DEVELOPMENT OF A GINGER SPLITTING MACHINE

BY

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DECLARATION

I declare that the work in this thesis entitled "Development of a Ginger Splitting Machine" has been performed by me and that it is a record of my own research work.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree at any University.

Guwo, Ayuba Nguluwa -------------------------------- **June 30, 2008**

CERTIFICATION

This thesis entitled "DEVELOPMENT OF A GINGER SPLITTING MACHINE" by Guwo, Ayuba Nguluwa meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

A ginger splitting machine was developed based on the physical and mechanical property data of two ginger varieties namely, Tafin Giwa (yellow ginger) and Yatsun Biri (black ginger). The effects of moisture content, cutting speed (impeller speed) and crop variety were investigated on splitting efficiency, percentage of bruised and broken ginger rhizomes, material loss and throughput capacity of the machine. Three levels of moisture contents (wet basis), five levels of impeller speed and two ginger varieties were used for the study. Data for the performance evaluation were subjected to the analysis of variance for test of significance of the experimental factors and their interactions. The results showed that splitting efficiency decreased with increase in impeller speed and with decrease in moisture content for the speed and moisture content ranges studied. Highest splitting efficiency of 82.1 and 67.9% were obtained at impeller speed of 240rpm and at 84.35% moisture content for Tafin Giwa and Yatun Biri ginger varieties respectively. A higher splitting efficiency was obtained for Tafin Giwa variety compared with the Yatsun Biri variety. The Percentage of bruised and broken ginger rhizomes increased with an increase in impeller speed and with a decrease in moisture content for the two ginger varieties. The lowest percentage of bruised and broken ginger rhizomes of 17.93 and 32.05% at 240rpm and 84.4% were obtained for the two ginger varieties. Yatsun Biri ginger variety had higher percentage of bruised and broken rhizomes than Tafin Giwa ginger varieties at all moisture contents and speed ranges studied. Material loss of the two ginger varieties was in the range of 4.0 to 5.82% for all the moisture contents studied. At

critical speed of the machine, a throughput capacity of 67.95 and 55.76kg/h were obtained for Tafin Giwa and Yatsun Biri varieties respectively.

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CHAPTER 1 INTRODUCTION

1.1 Background Study

Ginger (*Zingiber Officinale Roscoe*) belongs to the plant family of *Zingbe*r *raceae*. It is an erect herbaceous plant, which produces underground tuberous stems or rhizomes characterized by its strong essence (Erinle, 1987). Though a perennial plant, it is cultivated vegetatively as an annual crop in tropical regions to yield the fleshy underground rhizomes (Ebewele & Jimoh, 1988). It is one of the oldest and most important of all the spices and condiments. It has been under cultivation for millennia in many parts of the world (Spore, 1992). Its importance as a spice is underscored by the fact that it is now grown on commercial scale in many countries of the world.

Ginger is native to South Eastern Asia (Parry, 1969), a region whose cuisines still feature this wonderfully spicy herb. Ginger is mentioned in ancient Chinese, Indian and middle Eastern literatures, and has long been priced for its aromatic, culinary and medicinal properties. The ancient Romans imported ginger from china during the first century (Purseglove 1988). Its popularity in Europe remained centred in the Mediterranean region until the middle Ages, when its use spread throughout other countries of Europe. In an attempt to make it available, Spanish explorers are reported to have introduced the crop to the West Indies, Mexico and South America in the 16th century, while the Portuguese introduced it to West Africa within the same period (Purseglove, 1988).

Ginger is cultivated extensively in India, Nigeria, Jamaica, Sierra-Loene, Indonesia, China, Fiji and Australia, with India producing about 50% of the world's production (Ali *et al.*, 1991).

Cultivation of ginger in Nigeria started seriously around 1927 (Arene, 1986; Erinle, 1987), when the colonial government carried out an investigation to find a crop that would generate internal trade and income for the populace of the present southern part of Kaduna state toenable them pay taxes. Today, ginger is commonly grown in this area, comprising of Kafanchan, Kagoro, Kachia, Zonkwa, Jaba, and Kubacha among others and has remained the most important ginger growing area in the country. It is today referred to as the traditional home of ginger production in Nigeria, and has placed Nigeria on the world map as one of the major producers of ginger. Trials by the National Root Crop Research institute (NRCRI), Umudike has established that good quality rhizomes could be grown in the southern part of the country, further confirming Nigeria as a potential producer of the crop (Meadows, 1988).

There are no available data on the volume of ginger produced in Nigeria. This has been difficult due to the land tenure system of farming being practiced in the country. However, the average ginger farm size for individual farmers has been reported as 0.26 ha, about half an acre (Ahmed *et al.*, 2004), and that a farmer could have more than one plot of small sizes at different locations. In nearly eighty years of ginger production in Nigeria, farmers have relied almost exclusively on two major varieties, the yellow ginger "Tafin Giwa" known for its spicy and pungent flavour, and the black ginger "Yatsun biri," widely cultivated for extraction of its essential oils. The yellow variety is mostly grown in Nigeria because it has the highest demand in the Nigerian market.

1.2 Statement of the Problem

In Nigeria, the splitting of ginger rhizomes is still done on a small scale. The farmers split harvested ginger rhizomes with local manually with local knives using family members or hired labour (simonyan *et al*., 2003). This method is slow and labour –intensive as about 32kg of ginger rhizomes could be split by a labourer per day (Sharma *etal*. 1980). The economics of splitting ginger manually offers little prospects of making large- scale production of ginger splits. The existing prototype machines developed in the country have not been able to split ginger longitudinally. Those designed by Iteke *et al*. (1988) and Simonyan *et al*. (2003) have only succeeded in slicing ginger laterally in form of shreds.

The imported machines do not seem to be acceptable to Nigerian farmers due to prohibitive initial cost and the type of slices produce. Ahmed *et al.* (2004) reported a highly mechanized ginger-slicing machine at Belphins Nigeria ltd., Kafanchan with a capacity of about 500kg/hr of ginger slices. However, this machine has not been attractive to farmers because it slices ginger rhizomes laterally in form of shreds. Since a ginger splitting machine that meets farmers’ demand is not available, farmers still resort to using the manual method of splitting ginger using a knife.

1.3 Justification of the Study

To overcome the drudgery associated with the manual splitting method a ginger splitting machine was developed with the aim of increasing the rate of splitting and to produce more even splits for drying. The machine will improve the post harvest quantity and quality of split dried ginger, and also encourage production of ginger rhizomes in the country. This research, which falls within the mandate of the institute for agricultural Research (I.A.R), is being undertaken with a view to eliminating the affore-mentioned problems by developing a machine that splits ginger longitudinally, requiring less human effort and makes splitting fast and easily handled.

1.4 Objectives of the Study

The general objective of this work is to develop a ginger splitting machine that will split ginger rhizome longitudinally without compromising quality. Specifically the objectives are:

1. To determine some physical and mechanical properties of the Nigerian ginger varieties that are relevant in the design of a ginger splitting machine.
2. To design and fabricate a ginger splitting machine that splits ginger rhizomes longitudinally.
3. To evaluate the performance of the splitting machine at varying levels of ginger rhizomes moisture content, equipment operational speed and crop variety.

CHAPTER 2 LITERATURE REVIEW

2.1 Economic Importance of Ginger

The importance of ginger as an export crop cannot be over-emphasized. According to Eleagu and Ugwu (1988), ginger has a higher market value per unit weight than most agricultural commodities, and is therefore very important both for export and domestic consumption. Ginger is processed for the market in three major forms fresh (green), preserved ginger, and split-dried ginger (Ebewele and Jimoh, 1988). The most important form in which ginger is traded international is the split-dried form. In Nigeria, peak prices for split-dried ginger are reportedly witnessed between July and October, where a bag of 100 kg could be sold for as much as ₦6, 000.00 to ₦10, 000.00 depending on the market situation (Ahmed *et al*., 2004). The higher prices of ginger have been attributed to its coarseness, pungency and pronounced camphoric taste, a flavour characteristics mostly demanded by consumers (Ebewele and Jimoh, 1988). The main market outlets for ginger are the food, perfumery and pharmaceutical industries, with the food industry having the lion share of ginger market.

Split dried ginger is useful in the food industry because they improve the quality of food by giving appealing and appetizing flavours. It has a penetrating flavour upon which the response of the digestive system depends and is mostly used for meat preparations, soups, bakery products, snacks, confectionaries, pickles, ginger beer, beverages, and ginger tea, among others. The dried ginger is valued for its pleasing combination of aroma, flavour and pungency, and is employed in the spice trade for the preparation of essential oils and to some extent in the perfumery industry. Ginger owes these peculiar flavour properties due to their content of essential oils as well as various amounts of fixed oils and resins which together give its aromatic and pungent properties. The ginger oil and oleoresin have been blended with honey at Belphins processing plant, Kafanchan , to produce ginger tonic (Ahmed *et al.*, 2004). The fresh ginger is used in the preparation of ginger beer in Nigeria. Fresh ginger is used for culinary purposes and as raw material for further processing (Akomas and Oti, 1988). Ginger in its preserved form as essential oil, oleoresin or as concentrate in processing industries is used in various perfumes and in flavouring curries and beverages. Ginger is not just an important spice. It has some positive health benefits. The underground stem or rhizome and the ginger plant is traditionally used in Nigeria for both medicinal and culinary purposes (Erinle, 1987). The oleoresin, which has the full pungency is used medicinally (Okwouwulu and Ene, 1988), when chewed fresh, stimulates the flow of saliva. It is also stermanatory when inhaled and tends to promote healthy sweating by keeping the sweat pores open, thereby increasing perspiration with subsequent fall in temperature (Cobley and Steele, 1975). Ginger is not just an important spice, it is used to treat many illnesses, particularly nausea and motion sickness. Ginger is said to have medicinal properties where the rhizomes are incorporated into indigenous system of medicine. The aqueous extract prepared by macerating ginger rhizomes with water has been regarded as a panacea for all ailments particularly for blood pressure complaints. Studies by (Srivastara and Mustafa, 1989, 1992) showed that ginger reduces all symptoms associated with motion sickness including dizziness, nausea and vomiting. When swallowed, it acts as a stimulating tonic, and is known to be very effective in alleviating symptoms of gastro intestinal distress, and also contain very potent anti-inflammatory compounds called ginger oils, substances which are believed to reduce pain levels of Ostera arthritis or rheumatoid when consumed. Ginger in powdered form is used as a stimulant in tea and corn pap in some parts of Nigeria (Okwuowulu and Ene, 1988).

Echendu (1988) investigated the use of ginger as protectant against *Callosobruchus maculatus* (F) on cowpea in storage. The result showed that ginger significantly reduced infestation, number of eggs laid and adult emergence.

2.2 Physical Properties of Ginger and other Agricultural Products

Physical properties of agricultural materials are those properties that distinguish them from another (Nwadikom and Njoku 1988). Knowledge of these properties constitutes an important and essential engineering reference in the design of machines, structures, processes and controls. This is useful in analysing and determining the efficiency of a machine or an operation, in developing new consumer products of plant or animal origin, and in evaluating and retaining the quality of the final product (Mohsenin, 1980). Some of the physical properties of agriculture materials include shape, size, surface area, density, volume, mass and moisture content. Others include porosity, angle of repose, coefficient of friction and colour. These properties are important in many problems associated with the design of a specific machine or analysis of the behaviour of the product in handling of the product.

Determination of physical properties of agricultural materials is problematic due to their variable sizes, irregularity in shape and porosity. However, a thorough study of these properties is required in order to arrive at an accurate quantification and description of their shape and size.

According to Mohsenin, (1980), shape and size are inseparable in a physical object, and both are necessary if the object is to be satisfactorily described. They are important in problem of stress distribution in the material under load and in developing of sizing and grading machines. What shape is to be assumed for the material and which dimension is to be employed in calculations are two questions that need to be investigated. Nwadikom and Njoku, (1988), reported that shape and size are important in the design of metering mechanisms and for the design of hopper for any flow process that may be involved. Average volume on the other hand, is useful in the design of containers for handling and storage of agricultural products. It is involved in the calculation of density of the product. Average weight of ginger is required in calculating the power requirement for handling or processing of agricultural products.

There are infinite number of measurements required in the determination of shape and size of agricultural products. However, measurements of the three perpendicular axes of length, width and thickness have been found to be efficient enough in describing shape and size. Waziri and Mittal (1983) determined the surface area of orange, bitter lemon and grape fruits using roundness and estimated the surface area of pepper by approximating the known geometrical shape. Nwadikom (1984) determined the surface area of yam using the wrapping methods. Nwadikom (1984) also determined the shape of yam tuber by taking linear dimensions of various points on the tuber, and concluded that a yam tuber was cylindrical with semi spherical ends. In the same vain, Nwadikom and Njoku (1988) determined some physical properties of ginger. They concluded that ginger finger was approximately a cone with an elliptical cross-section. Empirical equations relating mass, volume and surface area were developed.

2.3 Mechanical Properties of Ginger and other Agricultural Products

Agricultural materials are usually subjected to static or dynamic loading during processing that can cause failures that may be desired as part of the process (Mohsenin, 1980). Such failures could be cutting, shearing or peeling. For ginger crop, the process of producing splits from fresh rhizomes involves application of some mechanical processes of cutting or splitting to enhance drying of the product. Therefore, mechanical properties such as compressive strength, impact and shear resistance are important in studying size reduction of these materials. The compression test on biological materials merely means applying a truly concentric or axial load so that bending stresses are not set up as a result of the irregularities in alignment, avoiding friction between the end surface of the specimen and the bearing plate of the testing machine. Guner *et al.* (2003) carried out uni-axial compression test for Hazelnut in lateral and longitudinal axes between two parallel plates to determine the specific deformation, rupture force and rupture energy required to initiate shell and kernel rupture.

