**

Table D2: Coefficient of Rolling Resistance of TMS 30572 with Cortex (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.2	0.08	(2^0)	0.15	(4^0)	0.24	(5^0)
2nd trial	2.9	0.10	(2^0)	0.15	(3^0)	0.20	(4^0)
3rd trial	2.4	0.13	(3^0)	0.21	(5^0)	0.25	(6^0)
4th trial	2.4	0.13	(3^0)	0.18	(4^0)	0.21	(5^0)
5th trial	1.9	0.07	(2^0)	0.10	(3^0)	0.13	(4^0)
Average		**0.10**	**(2^0)**	**0.16**	**(4^0)**	**0.20**	**(5^0)**

Table D3: Coefficient Rolling Resistance of TMS 30572 with Flesh (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	1.9	0.07	(2^0)	0.10	(3^0)	0.13	(4^0)
2nd trial	2.7	0.09	(2^0)	0.14	(3^0)	0.14	(3^0)
3rd trial	2.2	0.12	(3^0)	0.15	(4^0)	0.19	(5^0)
4th trial	2.2	0.08	(2^0)	0.12	(3^0)	0.15	(4^0)
5th trial	1.7	0.06	(2^0)	0.09	(3^0)	0.12	(4^0)
Average		**0.08**	**(2^0)**	**0.12**	**(3^0)**	**0.15**	**(4^0)**

Table D4: Coefficient of Rolling Resistance of TME 419 with Periderm (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	3.1	0.16	(3^0)	0.21	(4^0)	0.20	(5^0)
2nd trial	3.1	0.16	(3^0)	0.21	(4^0)	0.27	(5^0)
3rd trial	2.8	0.15	(3^0)	0.24	(5^0)	0.29	(6^0)
4th trial	2.7	0.14	(3^0)	0.19	(4^0)	0.24	(5^0)
5th trial	2.4	0.08	(2^0)	0.17	(4^0)	0.21	(5^0)
Average		**0.14**	**(3^0)**	**0.20**	**(4^0)**	**0.25**	**(5^0)**

Table D5: Coefficient of Rolling Resistance of TME 419 with Cortex (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.9	0.10	(2^0)	0.20	(4^0)	0.20	(4^0)
2nd trial	3.0	0.15	(3^0)	0.21	(4^0)	0.21	(4^0)
3rd trial	2.7	0.19	(2^0)	0.14	(3^0)	0.24	(4^0)
4th trial	2.6	0.14	(3^0)	0.18	(4^0)	0.18	(4^0)
5th trial	2.7	0.14	(3^0)	0.19	(4^0)	0.19	(4^0)
Average		**0.12**	**(3^0)**	**0.18**	**(4^0)**	**0.20**	**(4^0)**

Table D6: Coefficient of Rolling Resistance of TME 419 with Flesh (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.7	0.09	(2^0)	0.14	(3^0)	0.14	(3^0)
2nd trial	2.8	0.10	(2^0)	0.15	(3^0)	0.20	(4^0)
3rd trial	2.6	0.09	(2^0)	0.14	(3^0)	0.18	(4^0)
4th trial	2.4	0.08	(2^0)	0.13	(3^0)	0.17	(4^0)
5th trial	2.7	0.09	(2^0)	0.09	(2^0)	0.14	(3^0)
Average		**0.09**	**(2^0)**	**0.13**	**(3^0)**	**0.17**	**(4^0)**

Table D7: Coefficient of Rolling Resistance of TME 7 with Periderm (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	3.1	0.16	(3^0)	0.27	(5^0)	0.33	(6^0)
2nd trial	2.95	0.15	(3^0)	0.31	(6^0)	0.36	(7^0)
3rd trial	2.7	0.14	(3^0)	0.23	(6^0)	0.28	(6^0)
4th trial	2.5	0.13	(3^0)	0.26	(6^0)	0.31	(7^0)
5th trial	2.4	0.17	(4^0)	0.25	(6^0)	0.29	(7^0)
Average		**0.15**	**(3^0)**	**0.26**	**(6^0)**	**0.30**	**(5^0)**

Table D8: Coefficient of Rolling Resistance of TME 7 with Cortex (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	3.0	0.16	(3^0)	0.21	(4^0)	0.33	(5^0)
2nd trial	2.9	0.15	(3^0)	0.25	(5^0)	0.36	(6^0)
3rd trial	2.6	0.09	(2^0)	0.18	(4^0)	0.23	(5^0)
4th trial	2.4	0.13	(3^0)	0.21	(5^0)	0.25	(6^0)
5th trial	2.3	0.12	(3^0)	0.12	(4^0)	0.24	(6^0)
Average		**0.13**	**(3^0)**	**0.19**	**(4^0)**	**0.26**	**(6^0)**

Table D9: Coefficient of Rolling Resistance of TME 7 with Flesh (12 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.8	0.10	(2^0)	0.15	(3^0)	0.20	(4^0)
2nd trial	2.7	0.09	(2^0)	0.14	(3^0)	0.24	(5^0)
3rd trial	2.4	0.08	(2^0)	0.13	(3^0)	0.17	(4^0)
4th trial	2.2	0.08	(2^0)	0.15	(4^0)	0.15	(4^0)
5th trial	2.05	0.07	(2^0)	0.11	(3^0)	0.18	(5^0)
Average		**0.08**	**(2^0)**	**0.14**	**(3^0)**	**0.19**	**(4^0)**

Table D10: Coefficient of Rolling Resistance of TMS 30572 with Periderm (15months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	3.3	0.23	(4^0)	0.46	(8^0)	0.52	(9^0)
2nd trial	2.9	0.25	(5^0)	0.36	(7^0)	0.41	(8^0)
3rd trial	3.0	0.26	(5^0)	0.26	(8^0)	0.32	(9^0)
4th trial	2.8	0.20	(4^0)	0.29	(7^0)	0.39	(8^0)
5th trial	2.7	0.24	(5^0)	0.28	(7^0)	0.40	(8^0)
Average		**0.24**	**(5^0)**	**0.33**	**(7^0)**	**0.41**	**(8^0)**