Bamgboye and Ojo (2004) studied the impact and uni-axial compression tests in lateral and longitudinal axes of cocoa pods with a view to reducing the pod into smaller particles.

Studies by El Hug *et al.* (1971); Persson, (1987); Mequita and Hanna, (1995) and Prince *et al.* (2002) as reported in Chen *et al.* (2004) showed that cutting energy is related to the stem mechanical properties. They reported that types of cutting blade edge affect cutting energy requirement. A serrated blade edge gives a higher cutting force and requires more cutting energy than a smooth edge. Persson (1987) reviewed several studies on cutting speed and concluded that cutting power is only slightly affected by cutting speed, although an increase in cutting speed will often increase the power losses caused by material acceleration.

Studies conducted on Cassava tubers (Balasubramanian *et al.*, 1993), raw banana (Kachru *et al.*, 1996) showed that the cutting efficiencies are functions of the physical and mechanical properties. Balasubramanian *et al.* (1993) designed and developed a cassava-chipping machine. They evaluated the performance of the chipper for chip recovery and capacity, with respect to the different speeds of the disc. The effect of the disc speed on the chip recovery of cassava and the capacity of the chipper are related to the physical and mechanical property. They observed a decrease in chip recovery with increase in speed, and an increase in capacity with increasing speed. The capacity of the chipper was assessed as 270 kg / hr and chip recovery of 92% for 1mm chips at 295 rpm.

An electrically operated rotary slicer for raw banana was designed, fabricated and evaluated by Kachru *et al.* (1996) in terms of the operating capacity, by feeding peeled banana into the machine and finally weighing all slices irrespective of damage per unit time. The slicing efficiency and operating capacity of the machine were determined as 90 % and 61 kg/hr respectively, at a speed of 250 rpm.

Cutting energy of a plant stem can be estimated from the relationships between the force of cutting the stem and the displacement of the knife. Information on plant properties and the power or energy requirement of equipment has been very valuable for selecting design and operational parameters of the equipment (Persson, 1987). However, no literatures have been reported on the mechanical properties of ginger.

2.4 Cutting/ Slicing Mechanisms

Cutting is a size reduction process which is produced by pushing a foreign material or a thin sharp knife through the material to be reduced (Henderson and Perry, 1976). Cutting is especially well adapted for reduction of high moisture agricultural materials like fruits and vegetables so that, drying or transfer of liquid from the material is facilitated. The chemical properties of the material remain unchanged since the new surfaces produced by the sharp edge of the knife are relatively undamaged. The penetration of the knife into the material causes some deformation by compacting successive regions of the material so that forces of the cutting edge overcome the cohesion of the material (Jenkendra and Singh, 1991).

A common way of applying the cutting force is by means of two opposed shearing elements which meet and pass each other with little or no clearance between them (Kepner *et al.*, 1978). Usually, one or both of these elements may be moving with uniform velocity, reciprocating or rotary. Cutting is achieved when the knife slices through the material giving it a smooth cut with minimum energy requirement. The most satisfactory cutting device is a knife of extreme sharpness and as thin as can be structurally possible (Henderson and Perry, 1976). Ginger rhizomes are fibrous in nature, and therefore, splitting of the fibre, is a very important part of the cutting process. Essentially a shearing process is usually involved in reducing the material into smaller sizes using a continuously rotating cutting device. Cutting takes place by impact, and since the knife velocity is an important factor, it will be important at the point of impact (Kepner *et al.*, 1978). The edge of the blade must be sharp and its motion considered from the instant the blade impacts on the material, until complete cut occurs (Akritidis, 1974). Sometimes the term shearing is used for a process which is actually a cutting process and not true shearing (Mohsenin, 1980).

A number of researchers that include Wieneke, (1972); O' Dogherty, (1981); Persson, (1987), Balasubramanian *et al.*, (1993); Kachru *et al*, (1996) in their studies reported that cutting force, cutting energy and the effect of cutting on agricultural materials are influenced by the cutting velocity, shear angle of cut and bevel angle of knife with respect to material and the counter edge that react to the cutting force. They concluded that cutting force is the resultant of the stresses applied on the material. Prasad and Gupta (1975) in their studies of cutting energy on maize stalks reported that the cutting process is complex in nature. They concluded that the cutting energy and the maximum cutting forces are directly proportional to the cross-sectional area and inversely proportional to the moisture content. They determined the energy required for cutting stalk materials using a swinging knife pendulum as:

$$E = W_t (h_c - h_o) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where, E = energy required in cutting stalks N-m

W_t = total weight of swinging arm (N)

h_c = Vertical component of displacement after cutting, m

h_o = Vertical component of displacement before cutting, m

This therefore, implies that the cutting energy is the product of cutting force and the depth of cut.

2.5 Methods of Splitting Ginger

Various methods of processing ginger have been highlighted by Akomas and Oti (1988). Splitting has been reported as one of the most important processing operations of ginger, since it facilitates the drying process. It is therefore necessary that it is done in such a way to minimize tissue damage (flavour losses) as this contains the essential oil, upon which the aroma of ginger depends. Damage of these cells leads to loss of essential oil, which is a prime factor in determining the economic value of ginger (Ali *et al.*, 1991).

2.5.1 Traditional method

There are basically two methods of splitting ginger in Nigeria the manual (traditional) method and the modern (mechanical) method. The former is largely practiced in Nigeria. This method is achieved by splitting washed ginger longitudinally through the length into two equal halves using sharp knife. Splits are spread on a mat-covered platform and turned 3 to 4 times a day for 5 to 7 days until completely dried to a moisture content of 10 to 12% (Meadows, 1988; Njoku *et al.*, 1995).

2.5.2 Mechanical method

Mechanical slicing of ginger, like any other crop is achieved by applying the cutting force by means of two opposed shearing elements. Usually one of these elements may be moving and the motion may be reciprocating or rotary. Cutting is achieved by the movement of the knife with respect to the material being cut and the counter shear on impact. The impact cutter relies upon the inertia of the material being cut to furnish the opposing force required for shear. Ebewele and Jimoh, (1988) suggested the use of sharp mechanical slicers for slicing ginger rhizomes.

2.6 Criteria for Performance Evaluation

The ginger splitting machine like any other machine requires evaluation of its functional performance in terms of the quality of ginger splits produced. The need for evaluation of its functional performance is to determine points of excessive stress and any other possible short coming in durability, wear and other limitations that may be encountered in the course of using the machine. It also permits a statistical analysis of the results generated by the machine. Many researchers comprising Balasubramanian *et al.*(1993), cassava, Kachru *et al.*(1996), banana, and Simonyan *et al*. (2003), ginger, determined the performance of slicing machines using Slicing efficiency, Percentage damage and Operating capacity as performance indicators.

2.7 Research and Development Efforts on Ginger Splitting

Sharma *et al*. (1980) developed a motorized ginger-slicing machine that uses rotary knife. It consisted essentially of a hopper, a trough, belt pulley drive, prime mover and a disc type mild steel blade of 50cm diameter and 5 mm thickness in-built inside the trough and the slicing blade mounted on to a shaft passing inside the trough. Ginger fed through the hopper to the trough fall by gravity where it is cut into sizes (shreds), sliced pieces fall by gravity through the outlet into the collecting tray. The machine was rated at 100 kg/hr of ginger slices.

Iteke *et al*. (1988) developed a ginger shredding machine. The design of the shredder provided among other considerations a mechanized orientor to line up ginger roots in the direction of the shredder using a mechanized feeder, a feed port and the right size and shape of blade. The shredder was rated at 500kg/day.

A motorized reciprocating ginger slicer was developed at the college of Agriculture,

Ahmadu Bello University, Samaru, Zaria, by Simonyan *et al.* (2003). The machine consisted of the feeding unit, slicing mechanism, driving mechanism and housing. The ginger rhizomes fed manually into the hopper falls by gravity into the cylinder at the bottom dead center of the piston. It is pushed horizontally to the stationary knife blade as the piston moves towards the top dead center. The pushing of the rhizomes forces the ginger through the blade, which are collected at the outlet. They observed that higher slicing efficiency was achieved at higher moisture content; 76.8% slicing efficiency at 30% moisture content, dry basis (mcdb) and 64.6% slicing efficiency at 22% mcdb. They also observed lower percentage damage at higher moisture content 23.2% at 30% mcdb compared with 35.4% at lower moisture content 22% mcdb.

A prototype of ginger splitting machine had been developed by the Institute of Agriculture Research (I.A.R) in collaboration with the National Root Crop Research Institute (NRCRI), Umudike, but no further development has been heard about the progress of work on the machine (Ahmed *et al.*, 2004).According to Ahmed *et al.* (2004), studies have also been made by some organizations to determine the best method of splitting ginger. The Federal Institute of Industrial Research,Oshodi (F.I.I.R.O) has been quoted as an organization making efforts towards developing a ginger splitting machine, but the machine development has been stalled due to lack of fund.

CHAPTER 3 MATERIALS AND METHODS

3.1 Crop Variety

Fresh ginger rhizomes of two identified ginger varieties in Nigeria namely, Tafin Giwa (Yellow ginger) and Yatsun Biri (black ginger) were used for the study. They were purchased from Kafanchan and Dogon Kurmi in Kaduna State. These are the varieties popularly grown in Nigeria. The rhizomes were washed to remove all the soil particles. Each sample was prepared by cutting off the fingers from the interconnecting tangled clumps (Nwadikom and Njoku, 1988), with each finger left with one bud.

3.2 Preliminary Investigation and Laboratory Work

Prior to the design and fabricating the ginger splitting machine, it was necessary to determine some design parameters based on the physical and mechanical properties of ginger that are useful guides in the design of ginger splitting machine. These properties include moisture content, axial dimensions (length, width, and thickness), weight, volume, density, angle of repose and shear force. The procedures for the determination of these properties are those set forth in the sections following. The instruments used are also described.

3.2.1 Moisture Content

The initial moisture contents of the fresh rhizomes were determined in the Crops Processing Laboratory of the Department of Agricultural Engineering, Ahmadu

Bello University (ABU), Zaria. The oven dry method was used for determining the moisture content of samples. Samples were oven dried at 130 ^{o}C for 24 hours as recommended by ASAE (1994). The oven used was the Eijelkamp UM-300 Memmert oven with temperature-preset functions. Weights of samples before and after oven drying were determined using a Mettler type top loading balance model PN1210. The balance has an accuracy of 0.01 g and a capacity of 1600g.

3.2.2 Axial Dimensions

The three axial dimensions namely, length, width and thickness are very important in the design of metering mechanism and for free flow that the crop may be involved (Fig.3.1). The length and thickness of ginger rhizomes are required in the design of the splitting mechanism. The length is critical in the design of the hopper, length of impeller and the length of the splitting blade. The thickness is required for the design of the splitting chamber. Axial dimensions namely, length, width and thickness of the two varieties of ginger studied were determined using a vernier caliper with an accuracy of 0.01mm. The length, width and thickness of 25 samples of each ginger variety were determined by measuring at 10mm interval along the length. The geometry of ginger rhizomes under study indicating the axial dimensions are presented in Figure 3.1 below.

3.2.3 Weight

Twenty five samples of fresh rhizomes of each variety of ginger studied were weighed using the top loading electronic Mettler balance, model PN 1210. The instrument has an accuracy of 0.01g.

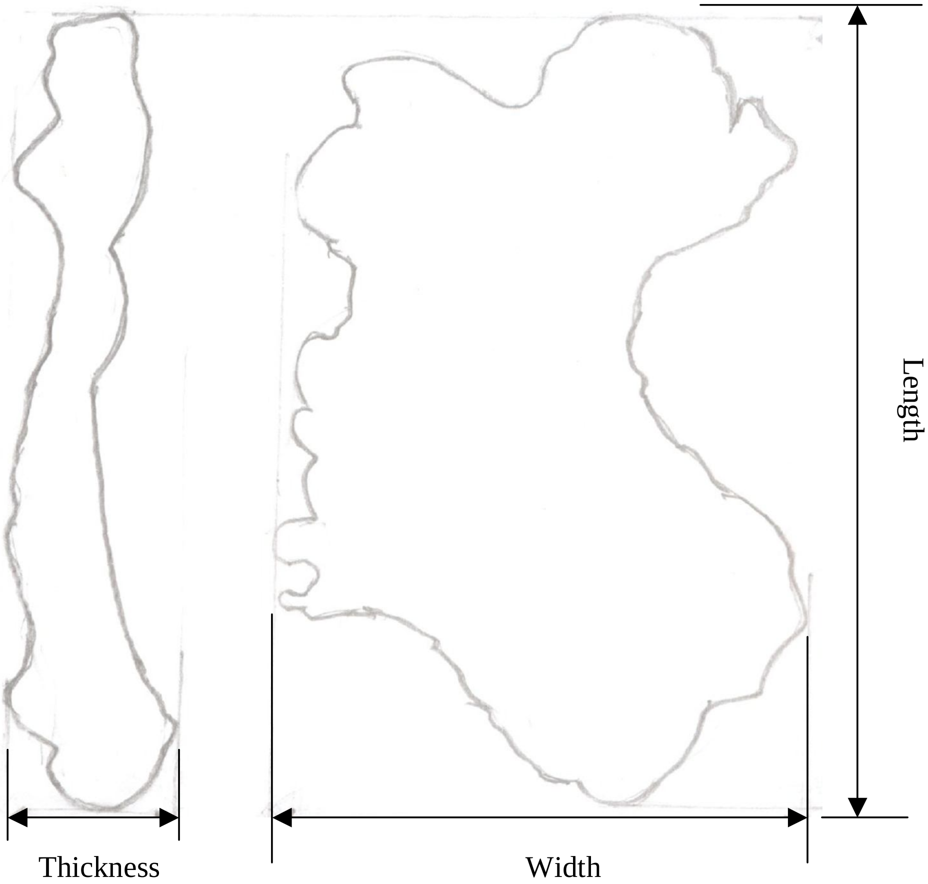

Figure 3.1: Axial dimensions of fresh ginger rhizome

3.2.4 Volume

The volume of 25 samples of each of the two ginger varieties was determined using the water displacement technique as outlined by Mohsenin (1980). Each sample of a known weight was dropped inside a calibrated beaker with a known volume of water. The displaced water gave the equivalent volume of water and hence of the volume of ginger. The average volume of ginger is required in the design of hopper and similar storage facilities for ginger

3.2.5 Density

The density of ginger rhizomes were determined based on the mass volume ratio, using weight and volume properties determined as stated above. Density was useful in determining the number of ginger rhizomes contained in the hopper.

3.2.6 Angle of Repose

The angle of repose of 25 ginger rhizomes of each of the two ginger varieties was determined using the method set forth by Kramer (1944) and as reported by Mohsenin (1980). A mild steel sheet was constructed with a fulcrum, horizontal platform and a vertical graduation in degrees. Individual samples were placed on the mild steel sheet and raised until the ginger rhizomes start to slide. The angle of inclination on the vertical graduation was determined for each sample, and reported as the angle of repose. The angle of repose is needed for the determination of the free flow of ginger rhizomes with respect to the hopper.

3.2.7 Shear Force

A single knife section and a counter shear surface were used as the cutting tool. The knife section was attached on to one of the movable crossheads of a Monsanto universal testing machine (Fig 3.2). The machine has a capacity of measuring forces up to 20KN on a test piece, and can be scaled down from 0 - 100N. Samples were prepared by cutting them into rectangular shapes of 8cm x 2cm using a sharp knife blade. Longitudinal sides of samples were cut into flat shapes to avoid unequal forces being applied, and to avoid buckling. Samples were compressed in-between the knife blade and one of the chuck tips (counter shear) and subjected to compressive (cutting) forces by manually turning the pulley shaft handle. Cutting was monitored by the movement of the mercury level on the force scale until no further movement of the mercury level observed, and also by a force-deformation curve recorded on a graph sheet during the cutting process. The shear force is required in the calculation of the power required for splitting ginger rhizomes.

3.3 Design Considerations

Since the splitting process has to be in conformity with the quality of ginger splits demanded in the market, the machine was designed to meet consumers' acceptability with the following considerations:

1. It was essential that the ginger fingers fall freely inside the hopper to the splitting mechanism. The physical properties like angle of repose, length and width of ginger fingers where considered in the design of the hopper. The

width of the splitting chamber was determined based on experimentally determined thickness of fresh ginger rhizomes.

2. Power requirement for splitting the ginger rhizomes was derived based on the strength in shear of ginger rhizomes under the action of statically applied knife edge load, determined experimentally on a Mosanto type Universal Testing Machine.

3. A speed of 300 rpm was selected as the design speed to determine the power required for splitting ginger rhizomes. The speed was based on the recommendations of Sharma *et al.* (1980).

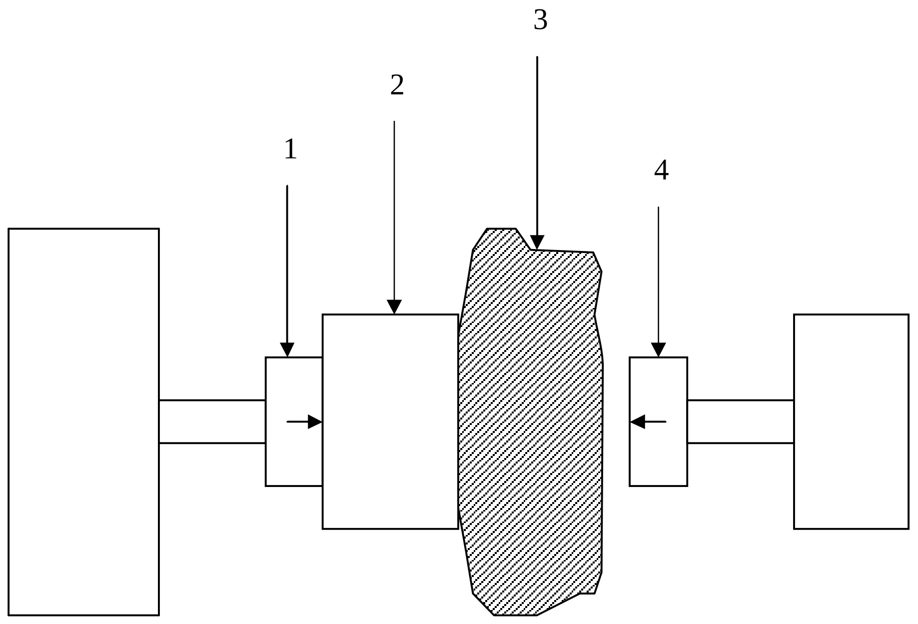

Figure 3.2: Sample of ginger rhizome in longitudinal shear. Indicated are the Movable Base Plate (1), Knife Blade (2), Ginger Piece (3) and Moving Parallel Plate (4).

3.4 Machine Description and Working Principles

3.4.1 Machine Description

The ginger splitting machine consists of the following components: frame, hopper, splitting unit, and power transmission system (Fig. 3.3).

Frame: The splitting machine had a rectangular structure with overall dimensions of 1000 x 800 x 800 mm. The frame was fabricated by using 30 x 30 x 3mm angle iron. On the frame are mounted the bearings, shaft with splitting unit, hopper and prime mover.

Hopper: This is the component through which ginger is fed into the machine for splitting. The hopper was made up of gauge 16 metal sheet. This sheet was cut into size and welded to form a trapezoidal shape with the following dimensions: Parallel walls of size, 360 mm and 30 mm, width of 150 mm were used in constructing the hopper with an angle of repose of $42^{o.}$ This angle was considered a little above the material (ginger fingers) angle of repose in order to enhance gravity flow into the splitting chamber. The hopper was fabricated with an adjustable bottom opening and with a holding capacity of 8.3 kg of ginger rhizomes.

Splitting unit: The splitting unit consists of a splitting chamber, stationary cutting blade and two revolving impellers. The splitting chamber of diameter 300mm and a width of 22mm were fabricated using gauge 16 mild steel sheets. The width of the chamber was almost the average thickness of ginger. The splitting blade is stationary and is concentrically located across the circle of the splitting chamber. Two impellers of 150

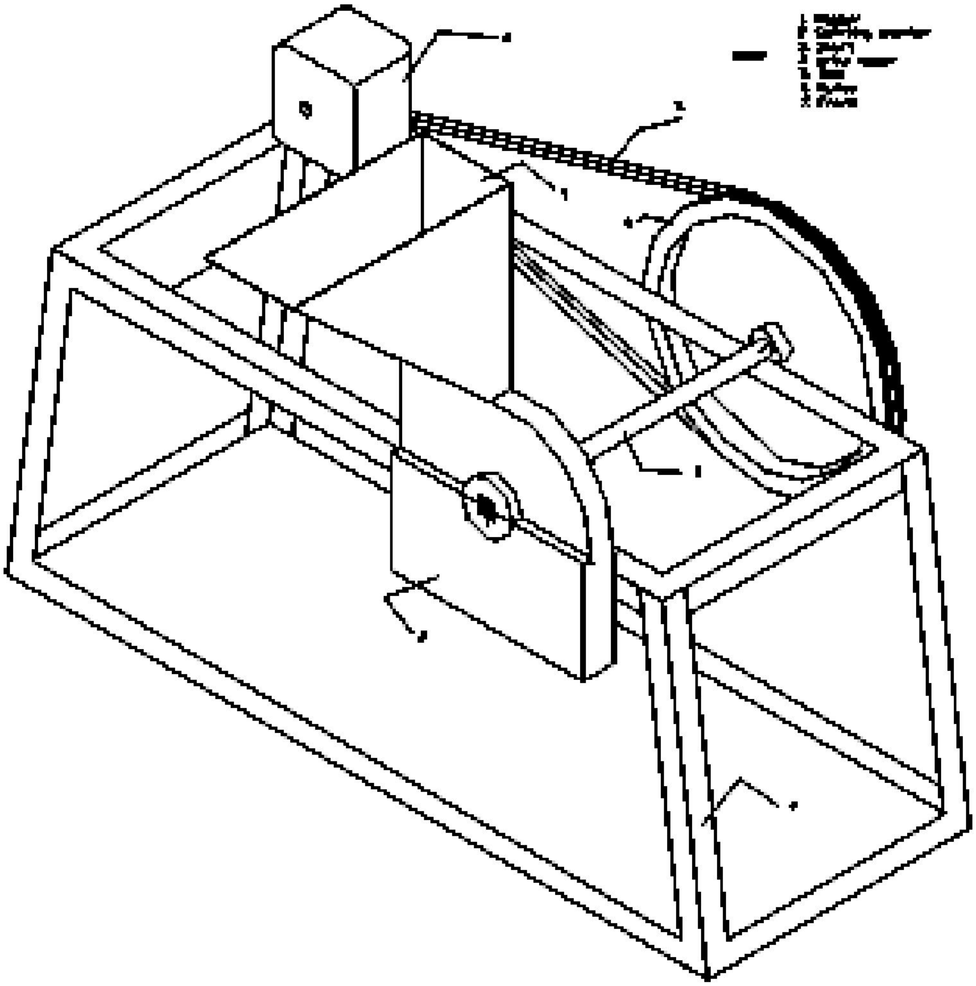

Fig. 3.3: Isometric view of the Ginger splitting machine

x 22 x 10mm length, width and thickness respectively, was fabricated. The two impellers were keyed to and carried on the shaft spaced equally across the blades lateral cross section and along the shaft's longitudinal axis to avoid obstruction. The impellers revolving at high speed discharge the split ginger rhizomes through the outlet.

Power Transmission Unit: The power was provided by a 1.5 hp, 300 rpm prime mover (petrol engine). The V-belts and pulley assembly were used to transmit the power to the splitting unit at a speed of 300 rpm. The prime mover was mounted on a slotted plate on the frame to facilitate adjustment of the belt tension.

3.4.2 Working principles

The feeding of ginger rhizomes to the hopper is done manually. Ginger rhizomes slide on their larger surface areas into the hopper longitudinally. Constant rotation of the impellers created a synchronized flow of ginger rhizomes inside the splitting chamber. The impellers carry the fallen ginger rhizomes on its path and are accelerated to its own speed and pressed against the stationary blade positioned in-between them. The centrifugal force of the impellers due to their rotation against the stationary knife blade accomplishes the splitting process. The impellers revolving at high speed discharge the split ginger rhizomes through the outlet where it is collected in a container. Fig 3.4 shows the impeller-blade arrangement.

3.5 Design Calculations and Selection of Machine Components

The design of the various components of the equipment and the materials selected for their construction are presented as follows.

3.5.1 Hopper

The hopper was shaped in form of a trapezoidal prism with an angle of inclination of 42 ° which is chosen greater than the material angle of repose to ensure free flow of ginger rhizomes into the splitting chamber. The material selected for the construction of the hopper was a gauge 16 mild steel sheet. This was based on its availability and cost of materials.

3.5.2 Product Feed Opening

The pooled mean thickness of the two ginger varieties was experimentally determined as 21mm. In order to allow for individual flow of ginger rhizomes into the Splitting chamber, a discharge opening of 25mm at the bottom of the hopper was therefore selected.

The angle of repose of ginger was 30.5^o (determined experimentally). This was the average angle of repose for which rhizomes begin to flow freely. Therefore to increase the free flow of ginger in the hopper to the splitting chamber, an angle of 42^0 was selected. Based on anthropometric considerations, the height and base of the hopper was chosen as 300mm and 30mm respectively (Fig. 3.3).