Table D11: Coefficient Rolling Resistance of TMS 30572 with Cortex (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.9	0.25	(5^0)	0.24	(7^0)	0.41	(8^0)
2nd trial	2.8	0.24	(5^0)	0.29	(6^0)	0.34	(7^0)
3rd trial	2.9	0.20	(4^0)	0.30	(6^0)	0.41	(8^0)
4th trial	2.7	0.20	(4.5^0)	0.28	(6^0)	0.33	(7^0)
5th trial	2.6	0.21	(4.5^0)	0.26	(6^0)	0.31	(7^0)
Average		**0.22**	**(4.6^0)**	**0.27**	**(6^0)**	**0.36**	**(7^0)**

Table D12: Coefficient of Rolling Resistance of TMS 30572 with Flesh (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.65	0.19	(4^0)	0.26	(5.5^0)	0.28	(6^0)
2nd trial	2.55	0.18	(4^0)	0.23	(5^0)	0.31	(7^0)
3rd trial	2.65	0.16	(3.5^0)	0.23	(5^0)	0.28	(6^0)
4th trial	2.45	0.17	(4^0)	0.21	(5^0)	0.21	(5^0)
5th trial	2.35	0.14	(3.5^0)	0.21	(5^0)	0.25	(6^0)
Average		**0.17**	**(4^0)**	**0.23**	**(5^0)**	**0.26**	**(6^0)**

Table D13: Coefficient of Rolling Resistance of TME 419 with Periderm (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.8	0.20	(4^0)	0.24	(5^0)	0.29	(6^0)
2^{nd} trial	2.2	0.13	(3.5^0)	0.19	(5^0)	0.23	(6^0)
3^{rd} trial	1.75	0.14	(4.5^0)	0.16	(6^0)	0.25	(8^0)
4^{th} trial	2.2	0.15	(4^0)	0.19	(5^0)	0.23	(6^0)
5^{th} trial	2.45	0.17	(4^0)	0.21	(5^0)	0.26	(6^0)
Average		**0.16**	**(4^0)**	**0.20**	**(5^0)**	**0.25**	**(6^0)**

Table D14: Coefficient of Rolling Resistance of TME 419 with Cortex (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.7	0.14	(3^0)	0.19	(4^0)	0.24	(5^0)
2^{nd} trial	2.1	0.11	(3^0)	0.15	(4^0)	0.18	(5^0)
3^{rd} trial	1.65	0.26	(4^0)	0.14	(5^0)	0.14	(5^0)
4^{th} trial	2.1	0.11	(3^0)	0.14	(4^0)	0.14	(4^0)
5^{th} trial	2.35	0.12	(3^0)	0.16	(4^0)	0.21	(5^0)
Average		**0.15**	**(3^0)**	**0.16**	**(6^0)**	**0.18**	**(5^0)**

Table D15: Coefficient of Rolling Resistance of TME 419 with Flesh (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.5	0.09	(2^0)	0.13	(3^0)	0.17	(4^0)
2^{nd} trial	1.9	0.07	(2^0)	0.10	(3^0)	0.13	(4^0)
3^{rd} trial	1.5	0.07	(2.5^0)	0.09	(3.5^0)	0.13	(5^0)
4^{th} trial	1.9	0.07	(2^0)	0.10	(3^0)	0.13	(4^0)
5^{th} trial	1.2	0.07	(2^0)	0.11	(3^0)	0.15	(4^0)
Average		**0.07**	**(2^0)**	**0.11**	**(3^0)**	**0.14**	**(4^0)**

Table D16: Coefficient of Rolling Resistance of TME 7 with Periderm (15months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.4	0.17	(4^0)	0.25	(6^0)	0.29	(7^0)
2^{nd} trial	2.3	0.16	(4^0)	0.24	(6^0)	0.32	(8^0)
3^{rd} trial	2.2	0.13	(3.5^0)	0.19	(5^0)	0.31	(8^0)
4^{th} trial	2.2	0.15	(4^0)	0.23	(6^0)	0.27	(7^0)
5^{th} trial	2.25	0.16	(4.5^0)	0.25	(7^0)	0.25	(7^0)
Average		**0.15**	**(4^0)**	**0.23**	**(6^0)**	**0.29**	**(7^0)**

Table D17: Coefficient of Rolling Resistance of TME 7 with Cortex (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.3	0.12	(3^0)	0.20	(5^0)	0.24	(6^0)
2^{nd} trial	2.2	0.12	(3^0)	0.19	(5^0)	0.27	(7^0)
3^{rd} trial	2.05	0.12	(3^0)	0.18	(5^0)	0.22	(6^0)
4^{th} trial	2.1	0.11	(3^0)	0.22	(6^0)	0.22	(6^0)
5^{th} trial	2.05	0.11	(3^0)	0.22	(6^0)	0.26	(7^0)
Average		**0.12**	**(3^0)**	**0.20**	**(5^0)**	**0.24**	**(6^0)**

Table D18: Coefficient of Rolling Resistance of TME 7 with Flesh (15 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.1	0.07	(3^0)	0.11	(3^0)	0.18	(5^0)
2^{nd} trial	2.0	0.09	(2.5^0)	0.14	(4^0)	0.27	(6^0)
3^{rd} trial	1.17	0.08	(2.5^0)	0.13	(4^0)	0.19	(6^0)
4^{th} trial	1.19	0.07	(2^0)	0.17	(5^0)	0.17	(5^0)
5^{th} trial	1.17	0.06	(2.2^0)	0.12	(4^0)	0.15	(5^0)
Average		**0.07**	**(2^0)**	**0.13**	**(4^0)**	**0.18**	**(5^0)**

Table D19: Coefficient of Rolling Resistance of TMS 30572 with Periderm (18months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.45	0.15	(3.5^0)	0.19	(4.5^0)	0.21	(5^0)
2nd trial	1.85	0.11	(5.5^0)	0.15	(4.5^0)	0.18	(5.5^0)
3rd trial	2.5	0.17	(4^0)	0.22	(5^0)	0.24	(5.5^0)
4th trial	2.2	0.14	(4^0)	0.15	(4.5^0)	0.20	(6^0)
5th trial	1.95	0.13	(3^0)	0.17	(4^0)	0.19	(4.5^0)
Average		**0.14**	**(3.6^0)**	**0.18**	**(5^0)**	**0.20**	**(5.3^0)**