From the diagram below (Fig. 3.3),

$$\tan 42° = 300/M \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.5)$$

Therefore, $M = 300/\tan 42° = 300/0.9004 = 333 \text{ mm}$

$X = M + 30 = 333\text{mm} + 30\text{mm} = 363\text{mm}$

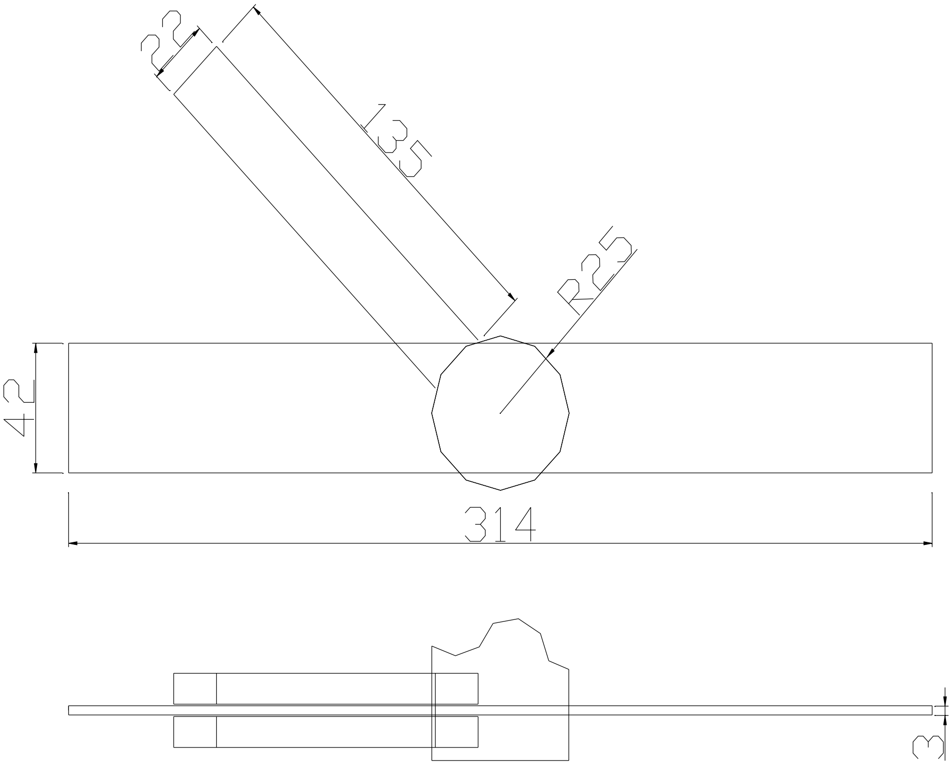

Fig.3.4: BLADE-IMPELLER ARRANGEMENT

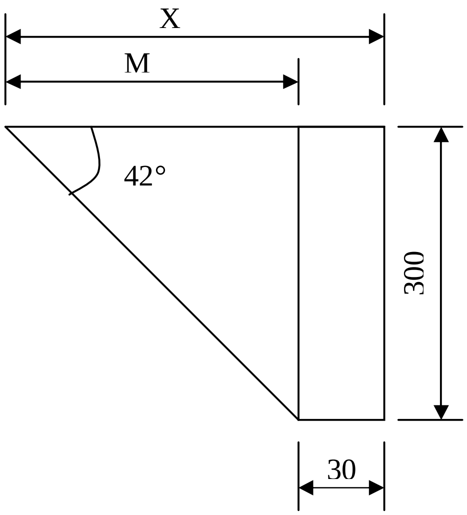

Fig 3.5 Side view of hopper

Hopper Size: In establishing the design parameter for hopper, two considerations are normally taken; these are volumetric capacity and gravimetric capacity.

Volumetric Capacity: The hopper is in form of trapezoidal shape. Using the trapezoidal formula for finding the volume of a trapezium to be:

$$V = \frac{1}{2}(a + b) * h * t \quad \ldots\ldots(3.6)$$

Where, V = Volume of Trapezium

a + b = Sum of parallel sides

h = height of hopper

t = width of hopper

This could be calculated using the area of trapezium of known parallel sides and a known height.

$$A = \frac{1}{2}(a + b)\, h \quad \ldots\ldots(3.7)$$

Where, A = area, a + b = sum of parallel sides, and h = height

Substituting the values above into equation (3.7) gives

$$A = \frac{1}{2}(30 + 363)\, 300 = 58950 \text{ mm}^2$$

Volume: The volume of a trapezium assumes the volume of the hopper as

$$V = \text{Area} * \text{width} \quad \ldots\ldots(3.8)$$

Where, w = width of hopper, set as 150mm (that is, greater than the average length of ginger rhizomes).

$$\text{Volume} = 58950 \text{ mm}^2 * 150 \text{ mm}$$

$$= 8842500 \text{ mm}^3$$

Gravimetric Capacity: This gives the weight in kilograms of ginger rhizomes the hopper can contain at a time. This can be determined as follows.

Density = Mass/ Volume ……………………………(3.9)

Average density of the two ginger rhizomes = 0.936g/cm^3, (determined experimentally).

Total mass of ginger contained in hopper = volume of hopper * density of ginger

= 8842.5 cm^3 x 0.936g/cm^3 = 8276.58 g

Total number of ginger pieces in hopper $= \frac{\text{Total mass of ginger in hopper}}{\text{Average mass of ginger}}$

= 8.3 kg/ 0.044 kg = 187 pieces

Considering 75% filling efficiency, it then implies that

Total Number of ginger pieces in the hopper = 6.225 kg/ 0.044 kg = 141 pieces.

3.5.3 Determination of Impeller Size

The material selected for the impeller was medium carbon steel (ASME code C1040), with density of 7800kg/m^3 (Mark 1951). The selection of medium carbon steel was based on rigidity to withstand stresses on impact. Twin impellers are mounted on to the shaft inside the splitting chamber. The shaft rotates inside the splitting chamber with the impellers with force required to split ginger rhizomes falling into the chamber. The impeller carry the falling ginger rhizomes on its path and are accelerated on its own speed and pressed against the stationary blade. Splitting is achieved due to the centrifugal force of the impeller against the stationary blade. The impact force required for splitting the ginger rhizomes is based on Newton's second law of motion, which is equivalent to the centrifugal force given by,

$F_c = ma$ ……………………………………(3.10)

Where F_c = Centrifugal force (N)

m = Mass of impeller (kg)

a = acceleration of impeller (m/s^2)

Average shear force required for the two ginger varieties = 90N (Determined experimentally, Appendix A). Assuming the centrifugal force of the impeller to be greater than the shear force of ginger by 25%.

25% of 90 N = 22.5 N

Therefore,

Centrifugal force = 90 + 22.5 = 112.5 N

Linear velocity of impeller is given as set forth by Hannah and Stephens (1984).

$V = \pi Dn/60$ ……………………………………(3.11)

Where, π = constant value, 3.14

D = Diameter of impeller, 300 mm

n = Angular speed, 300 rpm

$V = \pi * 490 * 300/60 = 7.697$ m/s

According to Hannah and Hillier (1988), acceleration,

$a = V^2/r$ ……………………………………(3.12)

Where, r = radius of impeller from axis of rotation.

$a = 7.697^2/0.15 = 394.949$ m/s ^{2}

The mass of the impeller was calculated as

$m = F_c/a = 112.50 / 394.949 = 0.285$ kg ……………………… (3.13)

Volume of impeller is calculated from the expression

Volume = mass/density ……………………………… (3.14)

Volume = 0.285 / 7800 = 0.000036538 m^3

Selecting the length and thickness of impeller as 150mm and 22mm respectively, the width of the impeller was determined from the expression

Volume = length * width * thickness

Width = volume/ (Length * thickness)

Width = 0.000036538 /(0.15*0.022) = 0.011m

= 11 mm

3.5.4 Power Requirement for Splitting Ginger Rhizomes

The power required for splitting can be calculated using the equation given by Hannah and Hillier (1988).

$P = F_c * V$ ……………………………………… (3.15)

Where, P = Power (Watts)

F_c = Centrifugal force of impellers, 112.5N

V = Velocity of impellers, 7.697 m/s

Therefore,

P = 1125 * 7.697

= 866 Watts (or 1.16 hp) ……………………………… (3.16)

This will be the minimum power required for the splitting process. However, allowing for a 0.3 factor due to frictional resistance a 1.5hp prime mover was selected for the operation.

3.5.5 Torque Requirement

The torque requirement in ginger splitting can be derived from the expression given by (Hannah and Hillier, 1988).

$$P = M_t . \omega \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.17)$$

P = Power, Watts

$\omega = 2\,\pi\,n/60$ = Angular velocity, rad/s

n = Speed of prime mover, 3000 rpm

$\pi = 3.14$

M_t = Torque on impeller shaft, Nm

Hence, torque on the impeller shaft

$$\begin{aligned} M_t &= P/\,\omega \\ &= 1119 / 31.42 \\ &= 35.61 \text{ Nm} \end{aligned}$$

3.5.6 Power Transmission System

The choice of petrol type prime mover for this design was based on the fact that the machine was expected to work in rural environments where there are no electricity supplies.

Considering the 1.5hp engine running at 1,500 rpm, and with a pulley diameter of 0.05m and splitting speed as 300 rpm. The diameter of the pulley on splitting shaft was determined using the expression relating driver and driven pulleys as given below:

$N_1 D_1 = N_2 D_2$ ……………………………………(3.18)

Where, N_1 = Speed of prime mover, 1500 rpm

D_1 = Diameter of pulley on prime mover, 50mm

N_2 = Speed of splitting shaft, 300 rpm

D_2 = Diameter of pulley on splitting shaft (mm).

Substituting for these values in equation (3.18) gives

$1500 * 50 = 300 * D_2$

$D_2 = 250$ mm

Allowing for 2% slip factor (Kepner *et al.*, 1978),

$D_2 = D_1 (1 - 0.02) (V_r)$ ………………………………(3.19)

Where, Vr = Velocity ratio = N_1 / N_2

Therefore, $D_2 = 50 (1-0.02) (5) = 245$mm

3.5.7 Selection of V-belts

The length of v-belt between the prime mover pulley and the counter shaft pulley was calculated based on relationship and procedure given by Kepner et al. (1978).

$L = 2C + {}^{\pi}/_{2}(D+d) + ([D+ d]^2/4C)$ ………………………(3.20)

Where, L = Length of belt, mm

C = Center to center distance between shafts selected as 60mm

D = Diameter of larger pulley, 245mm

$d =$ Diameter of smaller pulley, 50mm

$L = 2 \times 60 + \pi/_2 (245 + 50) + ([245 - 50]^2/[4 * 600])$

$= 1200 + 463.40 + 15.84$

$= 1679.24\text{mm}$

From Table 14-2 in Black, (1955), a machine with range of 0.5 - 01.5 hp and a speed of 1800rpm requires a type A standard size v-belt.

3.5.8 Arc of Contact (α)

The angle of contact (α) for the belt and the pulley between the prime mover and counter shaft was calculated as

$$\alpha = 180^\circ - 2\sin^{-1} [D - d]/2C \qquad \text{……………………………(3.21)}$$

$\alpha = 180^\circ - 2\sin^{-1} [245 - 50]/(2 * 600)$

$= 180^\circ - 2\sin^{-1} [0.1625]$

$= 180^\circ - 19^\circ = 161^\circ$

α, in radians $= \alpha * \pi / 180^\circ$

$\alpha = (161^\circ * \pi)/180^\circ$

$= 2.81$ radians

3.5.9 Ratio of Tensions

By using the Euler's formula, the ratio of tensions for a v-belt drive was calculated as:

$$T_1/ T_2 = e^{\mu\alpha\operatorname{cosec}\beta} \qquad \text{…………………………………….(3.22)}$$

Where, T_1 = Tight-side tension, N

T_2 = Slack-side tension, N

μ = Coefficient of friction between belt and pulley, 0.3 to 0.5 (Creamers, 1976)

α = Angle of contact, 2.81 radians

e = Natural logarithm, 2.7183

β = Groove angle of pulley, 38°

$T_1/T_2 = e^{0.4 \times 2.81 \times \text{cosec } 38} = 38.53$ ……………………………(3.23)

$T_1 = 38.53T_2$ ………………………………………(3.24)

3.5.10 Tension in the Belt Transmitting Drive from the Prime Mover to the Splitter

If T_1 and T_2 are the tensions on belt and shaft respectively, using the torque equation (Hannah and Stephens, 1984):

$T = F.r$ ………………………………………(3.25)

Where T = torque, 35.61Nm

r = radius of pulley on shaft of prime mover (490/2) mm.

$T = (T_1 - T_2)r$ ………………………………………(3.26)

$35.61 = [T_1 - T_2](0.245/2)$ ………………………………………(3.27)

Substituting (3.24) in (3.27).

$35.61 = (38.53T_2)\ 0.1225$ ………………………………………(3.28)

$T_2 = 7.75$ N ………………………………………(3.29)

$T_1 = 38.53(7.75) = 298.44$ N ………………………………………(3.30)

Total belt tension, $T_t = T_1 + T_2$

$$= 7.75 + 298.44 = 306.18 \text{ N}$$

3.5.11 Shaft Material and Shaft Size Determination

Materials locally available; which can be machined into desired size was considered for the design of the shaft. Medium carbon steel (C.1040) was chosen which has the following strength properties as stated by ASME (1948):Yield proof stress (S_y) of 82.4kps (568.7MN/m^2) and tensile stress (S_t) of 97kps (668.8MN/m^2). Using the ASME code for steel which gives the steel allowable stress (S_a) the lower value between 18% S_y and 30% S_t is further reduced by 25% when there is stress concentration on the shaft as a result of keyway.

Thus, $0.18S_t = 0.18\ (668.8\ \text{MN/m}^2) = 120.38\text{MN/m}^2$

$0.30S_y = 0.30\ (568.7\ \text{MN/m}^2) = 170.16\text{MN/m}^2$

The lower value is 120.38 MN/m^2. Considering the keyway, the allowable shear stress, S_a is reduced as

$$S_a = (1 - 0.25)*120.38\ \text{MN/m}^2 = 90.3 \times 10^6\ \text{N/m}^2$$

The code for design for transmission shaft of the American standard association (ASA) recommends that the values of bending moment (M_b) and torque acting on the shaft must be multiplied by certain shock and fatigue factors (K_m) and (K_t) respectively, depending on the service conditions. The suddenly applied load with maximum shocks was the condition under which the shaft was designed in this machine. The values of K_m and K_t for this condition range from 1.0-2.0 and 1.0 – 1.5 respectively. Considering a shaft 60cm long and supported by self-aligning bearings as shown in the free body diagram (Fig 3.6). The shear force diagram is shown in fig 3.7.

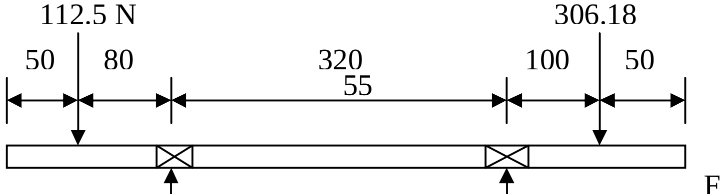

Figure 3.6: The shaft of the ginger splitting machine under loading

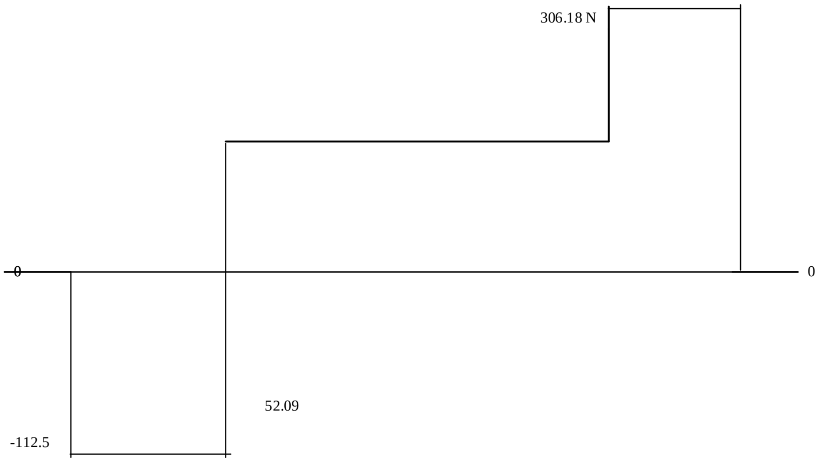

Figure 3.7: Shear force diagram

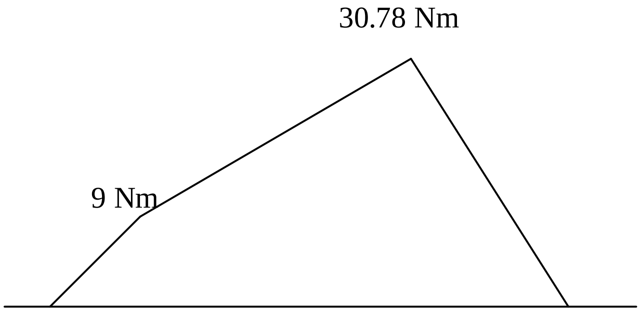

Figure 3.8: Bending moment diagram

Considering vertical forces at equilibrium

$\sum F_v = 0$

$R_1 + R_2 = 112.50 + 306.18 = 418.68N$ ………………………………(3.31)

$\sum M = 0$

Taking moments about R_2

$112.50 * 0.4 - R1 * 0.32 - 306.18 * 0.1 = 0$

$0.32R_1 = 14.38$

$R_1 = 44.94$ N

Substituting for R_1 in (3.31)

$44.94 + R_2 = 418.68$ N

Therefore, $R_2 = 373.736$ N

Bending moments (M_b) at various shaft sections in fig 3.8 were determined as:

$M_A = 0$

$M_B = 0$

$M_C = 112.5(0.08) = 9$ Nm

$M_D = 112.5(0.4) – 44.94(0.32) = 30.78$ Nm

$M_E = 112.5(0.5) – 44.94(0.42) – 373.74(0.1) = 0$

$M_F = 112.5(0.55) – 44.94(0.47) – 373.74(0.15) + 306.18(0.05) = 0$

Maximum bending moment $M_{b(max)}$ = 30.78 Nm and obtains at bearing point D (R_2). Shaft diameter was therefore calculated based on the formula given by Hall et al (1982)

$d^3 = (16/ \pi S_a)\sqrt{[(K_b M_b)^2 + (K_t M_t)^2]}$ ……… ……………………..(3.32

Where, d = diameter of shaft, mm

S_a = allowable shear stress for shafts

$= 90.3 * 10^6$ N/M^2

$K_b = K_t = 1.5$

M_b = bending moment; $M_b = M_{b(max)}$ = 30.78 Nm

M_t = torque moment, 35.61Nm

In determination of shaft diameter the maximum shearing stress is usually replaced by allowable stress.

$d^3 = [16/\pi(90.3 * 10^6)]\sqrt{[(1.5 * 30.78)^2 + (1.5 * 35.61)^2]}$

$d^3 = 3.982*10^{-6}$

$d \geq 15.85$ mm

A 25 mm shaft diameter was selected, giving considerations for bearings.

3.5.12 Selection of Bearings

The bearings of a shaft or other rotating piece must be able to permit the free rotation of the shaft. For the purpose of this work, a sealed ball bearing was selected since the load on the shaft is an axial load arrangement. The diameter of the chosen bearing was as close to the shaft diameter as possible so as to be tight fitted on the shaft.

3.5.13 Design of Cutting Blade

Considering the knife blade to be a beam of rectangular cross section with width, b and thickness, t, the moment of inertia is

$I = bt^3/12$

Considering moment of impellers due to rotation $= \text{moment on blade}$

$= 112.5\text{N} * 0.15\text{m}$

$= 16.88\text{Nm}$

Using the flexural formula (Shigley and Mitchell, 1986),

$\gamma_b = M_b y/I$ ……………………………………….(3.33)

Where, γ_b = bending stress (N/m^2)

$y = t/2$

$I = bt^3/12$

y = Centroidal axis (mm)

I = Moment of inertia (mm^4)

b = Width of blade (Set b = 50mm)

t = Thickness of blade (mm)

Assuming that the blade is made of high carbon steel with yield stress, γ_b of 4.2×10^8 N/m^2 (Mark, 1951).

Substituting for γ_b in the formula (3.33)

$4.2 * 10^8 = (16.88 * t * 12)/(0.05 * 2 * t^3)$

Therefore, $t^2 = (16.88 * 12)/(4.2 \times 10^8 * 0.05 * 2)$

$t^2 = 0.000004822$

$t = \sqrt{[0.000004822]} = 0.0022$ m

$t \geq 2.2$ mm

3.6 Performance Evaluation

3.6.1 Experimental Procedures

A constant weight of 500g of each ginger variety was fed singly into the hopper to avoid obstruction due to the irregular shape of the rhizomes. Each of three tests was repeated thrice. The split ginger rhizomes were discharged to the outlet by the motion of the impeller. The splits were collected at the outlet and weighed to determine the amount of material loss. Ginger rhizomes completely split were separated and weighed to determine the splitting efficiency. The remaining ginger rhizomes bruised or broken were also weighed on the Mettler balance.

The impeller speed was adjusted by using a petrol type prime move with variable speed. Time for splitting was recorded for each experimental run using a digital watch so as to determine the through put capacity of the machine.

3.6.2 Instrumentation and Measurement for Equipment Performance Evaluation

1. Weight Measurement

Sample weights before and after the experimental run was determined using a mettler model (PN1210) top loading balance. The balance has a capacity of 1600g and has an accuracy of 0.01g.

2. Shaft speed

Shaft rotational speed (rpm) for the splitter was measured using a LUTRON Digital photo/contact Tachometer. This instrument has a wide measuring range (0.5 to 100,000 rpm) and with an accuracy of 0.05 % + 1 digit. The instrument selects test range automatically and does not require any calibration before conducting the test.

3. Time Measurements

A digital watch was used in the course of study to record the timings taken to complete splitting. The stop watch used had a stop and reset function. The watch also gave readings correct to two decimal places.

3.6.3 Experimental design

The splitting speed, moisture content and Crop varieties were taken as independent parameters for the study. The moisture content of the two ginger varieties was selected at three levels. The first level was defined when freshly harvested. The second and third levels were defined after one and two weeks of harvest respectively. The conventional practice is that farmers harvest and keep ginger rhizomes under shades and splitting operations done gradually depending on availability of time and labour. The peripheral speed of the impellers was varied from 240-288rpm at five levels in order to determine the optimum speed required in splitting ginger rhizomes. The Tafin Giwa and Yatsun Biri varieties of the crop were used for the study. These factors of study were varied as follows:

Factor of study	Level
Moisture content (%), M	3 levels (84.4, 77.6 and 68.2% wet basis) as MC1,MC2 and MC3
Speed (rpm), S	5 levels (240, 284, 326, 345 and 388 rpm) as S1,S2….S5

Crop variety (Nominal), C 2 levels (Tafin Giwa and Yatsun Biri varieties of ginger)

This parameters gave a 3 x 5 x 2 factorial experiment fitted into a completely randomize design (CRD). This gave a total of 30 combinations or treatments. The experiment was repeated thrice giving a total of 90 experimental runs.

3.6.4 Performance Indicators

The performance of the machine was evaluated based on the following performance indicators:

(a) Splitting efficiency, SE (%) = 100 $[Q_{CSU}/ Q_o]$ ………………3.34

(b) Percentage Bruise, PB (%) = 100 $[Q_{BB} / Q_o]$ ………………3.35

(c) Material loss, M. loss(%) =100 $[Q_L / Q_F]$ ………………3.36

(d) Throughput capacity, C_T (kg/hr) = $[Q_o / t]$ ………………3.37

Where,

Q_f = Total quantity of ginger fed into machine, g

Q_o = Total quantity of ginger collected at outlet, g

Q_L = Total quantity of ginger lost in machine, g

Q_{CSU} = Total quantity of ginger completely split unbruised, g

Q_{BB} = Total quantity of ginger bruised or broken, g

t = Time taken to complete splitting (seconds)

Equations 3.34 – 3.37 were adapted from similar works reported by Kachru, *et al.* (1996) and Simonyan *et al*. (2003).

3.6.5 Statistical Analysis

The student t- test was used to compare the data of the physical and mechanical properties of the two ginger varieties at the 5% level of significance. Data for the performance evaluation were subjected to the analysis of variance (ANOVA) for the test of significance of experimental factors and their interactions. Mean separation with observed significant differences was compared using the Duncan's Multiple Range Tests (DMRT). The analysis of variance for each factor was done using the Genstat statistical software package. A significance level of probability ($P<0.05$) was used for all analyses.

Relationship between performance indicators and the influencing factors were determined using linear regression techniques. Graphical plots/ regression trends and their statistics were generated using both Microsoft Excel and Genstat software packages.

CHAPTER 4 RESULTS

4.1 Preliminary Experiment: Design Related Physical and Mechanical Properties of the Tafin Giwa and Yatsun Biri Varieties of Ginger

A summary of the axial dimensions (length, width and thickness) of both Tafin Giwa and Yatsun Biri varieties of ginger are presented in Table 4.1. The axial dimension of the two ginger varieties was compared using the student t-.test at 5% level of significance. The result showed that the axial dimensions of Tafin Giwa ginger variety were significantly different from those of Yatsun Biri ($P< 0.01$).

Table 4.2 shows the means of mass, volume, density, angle of repose and shearforce of Tafin Giwa and Yatsun Biri ginger varieties. It was observed that mean values of mass, volume, density and surface area of Tafin Giwa were found to be significant ($P< 0.01$) when compared with those obtained for Yatsun Biri . However there was no significant difference between the mean angles of repose and shear force of the two ginger varieties.

4.2 Performance Evaluation of the Ginger Splitting Machine

4.2.1 Effect of moisture content, speed and crop variety on splitting efficiency

Effect of moisture content on splitting efficiency: The results of moisture content on splitting efficiency are presented in Table 4.4. The 84.35% moisture content corresponds to highest splitting efficiency of 66.99%. This was followed by 68.2% moisture content with a splitting efficiency of 59.98%. The lowest splitting efficiency (56.35%) was however recorded at 77.6% moisture content. From Table 4.3, splitting efficiency increases with increasing moisture content between 68.2 and 77.6% moisture

Table 4.1 Summary of axial dimensions and surface area of fresh Tafin Giwa and Yatsun Biri ginger varieties at 84% (MCWb)

Variety	Statistics	Length (cm)	Width (cm)	Thickness (cm)	Surface area (cm^2)
Tafin Giwa	Min	8.90	5.35	1.86	26.06
	Max	14.30	9.40	3.02	71.92
	Mean	10.65	6.92	2.38	55.82
	S.D	1.44	1.08	0.26	10.94
Yatsun Biri	Min	4.44	2.88	1.56	26.70
	Max	10.96	6.78	2.42	59.16
	Mean	8.20	4.51	1.83	38.76
	S.D	1.51	0.95	0.19	9.93

Min=Minimum dimension, Max =Maximum dimension, Mean= Mean dimension, S.D = Standard deviation

Table 4.2: Summary of mass, volume, density and shear force of fresh Tafin Giwa and Yatsun Biri ginger varieties at 84% moisture content (Wet Basis)

Variety	Statistics	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Angle of Repose (º)	Shear Force (N)
Tafin Giwa	Min	43.29	30	0.370	26.60	50
	Max	110.02	300	1.650	31.90	145
	Mean	65.25	65.92	1.00	30.38	95.9
	S.D	15.78	34.26	0.123	1.14	23.2
Yatsun Biri	Min	12.99	15.00	0.520	27.30	17
	Max	47.67	50.00	0.979	31.70	130
	Mean	24.57	28.28	0.872	29.79	84.3
	S.D	7.99	8.36	0.11	1.45	26

Min=Minimum dimension, Max =Maximum dimension, Mean= Mean dimension, S.D = Standard deviation content and increases between the 77.6 and 84.35% moisture range. High water content in ginger fibres allows easy blade penetration. Analysis of variance (ANOVA) showed that moisture content had highly significant effect on splitting efficiency (Table 4.4).