Table D20: Coefficient of Rolling Resistance of TME 30572 with Cortex (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.35	0.12	(3^0)	0.16	(4^0)	0.18	(4.5^0)
2nd trial	1.75	0.09	(3^0)	0.12	(4^0)	0.12	(4^0)
3rd trial	2.2	0.13	(3.5^0)	0.17	(4.5^0)	0.19	(5^0)
4th trial	1.85	0.10	(3^0)	0.13	(4^0)	0.18	(5.5^0)
5th trial	2.3	0.10	(2.5^0)	0.12	(3^0)	0.16	(4^0)
Average		**0.11**	**(3^0)**	**0.14**	**(4^0)**	**0.17**	**(5^0)**

Table D21: Coefficient of Rolling Resistance of TME 30572 with Flesh (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.1	0.09	(2.5^0)	0.13	(3.5^0)	0.13	(3.5^0)
2nd trial	1.55	0.06	(2.5^0)	0.11	(4^0)	0.09	(3.5^0)
3rd trial	2.0	0.10	(3^0)	0.14	(4^0)	0.14	(4^0)
4th trial	1.7	0.07	(2.5^0)	0.10	(3.5^0)	0.13	(4.5^0)
5th trial	2.1	0.07	(2^0)	0.09	(3.5^0)	0.11	(3^0)
Average		**0.08**	**(3^0)**	**0.11**	**(3.5^0)**	**0.12**	**(4^0)**

Table D22: Coefficient of Rolling Resistance of TME 419 with Periderm (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.5	0.18	(4^0)	0.31	(7^0)	0.40	(9^0)
2nd trial	2.3	0.22	(5.5^0)	0.24	(6^0)	0.36	(9^0)
3rd trial	1.8	0.16	(5^0)	0.25	(6^0)	0.28	(9^0)
4th trial	2.2	0.21	(5.5^0)	0.23	(6^0)	0.31	(8^0)
5th trial	1.7	0.11	(4^0)	0.18	(6^0)	0.30	(10^0)
Average		**0.18**	**(5^0)**	**0.23**	**(6^0)**	**0.33**	**(9^0)**

Table D23: Coefficient of Rolling Resistance of TME 419 with Cortex (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.5	0.22	(5^0)	0.26	(6^0)	0.40	(9^0)
2nd trial	2.2	0.15	(4^0)	0.21	(5.5^0)	0.33	(8.5^0)
3rd trial	1.7	0.12	(4^0)	0.16	(5.5^0)	0.22	(7.5^0)
4th trial	2.1	0.17	(4.5^0)	0.22	(6^0)	0.30	(8.0^0)
5th trial	1.6	0.11	(4^0)	0.14	(5^0)	0.21	(7.5^0)
Average		**0.15**	**(4^0)**	**0.20**	**(7^0)**	**0.29**	**(8^0)**

Table D24: Coefficient of Rolling Resistance of TME 419 with Flesh (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1st trial	2.3	0.12	(3^0)	0.20	(5^0)	0.20	(5^0)
2nd trial	2.05	0.11	(3^0)	0.14	(4^0)	0.22	(6^0)
3rd trial	1.55	0.08	(3^0)	0.12	(4.5^0)	0.16	(6^0)
4th trial	1.95	0.10	(3^0)	0.15	(4.5^0)	0.20	(6^0)
5th trial	1.45	0.05	(2^0)	0.07	(3^0)	0.15	(6^0)
Average		**0.09**	**(3^0)**	**0.14**	**(4^0)**	**0.19**	**(6^0)**

Table D25: Coefficient of Rolling Resistance of TME 7 with Periderm (18months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	3.3	0.19	(3^0)	0.23	(4^0)	0.29	(5^0)
2^{nd} trial	2.9	0.15	(3^0)	0.20	(4^0)	0.30	(6^0)
3^{rd} trial	3.0	0.16	(3^0)	0.21	(4^0)	0.32	(6^0)
4^{th} trial	2.8	0.20	(4^0)	0.20	(4^0)	0.29	(6^0)
5^{th} trial	2.7	0.19	(4^0)	0.19	(4^0)	0.28	(6^0)
Average		**0.17**	**(3^0)**	**0.19**	**(4^0)**	**0.29**	**(6^0)**

Table D26: Coefficient of Rolling Resistance of TME 7 with Cortex (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.3	0.16	(4^0)	0.16	(4^0)	0.24	(6^0)
2^{nd} trial	2.2	0.15	(4^0)	0.19	(5^0)	0.23	(6^0)
3^{rd} trial	1.95	0.14	(4^0)	0.13	(4^0)	0.24	(7^0)
4^{th} trial	2.3	0.12	(3^0)	0.16	(4^0)	0.24	(6^0)
5^{th} trial	1.95	0.14	(4^0)	0.13	(4^0)	0.27	(8^0)
Average		**0.14**	**(4^0)**	**0.15**	**(4^0)**	**0.25**	**(7^0)**

Table D27: Coefficient of Rolling Resistance of TME 7 with Flesh (18 months)

	R (cm)	Stainless		Galvanize		Wood	
1^{st} trial	2.0	0.11	(3.2^0)	0.14	(4^0)	0.21	(6^0)
2^{nd} trial	1.9	0.09	(2.8^0)	0.13	(4^0)	0.20	(6^0)
3^{rd} trial	1.7	0.08	(2.7^0)	0.11	(3.8^0)	0.21	(7^0)
4^{th} trial	2.0	0.09	(2.8^0)	0.11	(3.3^0)	0.21	(6^0)
5^{th} trial	1.7	0.10	(3.2^0)	0.11	(3.8^0)	0.21	(7^0)
Average		**0.09**	**(3^0)**	**0.12**	**(4^0)**	**0.21**	**(6^0)**

APPENDIX E

Table E1: Compressive Strength Properties of TMS 30572 at 12 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	0.9242	6.8796	8.996
2	70	0.8749	7.7484	8.168
3	70	1.0049	8.0519	3.665
4	70	0.7413	5.0861	8.324
5	70	0.8734	5.5662	11.491
MEAN		**0.88374**	**6.66644**	**8.1288**
SD		**0.0959**	**7432**	**2.83**
1	65	0.7	3.5449	10.319
2	65	0.8102	5.7432	11.717
3	65	0.7208	3.3573	6.704
4	65	0.978	8.3033	6.133
5	65	0.8324	7.3077	11.508
MEAN		**0.80828**	**5.65128**	**9.2762**
SD		**0.1104**	**2.2071**	**2.67**
1	60	0.7202	5.9906	9.8434
2	60	0.8188	6.0085	6.3237
3	60	0.827	5.8872	4.2971
4	60	0.567	2.519	5.0232
5	60	0.7331	4.1601	5.6972
MEAN		**0.73322**	**4.91308**	**6.23692**
SD		**0.1048**	**1.5499**	**2.153**
1	55	0.6607	5.00	5.00
2	55	0.7886	7.6363	4.1299
3	55	0.8686	7.7328	5.696
4	55	0.8307	6.6372	6.7548
5	55	0.7538	4.4573	7.3199
MEAN		**0.78048**	**6**	**6**
SD		**0.0797**	**1.4285**	**1.3237**
1	50	0.5704	4.4292	4.6005
2	50	0.5295	3.2129	5.1552
3	50	0.675	5.6234	4.6294
4	50	0.7344	6.9345	6.2754
5	50	0.5206	3.745	3.3897
MEAN		**0.60598**	**4.789**	**4.81004**
SD		**0.0944**	**1.4966**	**1.0441**

Table E2: Compressive Strength Properties of TMS 30572 at 15 MAP

Sample	MC (%)	Stress @ Peak (N/mm^2)	Energy to Break (N.m)	Youngs Modulus (N/mm^2)
1	70	1.14	8.406	5.5764
2	70	1.17	11.628	4.7685
3	70	1.27	10.987	5.9066
4	70	1.01	6.549	6.1821
5	70	1.05	8.487	6.3821
Mean		**1.128**	**9.2114**	**5.76314**
SD		**0.09173876**	**1.857660313**	**0.566286198**
1	65	0.94	8.8214	5.8032
2	65	0.89	5.2265	6.7179
3	65	1.08	7.7661	5.0865
4	65	0.85	6.8079	3.0167
5	65	0.91	6.3817	5.7484
Mean		**0.934**	**7.00072**	**5.27454**
SD		**0.078638413**	**1.222203267**	**1.242619273**
1	60	0.77	6.5086	3.5947
2	60	1.09	9.4101	6.2528
3	60	1.14	7.5327	7.2873
4	60	0.92	6.6198	5.4098
5	60	1.01	7.2849	6.1054
Mean		**0.986**	**7.47122**	**5.73**
SD		**0.131240238**	**1.043963971**	**1.224864272**
1	55	0.7	4.3624	4.8558
2	55	0.87	5.963	7
3	55	0.8	4.1651	5.118
4	55	0.99	6.6878	6.814
5	55	1.07	8.7738	5.1884
Mean		**0.886**	**5.99042**	**5.77376**
SD		**0.131848398**	**1.686210969**	**0.888731711**
1	50	0.82	5.61	4.9979
2	50	1.04	6.967	5.3401
3	50	0.96	7.329	5.9591
4	50	1.26	12.117	4.9239
5	50	0.88	5.693	6.6132
Mean		**0.992**	**7.5432**	**5.56684**
SD		**0.153153518**	**2.385708985**	**0.638312267**

Table E3: Compressive Strength Properties of TMS 30572 at 18 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	0.8573	4.4563	4.4573
2	70	0.9167	7.1508	4.269
3	70	0.8751	5.2653	7.1103
4	70	0.7308	3.9235	6.4116
5	70	0.5694	3.2186	6.1653
MEAN		**0.7899**	**4.8029**	**5.6827**
SD		**0.1414**	**1.5108**	**1.2552**
1	65	0.7491	3.432	7.866
2	65	0.9145	4.7228	10.647
3	65	0.8354	5.1694	3.969
4	65	0.7963	4.5678	5.869
5	65	0.6687	3.5266	5.439
6	65	0.7813	5.8789	3.904
MEAN		**0.7909**	**4.5496**	**6.282**
SD		**0.0825**	**0.9463**	**2.586**
1	60	0.8552	5.7128	8.035
2	60	0.8224	4.6903	10.288
3	60	0.6762	4.0141	7.789
4	60	1.0117	6.1161	7.532
5	60	0.8427	4.9549	6.605
MEAN	**0.8416**		**5.0976**	**8.05**
SD	**0.1192**		**0.8331**	**1.363**
1	55	0.9531	6.2833	8.104
2	55	0.9982	5.1067	9.704
3	55	0.8917	3.9933	9.412
4	55	0.7862	5.2042	5.365
5	55	0.967	4.956	11.607
MEAN		**0.9192**	**5.1087**	**8.838**
SD		**0.0839**	**0.8149**	**2.31**
1	50	0.7545	3.8514	7.223
2	50	0.9262	5.5705	8.3475
3	50	0.7589	4.924	7.4704
4	50	0.7976	4.7199	8.0101
5	50	1.0711	6.3598	9.0959
MEAN		**0.8616**	**5.0851**	**8.0294**
SD		**0.1362**	**0.941**	**0.7419**

Table E4: Compressive Strength Properties of TME 419 at 12 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	1.0243	9.345	7.554
2	70	1.0175	8.134	10.16
3	70	1.0035	10.119	4.147
4	70	1.098	6.789	8.371
5	70	1.1214	8.669	5.997
MEAN		**1.05294**	**8.6112**	**7.2458**
SD		**0.0488**	**1.261**	**2.292**
1	65	0.845	7.0521	5.6363
2	65	0.7126	5.7904	6.1143
3	65	0.8169	7.1852	5.385
4	65	0.9139	6.9793	5.3175
5	65	0.5633	3.0045	4.6649
MEAN		**0.77034**	**6.0023**	**5.4236**
SD		**0.1365**	**1.7669**	**0.527**
1	60	0.7954	7.5225	8.1616
2	60	0.734	3.6917	6.9536
3	60	0.5833	3.1553	4.8262
4	60	0.9208	8.6242	6.9929
5	60	0.8582	6.4199	6.0637
MEAN		**0.77834**	**5.88272**	**6.5996**
SD		**0.1294**	**2.3839**	**1.2401**
1	55	0.6213	4.9954	4.3895
2	55	0.7139	8.4834	5.0803
3	55	0.7508	6.91	5.6229
4	55	0.5928	4.2517	4.9182
5	55	0.7398	5.836	4.4739
MEAN		**0.68372**	**6.0953**	**4.89696**
SD		**0.072**	**1.6615**	**0.4994**
1	50	0.7409	5.7033	4.1513
2	50	0.3811	2.6004	2.6288
3	50	0.483	3.0096	3.3424
4	50	0.6727	5.3148	2.9654
5	50	0.6561	5.6032	4.7947
MEAN		**0.58676**	**4.44626**	**3.57652**
SD		**0.1492**	**1.5119**	**0.8861**