Effect of impeller speed on splitting efficiency: The results of impeller speeds on splitting efficiency are presented in Table 4.5. It was observed that splitting efficiency generally decreased with increase in impeller speed. Splitting efficiency was highest (69.13%) at 240 rpm and decreased significantly to 57.44% at 388 rpm. The decrease in splitting efficiency with increase in impeller speed within the study range can be attributed to the high impact of force of the impeller which results or breaks in-coming rhizomes high speeds, indicating that less ginger rhizomes are fed to the splitting chamber by the impeller at high speeds of the impeller. Analysis of variance (ANOVA) showed that impeller speed had a highly significant effect on splitting efficiency ($p<0.01$).

Effect of crop variety on splitting efficiency: The results of crop variety on splitting efficiency showed that Tafin Giwa (C_1) had higher splitting efficiency 68.05%) to that of Yatsun Biri (C_2) with a splitting efficiency of 54.17%. This could be due to the large sizes of the Tafin Giwa variety in relation to the shape of the splitting chamber. The analysis of variance (ANOVA) showed that crop variety had highly significant effect on splitting efficiency ($p<0.01$).

Table 4.3 Mean splitting efficiency at different moisture contents.

	Moisture content (% wet basis)		
	84.35	77.6	68.2
Splitting efficiency	66.99 a	56.35 c	59.98 b

Means followed by the same letter are not significantly different.

Table 4.4: Analysis of variance (ANOVA) for Splitting Efficiency

Source of variation	d.f.	s.s.	m.s.	v. r.	F< pr.
Moisture	2	1755.20	877.60	21.45	<0.001**
Speed	4	2604.77	651.19	15.92	<0.001**
Moisture.speed	8	624.28	78.04	1.91	0.075 ns
Crop_Var	1	4335.99	4335.99	106.0	<0.001**
Moisture.Crop_Var	2	833.37	416.69	10.19	<0.001**
Speed.Crop_Var	4	306.94	76.74	1.88	0.126 ns
Moisture.Speed. Crop Var	8	772.69	96.59	2.36	0.028 *
Residual	60	2454.30	40.91		
Total	89	13687.55			

* = Significant at the 5% level; ** = Significant at the 1% level; ns = Not Significant

Table 4.5: Mean splitting efficiency at various impeller speeds

	Impeller speed (Rpm)				
	240	284	326	345	388
Mean (%)	69.13_{a}	64.84_{b}	60.24_{c}	53.88_{d}	57.44_{cd}

Means followed by the same letter are not significantly different.

Effect of interaction of moisture content and impeller speed on splitting efficiency: The interaction of moisture content and speed showed no significant effect on splitting efficiency. Interaction of moisture content and crop variety was highly significant on splitting efficiency (Table 4.6). It was observed that Tafin Giwa variety generally had higher splitting efficiency than Yatsun Biri ginger variety at all moisture contents levels. Table 4.6 also showed a general decrease in splitting efficiency with decreasing moisture content for both Tafin Giwa and Yatsun Biri ginger varieties. Analysis of variance (ANOVA) showed that combination of moistures content and crop variety had highly significant effect on splitting efficiency (Table 4.3). The interaction of impeller speed and crop variety on splitting efficiency was however not significant.

Effect of interaction of moisture content, impeller speed and crop varietyr speed on splitting efficiency: The results of the variation on splitting efficiency at different impeller speeds of the two ginger varieties are presented in Table 4.7. The effects are plotted in Figures 4.1 and 4.2 respectively. From Figure 4.1, splitting efficiency of Tafin Giwa at 84.4% moisture content decreased from 82.09% at 240 rpm to 66.99% at 388rpm. At 77.6% moisture content, the splitting efficiency decreased from 72.20% at 240 rpm to 66.18% at 388rpm. At 68.2% moisture content, the splitting efficiency decreased from 66.69% at 240 rpm to 57.67% at 388rpm.

Table 4.6: Interaction of moisture content and crop variety on mean splitting efficiency

Moisture content (%), Wet basis	Crop Variety	
	Tafin Giwa(c1)	Yatsun Biri (C2)
84.35	74.76 a	59.23 cd
77.6	66.54 b	46.16 e
68.2	62.85 bc	57. 11 d

Means followed by the same letter are not significantly.

It was observed that the highest splitting efficiency of Tafin. Giwa ginger was at 84.35% moisture content, followed by 77.6% moisture content and the least at 68.2% moisture content. It shows that the splitting efficiency of Tafin Giwa ginger decreases with decrease in moisture content. Higher splitting efficiencies were observed at lower impeller speeds at all moisture content levels.

The trend of the plot in Figure 4.2 showed that splitting efficiency of Yatsun Biri ginger variety at 84.35% moisture contents decreased from 67.95% at 240rpm to 64.08% at 388rpm. At 77.6% moisture content, the splitting efficiency decreased from 49.97% at 240 rpm to 45.79% at 388rpm. At 68.2% moisture content, the splitting efficiency decreased from 75.90% at 240 rpm to 43.94% at 388rpm. From the results, it was observed that there was a general decrease in splitting efficiency with the decrease in impeller speed. Higher splitting efficiencies were observed at lower speeds of the impeller. A decreased splitting efficiency with decrease in moisture content was also observed at all speed settings except at 68.2% moisture content level. The deviation from the general trend as observed at 68.2% moisture content could be attributed to the irregular sizes of Yatsun Biri in relation to the operating speed of the machine. The

Table 4.7: Interaction of moisture content, speed and crop variety on splitting efficiency

	Moisture content (% wet basis)														
	84.35					77.6					68.2				
	Impeller speed (RPM)					Impeller speed (RPM)					Impeller speed (RPM)				
Crop variety	240	284	326	345	388	240	284	326	345	388	240	284	326	345	388
Tafin Giwa (Ci)	82.09 a	80.09 a	74.18 Abc	70.42 Abc	66.99 Bcd	72.20 Abc	66.54 bcd	64.36 Cde	63.42 Bcde	66.18 Bcd	66.69 bcd	65.86 bcd	66.89 bcd	57.15 def	57.67 def
Yatsun Biri (C2)	67.95 bcd	65.28 Bcd	57.10 def	41.73 g	64.08 Bcde	49.97 Fg	48.16 fg	45.97 Fg	40.94 G	45.79 Fg	75.90 ab	63.10 cde	52.96 efg	49.65 fg	43.94 g

Means followed by the same letter are not significantly different

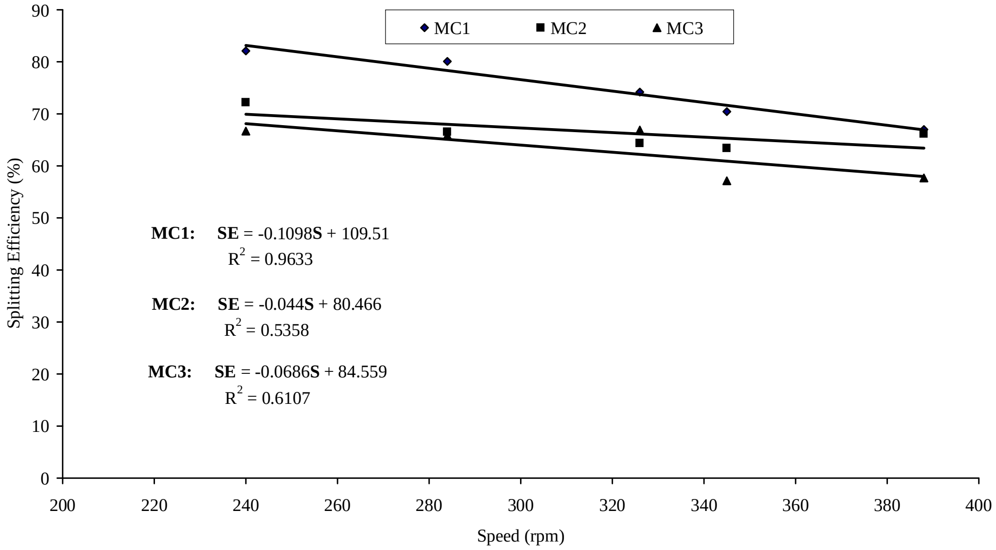

Figure 4.1: Effect of speed and moisture content on splitting efficiency for the Tafin Giwa ginger variety

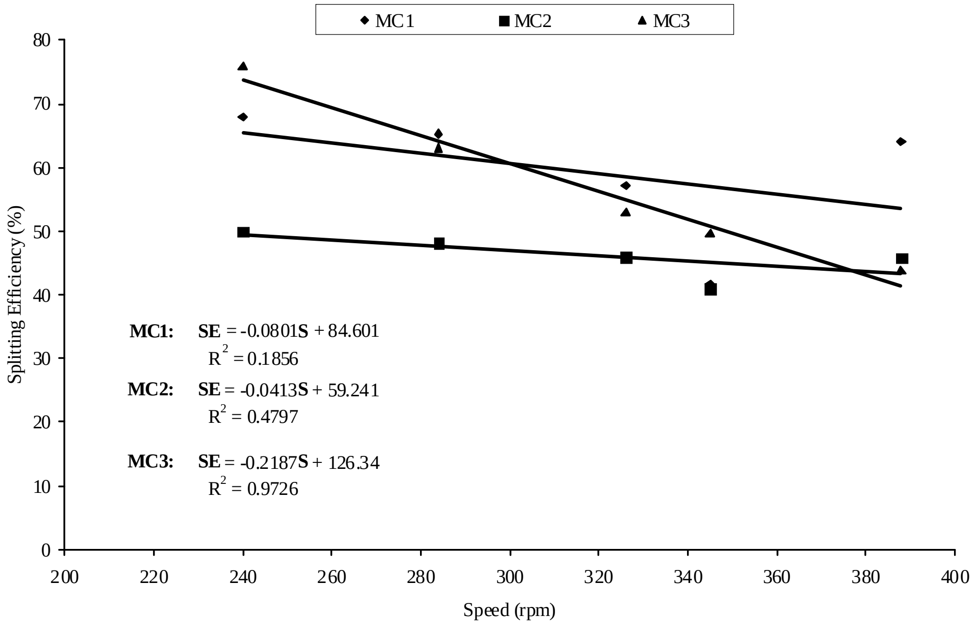

Figure 4.2: Effect of speed and moisture content on splitting efficiency for the Yasun Biri ginger variety

increase in splitting efficiency of both ginger varieties with increased moisture contents within the study range might be attributed to the fibrous nature of ginger rhizomes which are usually softer at higher moisture contents due to the high water molecules of

ginger when freshly harvested is believed to be responsible for this trend. With decrease in moisture content, splitting becomes difficult due to shrinkage of the ginger rhizomes. This tends to increase the fibrousness of ginger rhizomes hence, the tendency for low splitting efficiency. Decrease in slicing efficiency due to decrease moisture content has been reported by Simonyan *et al*. (2003) for Tafin Giwa ginger variety and Balasubramanian *et al.* (1993) for cassava .

The results of interaction of moisture, speed and crop variety on splitting efficiency for the two ginger varieties are also presented in Table 4.7 and their effect presented in Figures 4.3 - 4.5.respectively. At 84.4% moisture content, the slitting efficiency of Tafin Giwa from 82.09% at 240 rpm to 66.99% at 388 rpm, while that of Yatsun Biri decreased from 67.95% at 240 rpm to 64.08% at 388 rpm. At 77.6% moisture content, splitting efficiency of Tafin Giwa decreased from 72.20% at 240 rpm to 66.18% at 388 rpm and that of Yatsun Biri ginger variety from 49.97% at 240 rpm to 45.79% at 388 rpm. At 68.2% moisture content, the splitting efficiency of Tafin Giwa ginger decreased from 66.69% at 240 rpm to 57.67% at 388 rpm, while that of Yatsun Biri ginger decreased from 73.90% at 240 rpm to 43.94% at 388 rpm. From Figures 4.3-4.5, it was observed that splitting efficiency generally decreases linearly with increase in impeller speeds for both Tafin Giwa and Yatusn Biri ginger varieties at all moisture contents.