Table E5: Compressive Strength Properties of TME 419 at 15 MAP

Sample	MC (%)	Peak Stress (N/mm^2)	Energy to Break (N.m)	Youngs Modulus (N/mm^2)
1	70	0.95	7.4772	6.0928
2	70	0.92	7.2429	7.2812
3	70	1.07	9.4176	3.0728
4	70	1.2	9.8027	7.6253
5	70	0.83	4.0538	5.8738
Mean		**0.994**	**7.59884**	**5.98918**
SD		**0.128467895**	**2.043217316**	**1.60471345**
1	65	1.18	9.45	6.5099
2	65	1.33	12.388	7.3324
3	65	1.02	8.949	6.6355
4	65	1.11	9.386	4.1882
5	65	1.09	8.366	4.3956
Mean		**1.146**	**9.7078**	**5.81232**
SD		**0.10518555**	**1.394969018**	**1.274342788**
1	60	0.91	3.475	4.5951
2	60	1.25	9.833	5.1643
3	60	1.21	10.15	5.6222
4	60	1	6.319	4.717
5	60	1.25	10.413	5.7759
Mean		**1.124**	**8.038**	**5.1749**
SD		**0.14164745**	**2.723935535**	**0.470580726**
1	55	1.23	11.994	5.4194
2	55	1.13	9.349	6.6821
3	55	0.98	7.405	3.9348
4	55	1.2	10.806	8.3055
5	55	1.17	9.441	3.4426
Mean		**1.142**	**9.799**	**5.55688**
SD		**0.087498571**	**1.542334205**	**1.785567481**
1	50	0.99	7.0825	4.8589
2	50	1.06	8.3973	4.483
3	50	1.14	7.573	5.4852
4	50	1.13	6.1882	5.2269
5	50	0.93	5.5276	4.2066
Mean		**1.05**	**6.95372**	**4.85212**
SD		**0.080746517**	**1.010332059**	**0.467812344**

Table E6: Compressive Strength Properties of TME 419 at 18 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	1.2891	10.561	9.148
2	70	1.1752	8.59	7.181
3	70	1.3212	11.022	4.172
4	70	1.0658	7.984	5.804
5	70	1.3317	9.626	10.618
MEAN		**1.2366**	**9.557**	**7.384**
SD		**0.1139**	**1.282**	**2.57**
1	65	0.9245	5.821	5.1447
2	65	1.0042	7.93	5.8987
3	65	1.0832	8.053	7.8421
4	65	1.2486	10.374	5.3723
5	65	1.0807	9.45	5.1706
MEAN		**1.0682**	**8.326**	**5.8857**
SD		**0.1201**	**1.729**	**1.1349**
1	60	1.0608	8.951	6.358
2	60	1.2909	9.834	10.089
3	60	0.8736	6.834	3.783
4	60	1.3351	10.959	13.375
5	60	1.2744	8.74	4.634
MEAN		**1.1669**	**9.064**	**7.648**
SD		**0.1953**	**1.523**	**4.014**
1	55	1.1775	8.98	5.4794
2	55	0.9762	6.526	9.4087
3	55	1.0636	7.53	6.1856
4	55	1.3881	11.566	5.0364
5	55	1.0948	8.85	8.1161
MEAN		**1.14**	**8.691**	**6.8452**
SD		**0.1563**	**1.898**	**1.8546**
1	50	1.3682	13.176	11.479
2	50	1.206	8.793	4.856
3	50	1.1637	9.909	6.078
4	50	0.9464	7.383	7.107
5	50	1.2379	9.858	6.014
MEAN		**1.1845**	**9.824**	**7.107**
SD		**0.1534**	**2.137**	**2.571**

Table E7: Compressive Strength Properties of TME 7 at 12 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	1.0375	6.3668	5.1237
2	70	0.8949	4.6495	6.0634
3	70	0.7836	3.0772	4.5921
4	70	0.9593	5.2277	7.3514
5	70	0.8797	4.7353	8.5404
MEAN		**0.911**	**4.8113**	**6.3342**
S D		**0.0946**	**1.1866**	**1.1683**
1	65	0.9862	8.1307	6.9339
2	65	1.1179	9.9285	5.5632
3	65	1.0158	7.6611	4.7248
4	65	0.8454	4.9705	4.0501
5	65	0.7446	4.0791	6.0174
MEAN		**0.94198**	**6.95398**	**5.45788**
S D		**0.1472**	**2.3943**	**1.1205**
1	60	0.8872	5.601	4.452
2	60	0.9309	4.868	7.262
3	60	1.2959	11.91	5.599
4	60	0.9453	7.779	10.396
5	60	1.2199	10.722	7.087
MEAN		**1.05584**	**8.176**	**6.9592**
S D		**0.1876**	**3.088**	**2.239**
1	55	0.4908	4.4009	3.2188
2	55	0.5009	3.1332	4.78
3	55	0.4284	3.404	2.6382
4	55	0.5192	3.4935	3.7414
5	55	0.6027	4.6098	4.7495
MEAN	**55**	**0.5084**	**3.80828**	**3.82558**
S D		**0.6268**	**0.6542**	**0.942**
1	50	0.5994	4.6064	5.3402
2	50	0.6298	5.3868	5
3	50	0.3177	2.3018	3.712
4	50	0.3757	3.0287	2.0036
5	50	0.1297	0.8125	0.4796
MEAN		**0.41046**	**3.22724**	**3.22256**
S D		**0.2076**	**1.823**	**1.9729**

Table E8: Compressive Strength Properties of TME 7 at 15 MAP

Sample	MC (%)	Stress @ Peak (N/mm^2)	Energy to Break (N.m)	Youngs Modulus (N/mm^2)
1	70	1.74	14.562	5.6845
2	70	1.1	8.058	5.4511
3	70	0.78	6.316	2.313
4	70	0.7	5.038	2.7613
5	70	1.06	7.855	5.2934
Mean		**1.076**	**8.3658**	**4.30066**
SD		**0.366256741**	**3.287080309**	**1.45220381**
1	65	0.98	6.589	5.654
2	65	1.18	5.043	4.6281
3	65	1.21	10.682	5.0643
4	65	0.99	4.566	6.4108
5	65	1.29	11.7	6.1367
Mean		**1.13**	**7.716**	**5.57878**
SD		**0.123773988**	**2.932813325**	**0.65995033**
1	60	0.79	5.6883	3.1095
2	60	1.25	7.9405	6.9511
3	60	0.76	5.1561	3.1496
4	60	0.93	4.0051	3.3784
5	60	1	5.7237	5.6271
Mean		**0.946**	**5.70274**	**4.44314**
SD		**0.175795336**	**1.279766737**	**1.566980363**
1	55	1.12	9.975	4.1397
2	55	1.06	3.703	5.3774
3	55	1.29	11.302	3.5794
4	55	1.24	11.085	3.3986
5	55	1.03	4.17	4.7374
Mean		**1.148**	**8.047**	**4.2465**
SD		**0.10107423**	**3.389487218**	**0.734204424**
1	50	0.76	4.5036	3.5156
2	50	0.96	3.3028	4.452
3	50	1.13	8.324	5.6631
4	50	1.1	8.8066	4.5067
5	50	0.99	5.01	5.4417
Mean		**0.988**	**5.9894**	**4.71582**
SD		**0.130751673**	**2.180441174**	**0.771764393**

Table E9: Compressive Strength Properties of TME 7 at 18 MAP

SAMPLE	MC (%)	PEAK STRESS (N/mm^2)	ENERGY TO BREAK (N.m)	YOUNG MODULUS (N/mm^2)
1	70	1.3574	9.142	8.295
2	70	1.2183	8.434	7.662
3	70	1.1637	8.191	9.909
4	70	1.0633	4.412	7.442
5	70	1.3097	7.641	8.614
MEAN		**1.2225**	**7.564**	**8.384**
SD		**0.1169**	**1.843**	**0.974**
1	65	1.3123	9.271	7.9789
2	65	1.1575	5.005	7.3262
3	65	1.7005	13.401	5.8338
4	65	1.691	8.209	5.1311
5	65	1.1455	4.295	7.1804
MEAN		**1.297**	**8.036**	**6.6901**
SD		**0.2355**	**3.658**	**1.1694**
1	60	0.9907	3.8651	6.582
2	60	0.9897	4.3901	8.3233
3	60	1.1275	5.9307	7.1363
4	60	1.0704	5.7525	7.9909
5	60	1.1809	7.841	7.2758
MEAN		**1.0718**	**5.5559**	**7.4617**
SD		**0.0841**	**1.5507**	**0.6958**
1	55	1.0356	4.269	8.3823
2	55	1.1446	8.441	6.5572
3	55	1.1067	7.429	7.555
4	55	1.5031	10.065	6.0667
5	55	1.1036	4.74	5.6824
MEAN		**1.1787**	**6.989**	**6.8487**
SD		**0.1856**	**2.46**	**1.1076**
1	50	1.153	7.7626	8.9843
2	50	1.1579	7.7895	7.7933
3	50	1.0121	4.7552	5.8279
4	50	1.2127	9.0642	5.1811
5	50	1.2155	6.5092	9.2531
MEAN		**1.1502**	**7.1761**	**7.408**
SD		**0.0826**	**1.6272**	**1.8367**

APPENDIX F

Table F1: Analysis of Variance of Influence of Age on TMS 30572 Cassava Cultivar

Parameter		Sum of Squares	Df	Mean Square	F	Sig.
Length (mm)	Between Groups	36724.973	2	18362.487	2.253	.109
	Within Groups	1198172.020	147	8150.830		
Mass (g)	Between Groups	1135762.709	2	567881.355	14.087	.000
	Within Groups	5925862.213	147	40311.988		
PPW (%)	Between Groups	18.064	2	9.032	.449	.639
	Within Groups	2956.416	147	20.112		
Volume (cm^3)	Between Groups	2056785.453	2	1028392.73	25.721	.000
	Within Groups	5877330.340	147	39981.839		
D_H (mm)	Between Groups	434.332	2	217.166	2.308	.103
	Within Groups	13830.442	147	94.085		
D_M (mm)	Between Groups	1546.301	2	773.151	7.835	.001
	Within Groups	14505.296	147	98.675		
D_T (mm)	Between Groups	430.322	2	215.161	3.042	.051
	Within Groups	10398.857	147	70.741		
P_H (mm)	Between Groups	148.968	2	74.484	171.318	.000
	Within Groups	63.911	147	.435		
P_M (mm)	Between Groups	104.927	2	52.463	120.075	.000
	Within Groups	64.227	147	.437		
P_T (mm)	Between Groups	46.198	2	23.099	108.156	.000
	Within Groups	31.395	147	.214		
Density (g/cm^3)	Between Groups	1.923	2	.961	17.343	.000
	Within Groups	8.148	147	.055		

Table F2: Analysis of Variance of Influence of Age on TME 419 Cassava Cultivar

Parameter		Sum of Squares	Df	Mean Square	F	Sig.
Length (mm)	Between Groups	48670.680	2	24335.340	2.597	.078
	Within Groups	1377661.560	147	9371.847		
Mass (g)	Between Groups	1466784.107	2	733392.053	14.417	.000
	Within Groups	7478086.925	147	50871.340		
PPW (%)	Between Groups	701.252	2	350.626	9.157	.000
	Within Groups	5628.580	147	38.290		
Volume (cm^3)	Between Groups	1253758.493	2	626879.247	16.365	.000
	Within Groups	5631055.780	147	38306.502		
D_H (mm)	Between Groups	485.129	2	242.564	2.436	.091
	Within Groups	14638.314	147	99.580		
D_M (mm)	Between Groups	80.460	2	40.230	.373	.689
	Within Groups	15855.273	147	107.859		
D_T (mm)	Between Groups	103.200	2	51.600	.625	.537
	Within Groups	12135.544	147	82.555		
P_H (mm)	Between Groups	64.177	2	32.088	121.521	.000
	Within Groups	38.816	147	.264		
P_M (mm)	Between Groups	52.452	2	26.226	106.531	.000
	Within Groups	36.189	147	.246		
P_T (mm)	Between Groups	33.886	2	16.943	88.553	.000
	Within Groups	28.126	147	.191		
Density (g/cm^3)	Between Groups	.303	2	.152	2.147	.120
	Within Groups	10.381	147	.071		