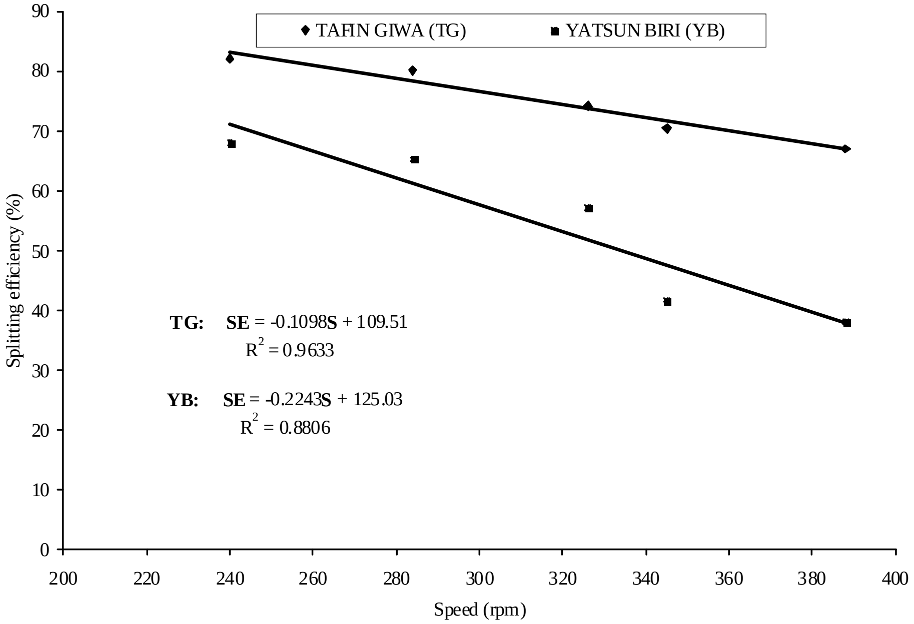

Figure 4.3: Effect of speed and crop variety on splitting efficiency at 84.4% moisture content of the rhizomes

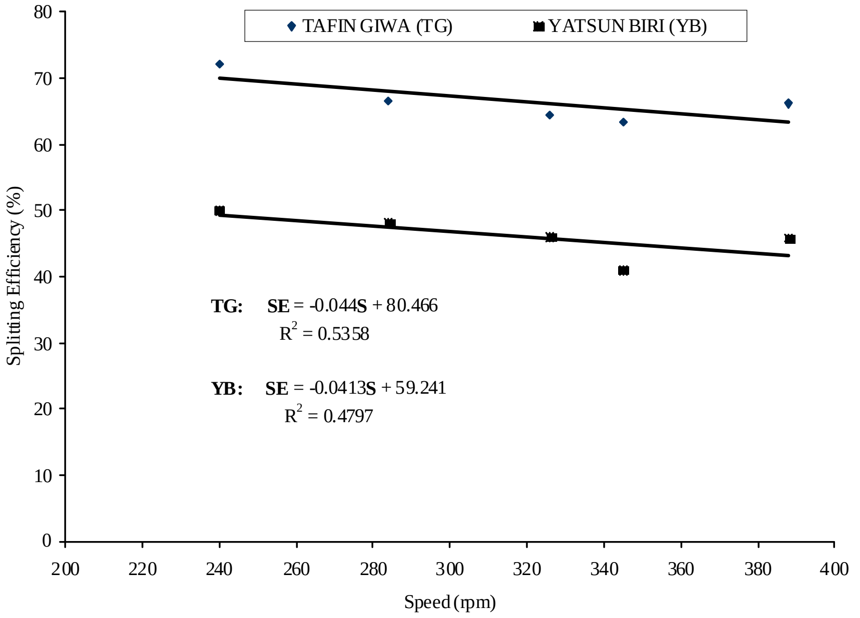

Figure 4.4: Effect of speed and moisture content on splitting efficiency at 77.6% moisture content of the ginger rhizome

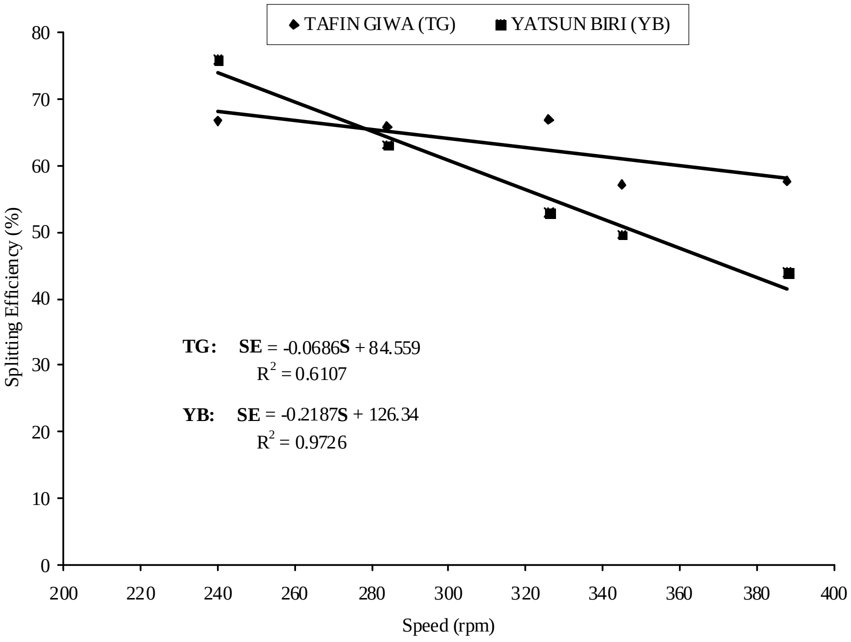

Figure 4.5: Effect of speed and crop variety on splitting efficiency at 68.2% moisture content of the ginger rhizome

At all speed settings, Tafin Giwa ginger generally had higher splitting efficiency than Yatsun Biri at 84.4% and 77.8% moisture contents, except at 68.2% moisture content where the splitting efficiencies of the two ginger varieties were equal at 284 rpm. The higher splitting efficiency of Tafin Giwa to that of Yatsun Biri may be due to the larger sizes of Tafin Giwa in relation to the width of the splitting chamber. The deviation from the general trend at 68.2% moisture content could be due to the shrinkage of the Yatsun Biri ginger, which has smaller sizes, which tends to escape by the sides of the blade at the point of impact with the impeller.

The linear regression trends of splitting efficiency at different impeller speeds and for the two ginger varieties and at three moisture content levels studied are as follows:

Tafin Giwa Ginger Variety

MC_1: $SE = -0.1098\mathbf{S} + 109.51$, $R^2 = 0.9633$

MC_2: $SE = -0.0686\mathbf{S} + 80.466$, $R^2 = 0.5358$

MC_3: $SE = -0.0686\mathbf{S} + 84.559$, $R^2 = 0.6107$

Yatsun Biri ginger variety

MC_1: $SE = -0.0801\mathbf{S} + 84.601$, $R^2 = 0.1856$

MC_2: $SE = -0.0413\mathbf{S} + 59.241$, $R^2 = 0.4797$

MC$_3$: SE = -0.2187**S** + 126.34, R^2 = 0.9726

Where, MC$_1$ = 84.35 moisture content, wet basis

MC$_2$ = 77.6 % moisture content, wet basis

MC$_3$ = 68.2 % moisture content, wet basis

S = Impeller speed (m/s)

SE = Splitting efficiency (%)

R^2 = Coefficient of determination

The speed based linear regression trends generated for Tafin Giwa at the various moisture contents of ginger rhizomes had acceptable coefficients of determination (0.54 – 0.96). This was not so for the Yatsun Biri variety at the higher moisture contents of 77.6% and 84.35% as the R^2 values were low at 0.19 and 0.48, respectively, suggesting that splitting efficiency for this variety at these levels of moisture is not linearly related to the speed of operation of the impeller. However, for this variety, at 68.2% moisture content, with an R^2 value of 0.97, a linear trend adequately describes the equipment splitting efficiency based on impeller speed within the range of the operational speeds studied.

4.2.2 Effect of Moisture Content, Speed and Crop Variety on Percentage Bruise and Broken Ginger

Effect of Moisture Content on Percentage Bruise and Broken Ginger: The results of effect of moisture content on percentage of bruised and broken ginger are presented in Table 4.8. From the figure, the lowest percentage of bruised and broken ginger

Table 4.8: Mean Percentage of bruised and broken ginger at different moisture content

	Moisture content (% wet basis)		
	84.35	77.6	68.2
Mean	33.08 c	43.94 a	39.90 b

Means followed by the same letter are not significantly different.

Table 4.9: Analysis of variance (ANOVA) for Percentage Bruised and Broken Ginger

Source of variation	d.f.	s.s.	m.s.	v.r.	F < Pr.
Moisture	2	1807.78	903.89	23.31	<0.001 **
Speed	4	2431.06	607.76	15.67	<0.001 **
Moisture.speed	8	645.09	80.64	2.08	0.052 ns
Crop_Var	1	4133.37	4133.37	106.58	<0.001**
Moisture.Crop Var	2	803.08	401.54	10.35	<0.001**
Speed.Crop_Var	4	360.06	90.01	2.32	0.067 ns
Moisture.Speed. Crop_Va	8	688.75	86.09	2.22	0. 038 *
Residual	60	2327.01	38.78		
Total	89	13196.20			

* = Significant at the 5% level; ** = Significant at the 1% level; ns = Not significant

(33.08%) was obtained at 84.4%% moisture content, followed by 39.90% at 68.2% moisture content. The highest mean of percentage bruised and broken ginger was of (43.94%) was recorded at 77.6% moisture content. This may be owing to the irregular structure of the ginger rhizomes, as they are fed into the machine. From these, the 84.4% moisture content is considered as the best condition for splitting ginger rhizomes since it gave the lowest value of bruised and broken ginger. The analysis of variance (ANOVA) in Table 4.9 showed that moisture content had a highly significant effect on percentage of bruised and broken ginger.

Effect of speed on percentage of bruised and broken ginger rhizomes: The analysis of variance (ANOVA) presented in Table 4.9 showed that the effect of speed on the percentage of bruised and broken ginger was highly significant at 1% level of significance. The mean percentage of bruised and broken ginger at 240, 284 and 326 rpm were at par, being 31.36, 38.23 and 39.78% (Table 4.10). Percentage of bruised and broken ginger increased significantly to 46.12% at 345rpm. The decrease in percentage of bruised and broken ginger from 46.12% at 345 rpm to 42.3% at 388 rpm was, however, not significant. This shows that higher percentage of bruised and broken ginger rhizomes could be obtained at higher speeds of the impeller, implying the highest performance of the machine and better be obtained at the lowest speed (240 rpm).

Effect of crop variety on percentage of bruised and broken ginger rhizomes: The effect of crop variety on percentage of bruised and broken ginger showed that Yatsun Biri had higher mean percentage of bruised and broken ginger rhizomes (45.75%) compared with 32.20% obtained for Tafin Giwa. The smaller sizes of Yatsun Biri might have accounted for the higher percentage of bruises as a lot of the bruised and broken ginger pieces were associated with the Yatsun Biri ginger variety.

Effect of interaction of moisture content and impeller speed on percentage of bruised and broken ginger rhizomes: The interaction of moisture content and impeller speed on percentage of bruised and broken ginger was however not significant. The interaction of moisture content and crop variety on percentage of bruised and broken ginger are presented in Table 4.11. At 84.4% moisture content, the percentage of bruised and broken of Yatsun Biri ginger (40.77%) was significantly higher than that obtained for Tafin Giwa (25.39%). At 77.6% and 68.2% moisture content, the percentage of bruised and broken Yatsun Biri ginger were 53.84 and 42.65% compared with 34.05 and 37.15% respectively obtained for Tafin Giwa ginger variety. From the results, it was observed that Yatsun Biri ginger variety gave higher percentage of bruised and broken ginger rhizomes than Tafin Giwa at all moisture contents.

The effects the interactions of moisture content, speed and crop variety on percentage of bruised and broken ginger rhizomes: The effects the interactions of moisture content, speed and crop variety - on percentage of bruised and broken ginger are presented in Table 4.12. From Table 4.12, it was observed that the percentage of bruised and broken Tafin Giwa at 84.4% varied from 17.93% at 240 rpm to 33.00% at 388 rpm. At 77.6% moisture content, it varied from

30.72% at 240rpm to 33.82% at 388 rpm. At 68.2%, the percentage of bruised and broken Tafin Giwa also varied from 33.31% at 240 rpm to 42.33% at 388 rpm. The highest percentage of bruised and broken Tafin Giwa was recorded at

Table 4.10: Mean Percentage of bruised and broken ginger at various Impeller speeds

	Impeller speed (Rpm)				
	240	284	326	345	388
Percentage Bruised or Broken Ginger	31.36 b	35.23 b	39.78 b	46.12 a	42.3 a

Means followed by the same letter are not significantly different.

Table 4.11: Interaction of Moisture content and crop variance on mean percentage of bruised and broken ginger.

	Crop variety	
Moisture content (% wet basis)	Tafin Giwa(C1)	Yatsun Biri (C2)
84.35	25.39 f	40.77 bc
77.6	34.05 de	53.84 a
68.2	37.15 cd	42.65 b

Means followed by the same letter are not significant

68.2% moisture content, followed by 77.6% moisture content, and the least percentage of bruised and broken ginger was however obtained at 84.4% moisture content.

From Table 4.12, Yatsun Biri ginger variety at 84.4% moisture content had a percentage of bruised and broken ginger of 32.03% at 240 rpm, which increased to 35.92% at 388 rpm. At 77.6% moisture content the percentage of bruised and broken ginger increased linearly from 50.03% at 240rpm t0 54.21% at 388rpm. At 68.2% moisture content, the percentage of bruised and broken ginger increased from 24.10% to 240 rpm to 54.90% at 388 rpm. From these, the highest percentage of bruised and broken ginger was recorded at 77.6% moisture content. This was followed by the values obtained at 68.2% moisture content. The lowest percentage of bruised and broken ginger was recorded at 84.4% moisture content. From Figures 4.6 and 4.7, it was observed that percentage of bruised and broken ginger increased with decrease in moisture content and with increasing speed. The deviation from the trends in Figure 4.7 at 68.2% and 77.6% moisture contents could be due to the variation in the physical structure of ginger rhizomes with the tested speed ranges.