Table F3: Analysis of Variance of Influence of Age on TME 7 Cassava Cultivar

Parameter		Sum of Squares	Df	Mean Square	F	Sig.
Length (mm)	Between Groups	195264.160	2	97632.080	12.455	.000
	Within Groups	1152333.500	147	7839.003		
Mass (g)	Between Groups	1903593.503	2	951796.751	15.146	.000
	Within Groups	9237967.440	147	62843.316		
PPW (%)	Between Groups	448.780	2	224.390	10.731	.000
	Within Groups	3073.890	147	20.911		
Volume (cm^3)	Between Groups	1721375.413	2	860687.707	22.472	.000
	Within Groups	5630077.980	147	38299.850		
D_H (mm)	Between Groups	963.770	2	481.885	2.990	.053
	Within Groups	23688.253	147	161.145		
	Total	24652.023	149			
D_M (mm)	Between Groups	2554.661	2	1277.330	8.331	.000
	Within Groups	22538.061	147	153.320		
D_T (mm)	Between Groups	1652.807	2	826.404	7.078	.001
	Within Groups	17162.529	147	116.752		
P_H (mm)	Between Groups	303.305	2	151.653	67.412	.000
	Within Groups	330.696	147	2.250		
P_M (mm)	Between Groups	275.299	2	137.649	126.642	.000
	Within Groups	159.777	147	1.087		
P_T (mm)	Between Groups	198.298	2	99.149	98.699	.000
	Within Groups	147.670	147	1.005		
Density (g/cm^3)	Between Groups	1.307	2	.653	6.380	.002
	Within Groups	15.055	147	.102		

Table F4: Two Way ANOVA Showing the Influence of Age and Variety on Physical Properties of Cassava

	Source	Type iii sum of squares	Df	Mean square	F	Sig
PPW (%)	Variety	798.345	2	399.173	15.099	.000
	Year	716.891	2	358.446	13.558	.000
	Variety * year	451.205	2	112.801	4.267	.000
Length (mm)	Variety	186063.551	2	93031.776	11.005	.000
	Year	115808.564	2	57904.282	6.849	.001
	Variety * year	164851.249	4	41212.812	4.875	.001
Mass (g)	Variety	89220.822	2	44610.411	.869	.420
	Year	4422101.988	2	2211050.994	43.065	.000
	Variety * year	84038.330	4	21009.583	.409	.802
D_H (mm)	Variety	282.337	2	141.168	1.120	.327
	Year	1302.707	2	651.354	5.168	.006
	Variety * year	883.592	4	220.898	1.753	.137
D_M (mm)	Variety	929.111	2	464.555	1.100	.334
	Year	805.887	2	402.944	.954	.386
	Variety * year	4740.493	4	1185.123	2.806	.025
D_T (mm)	Variety	1544.392	2	772.196	8.578	.000
	Year	558.244	2	279.122	3.101	.046
	Variety * year	1628.085	4	407.021	4.522	.001
P_H (mm)	Variety	.937	2	.469	5.183	.006
	Year	95.294	2	47.647	526.868	.000
	Variety * year	1.475	4	.369	4.077	.003
P_M (mm)	Variety	.076	2	.038	.940	.391
	Year	99.070	2	49.535	1222.107	.000
	Variety * year	1.513	4	.378	9.334	.000
Density (g/cm^3)	Variety	.334	2	.167	2.194	.113
	Year	.034	2	.017	.223	.800
	Variety * year	3.499	4	.875	11.485	.000

Table F5: Analysis of Variance of Coefficient of Friction of TMS 30572 across Ages

		Sum of Squares	df	Mean Square	F	Sig.
Stainless steel	Between Groups	.094	2	.047	85.877	.000
	Within Groups	.039	72	.001		
	Total	.133	74			
Galvanized Sheet	Between Groups	.011	2	.006	3.855	.026
	Within Groups	.106	72	.001		
	Total	.117	74			
Wood	Between Groups	.066	2	.033	19.819	.000
	Within Groups	.121	72	.002		
	Total	.187	74			

a Variety = 30572

Table F6: Means for Groups in Homogeneous subset for TMS 30572 on Galvanized Sheet

Duncan

Year	N	Subset for alpha = .05	
	1	2	1
15	25	.4572	
18	25	.4700	.4700
12	25		.4872
Sig.		.242	.117

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 25.000.

b Variety = 30572

Table F7: Analysis of Variance of Coefficient of Friction of TME 419 across Ages

		Sum of Squares	Df	Mean Square	F	Sig.
Stainless Steel	Between Groups	.004	2	.002	2.065	.134
	Within Groups	.063	72	.001		
	Total	.066	74			
Galvanized Sheet	Between Groups	.079	2	.040	11.830	.000
	Within Groups	.242	72	.003		
	Total	.321	74			
Wood	Between Groups	.124	2	.062	20.257	.000
	Within Groups	.220	72	.003		
	Total	.344	74			

a Variety = 419

Table F8: Means for Groups in Homogeneous subset for TME 419 on Galvanized Sheet

Duncan

Year	N	Subset for alpha = .05	
	1	2	1
15	25	.4136	
12	25		.4820
18	25		.4832
Sig.		1.000	.942

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 25.000.

b Variety = 419

Table F9: Analysis of Variance of Coefficient of Friction of TME 7 Cultivar across Ages

		Sum of Squares	Df	Mean Square	F	Sig.
Stainless steel	Between Groups	.016	2	.008	10.694	.000
	Within Groups	.053	72	.001		
	Total	.069	74			
Galvanized sheet	Between Groups	.059	2	.029	17.521	.000
	Within Groups	.121	72	.002		
	Total	.179	74			
Wood	Between Groups	.305	2	.153	40.239	.000
	Within Groups	.273	72	.004		
	Total	.578	74			

a Variety = TME 7

Table F10: ANOVA of Coefficient of Internal Friction of Cassava across Ages

		Sum of Squares	df	Mean Square	F	Sig.
TMS 30572	Between Groups	.033	2	.016	4.553	.014
	Within Groups	.260	72	.004		
	Total	.293	74			
TME 419	Between Groups	.146	2	.073	26.574	.000
	Within Groups	.198	72	.003		
	Total	.343	74			
TME 7	Between Groups	.112	2	.056	19.068	.000
	Within Groups	.211	72	.003		
	Total	.323	74			

Table F11: ANOVA of Coefficient of Rolling Resistance TMS 30572 across Ages

		Sum of Squares	df	Mean Square	F	Sig.
Stainless Steel	Between Groups	.100	2	.050	44.025	.000
	Within Groups	.048	42	.001		
	Total	.148	44			
Galvanized Sheet	Between Groups	.153	2	.077	25.222	.000
	Within Groups	.128	42	.003		
	Total	.281	44			
Wood	Between Groups	.276	2	.138	36.126	.000
	Within Groups	.160	42	.004		
	Total	.436	44			

a Variety = 30572

Table F12: ANOVA of Coefficient of Rolling Resistance TME 419 across Ages

		Sum of Squares	df	Mean Square	F	Sig.
Stainless Steel	Between Groups	.002	2	.001	.527	.594
	Within Groups	.096	42	.002		
	Total	.098	44			
Galvanized Sheet	Between Groups	.011	2	.006	2.241	.119
	Within Groups	.105	42	.003		
	Total	.116	44			
Wood	Between Groups	.052	2	.026	6.757	.003
	Within Groups	.161	42	.004		
	Total	.213	44			

a Variety = 419

Table F13: ANOVA of Coefficient of Rolling Resistance of TME 7 across Ages

		Sum of Squares	df	Mean Square	F	Sig.
Stainless Steel	Between Groups	.004	2	.002	1.667	.201
	Within Groups	.055	42	.001		
	Total	.059	44			
Galvanized Sheet	Between Groups	.012	2	.006	2.289	.114
	Within Groups	.109	42	.003		
	Total	.121	44			
Wood	Between Groups	.003	2	.002	.547	.583
	Within Groups	.124	42	.003		
	Total	.127	44			

a Variety = 3001

Table F14: ANOVA of the Influence of Tuber Coverings on Coefficient of Rolling Resistance of TME 7

		Sum of Squares	df	Mean Square	F	Sig.
Stainless Steel	Between Groups	.016	2	.008	61.590	.000
	Within Groups	.002	12	.000		
	Total	.018	14			
Galvanized Sheet	Between Groups	.025	2	.013	25.728	.000
	Within Groups	.006	12	.000		
	Total	.031	14			
Wood	Between Groups	.023	2	.012	9.994	.003
	Within Groups	.014	12	.001		
	Total	.037	14			

Table F15: R^2 for different Regression Models for TMS 30572 Cultivar

Parameter	linear	Linear + interaction	Quadratic	Quadratic + interaction	Cubic
Stress at Peak	0.130	0.295	0.834	0.843*	0.876
Energy to Break	0.107	0.142	0.788	0.821*	0.840
Young Modulus	0.034	0.564	0.844	0.856*	0.856

*Fitted model

Table F16: Analysis of Variance for the 2nd Order Polynomial Model for the Peak Stress of TMS 30572

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	0.0152	0.0152	0.9902	2	0.338
Moisture Content	0.1281	0.1281	0.8243	4	0.381
Age*MC	0.0218	0.0218	1.4672	5	0.247
Overall Interaction	0.1793	0.0359	9.0532	7	0.021*

*Significant at 95% confidence level

Table F17: Analysis of Variance for the Toughness of TMS 30572

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	1.4062	1.4062	0.7702	2	0.396
Moisture Content	1.2937	1.2937	0.7053	4	0.416
Age*MC	0.1468	0.1468	0.0763	1	0.077
Overall Interaction	20.6467	2.9495	4.5938	7	0.031*

*Significant at 95% confidence level

Table F18: Analysis of Variance for the Stiffness of TMS 30572

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	0.7182	0.7182	0.3338	2	0.573
Moisture Content	0.2613	0.2613	0.1195	4	0.735
Age*MC	0.3732	0.3732	0.1714	1	0.686
Overall Interaction	24.5626	3.5089	5.9520	7	0.015*

*Significant at 95% confidence level

Table F19: R^2 for different Regression Models for TME 419 Cultivars

Parameter	linear	Linear + interaction	Quadratic	Quadratic + interaction	Cubic
Stress at Peak	0.705	0.784	0.872	0.917*	0.925
Energy to Break	0.583	0.687	0.737	0.749*	0.776
Young Modulus	0.462	0.651	0.766	0.787	0.841*

*Fitted model

Table F20: Analysis of Variance for the Strength of TME 419 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	0.3803	0.3798	24.9168	1	0.000*
Moisture Content	0.0276	0.0276	0.6512	1	0.434
Age*MC	0.3296	0.3296	17.2077	1	0.001*
Overall Interaction	0.5304	0.0758	10.9967	7	0.003*

*Significant at 95% confidence level

Table F21: Analysis of Variance for the Toughness of TME 419 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	24.7936	24.7936	14.1992	1	0.002*
Moisture Content	2.4367	2.4367	0.8471	1	0.379
Age*MC	19.3307	19.3307	12.2582	1	0.004*
Overall Interaction	29.8256	4.2608	2.9809	7	0.086

*Significant at 95% confidence level

Table F22: Analysis of Variance for the Stiffness of TME 419 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	6.3066	6.3066	6.9165	1	0.021*
Moisture Content	3.3134	3.3134	2.9012	1	0.112
Age*MC	7.3133	7.3133	8.7648	1	0.010*
Overall Interaction	14.2854	2.0408	3.6869	7	0.053*

*Significant at 95% confidence level

Table F23: Analysis of Variance for the Peak Stress of TME 7 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	0.4368	0.4368	13.7454	1	0.003*
Moisture Content	0.1141	0.1141	2.0156	1	0.179
Age*MC	0.4839	0.4839	17.1878	1	0.001*
Overall Interaction	0.7313	0.1045	6.1632	7	0.014*

*Significant at 95% confidence level

Table F24: Analysis of Variance for the Energy to Break of TME 7 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	6.9723	6.9723	3.0033	1	0.107
Moisture Content	5.2417	5.2417	2.1354	1	0.168
Age*MC	8.3904	8.3904	4.084	1	0.064
Overall Interaction	24.4238	3.4891	1.9189	7	0.205

Table F25: Analysis of Variance for the Stiffness of TME 7 Cultivar

Source	Sum of Squares	Mean Square	F	Degree of Freedom	F-Sig
Age	6.9723	6.9723	3.0033	1	0.107
Moisture Content	5.2417	5.2417	2.1354	1	0.168
Age*MC	8.3904	8.3904	4.084	1	0.064
Overall Interaction	24.4238	3.4891	1.9189	7	0.205