Table 4.12: Interaction of moisture content, speed and crop variety on percentage of bruised and broken ginger rhizomes

	Moisture content (% wet basis)														
	84.35					77.6					68.2				
	Impeller speed (RPM)					Impeller speed (RPM)					Impeller speed (RPM)				
Crop variety	240	284	326	345	388	240	284	326	345	388	240	284	326	345	388
Tafin Giwa	17.93	20.50	25.95	29.58	33.00	30.72	33.46	35.66	36.58	33.82	33.31	34.14	33.11	42.85	42.33
(Ci)	Bc	bc	fghi	fgh	fgh	efg	efg	defg	def	efg	efg	efg	efg	cde	cde
Yatsun	32.03	34.72	42.90	58.27	35.92	50.03	51.84	34.03	59.06	54.21	24.10	36.83	47.04	50.35	54.90
Biri (C2)	efg	efg	cde	ab	defg	abc	abc	abc	a	abc	fghi	def	bcd	abc	ab

Means with the same letter are not significantly different

The effects of speed and crop variety on percentage of bruised and broken ginger at different moisture contents and presented in Figures 4.8 – 4.10. The results showed that the percentage of bruised and broken Yatsun Biri at 84.4% moisture content from 32.03% at 240 rpm to 35.92% at 388 rpm, while that of Tafin Giwa varied linearly from 17.93% at 240 rpm to 33.00 at 388 rpm. At 77.6% moisture content, percentage of bruised and broken Yatsun Biri ginger varied from 30.72% at 240rpm to 33.82% at 388rpm. At 68.2% moisture contents the percentage of bruised and broken ginger varied linearly from 24.10% at 240 rpm to 54.90 at 388 rpm, while that of Tafin Giwa varied from 33.31% at 240 rpm to 42.33% at 388 rpm. From these, it was observed in Figures 4.8 – 4.10 that at the same speed setting, Yatsun Biri ginger generally had higher percentage of bruised and broken ginger rhizomes than Tafin Giwa at all moisture contents. The trends of the two ginger varieties also showed that percentage of bruised and broken ginger generally increased with corresponding increase in impeller speed within the tested moisture contents and speed levels, thus indicating that lower percentage of bruised and broken ginger are better obtained at lower speed and at high moisture content.

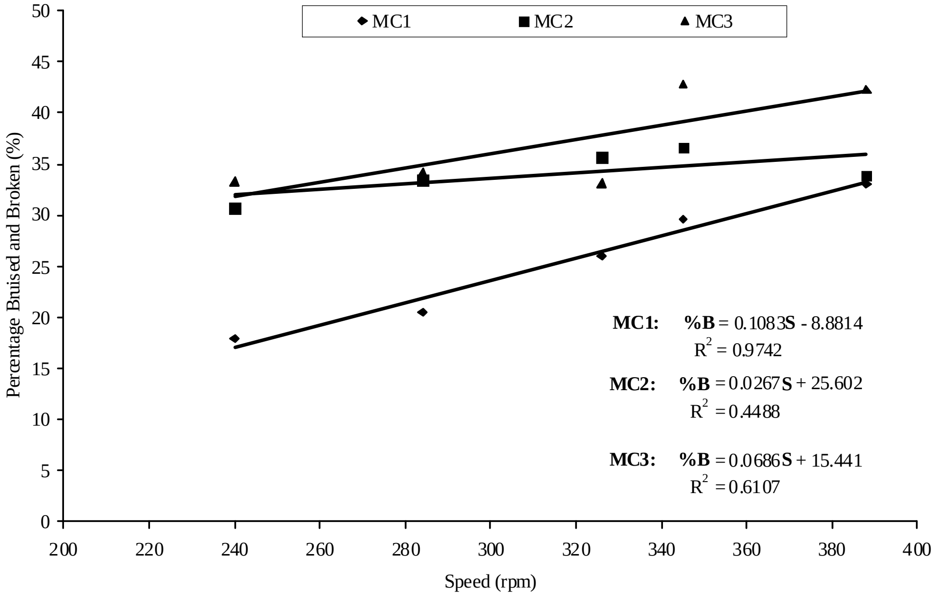

Figure 4.6: Effect of speed and moisture content on percentage bruised and broken ginger rhizomes for the Tafin Giwa ginger variety

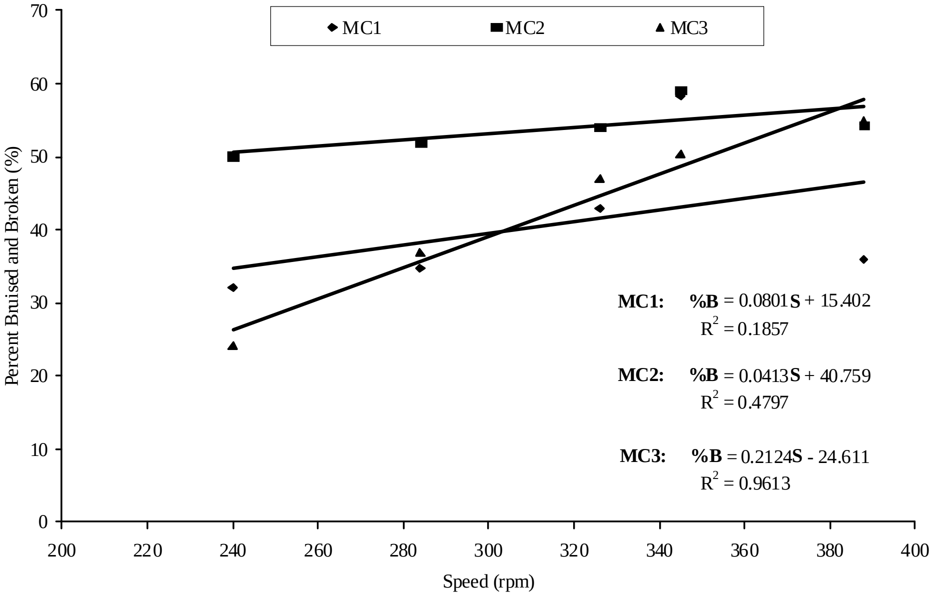

Figure 4.7: Effect of speed and moisture content on the percentage of bruised and broken rhizomes for the Yatsun Biri ginger variety

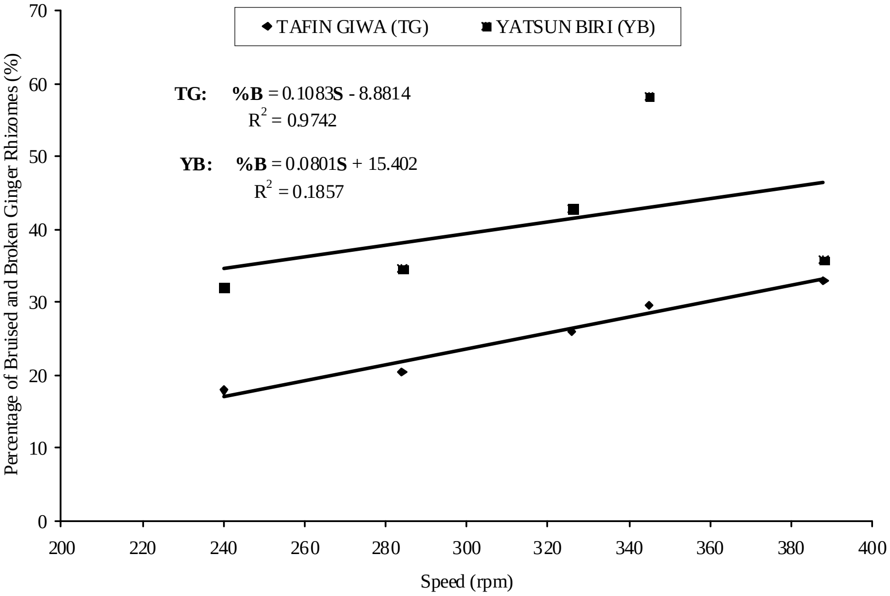

Figure 4.8: Effect of speed and crop variety on percentage of bruised and broken ginger rhizomes at 84.4% moisture content of the ginger rhizome

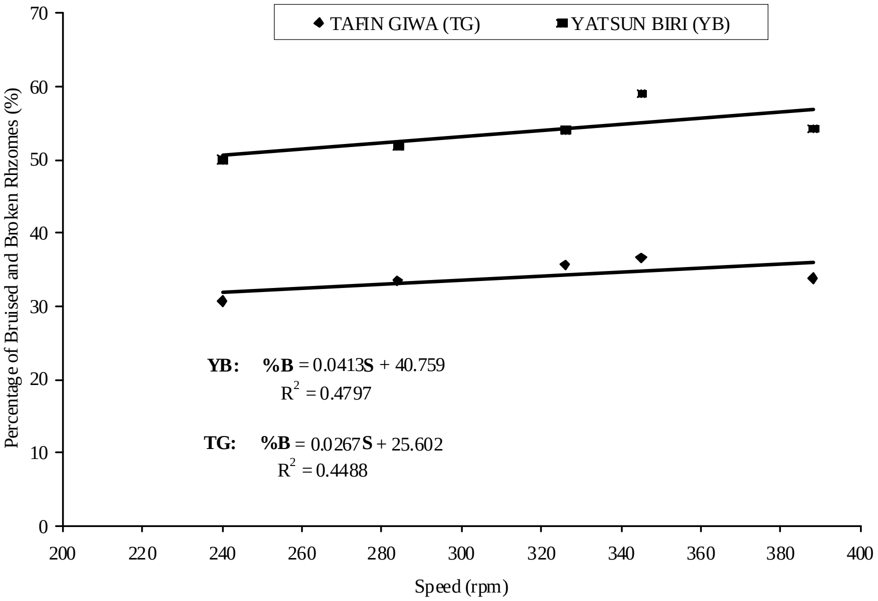

Figure 4.9: Effect of speed and crop variety on percentage of bruised and broken ginger rhizomes at 77.6% moisture content of the rhizome

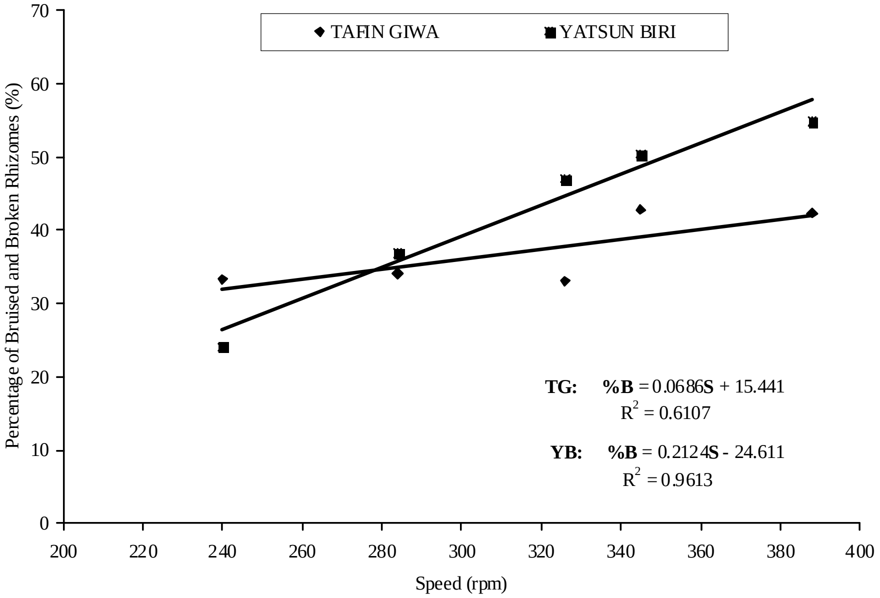

Figure 4.10: Effect of speed and crop variety on percentage of bruised and broken ginger rhizomes at 68.2% moisture content of the ginger rhizome

Analysis of variance (ANOVA) showed that the interaction of moisture content, impeller speed and crop variety had a significant effect on percentage of bruised and broken ginger at 5%level of significance (Table 4.9). The relationships existing between impeller speed and percentage of bruised and broken ginger (%B) for the two ginger varieties at the three moisture contents levels is linear and can be represented by the following regression equations:

Tafin Giwa ginger variety

MC_1: $\%B = 0.1083\mathbf{S} - 8.8814$, $R^2 = 0.9742$

MC_2: $\%B = 0.0267\mathbf{S} + 25.602$, $R^2 = 0.4488$

MC_3: $\%B = 0.0686\mathbf{S} + 15.441$, $R^2 = 0.6107$

Yatsun Biri ginger variety

MC_1: $\%B = 0.0801\mathbf{S} + 15.402$, $R^2 = 0.1857$

MC_2: $\%B = 0.0413\mathbf{S} + 40.759$, $R^2 = 0.4797$

MC_3: $\%B = 0.2124\mathbf{S} - 24.611$, $R^2 = 0.9613$

Where, MC_1, MC_2 and MC_3 are the 84.35, 77.6 and 68.2% moisture contents, in wet basis, respectively; S is impeller speed (m/s); %B is the Percentage of bruised and broken ginger (%); and R^2 is the coefficient of determination.

4.2.3 Effect of Moisture Content, Speed and Crop Variety on material Loss

The effects of different levels of moisture content on material loss are presented in Table 4.13. It was observed that the highest mean material loss of 5.82% was at 77.6% moisture content which was statistically at par with the mean material loss of 5.22% obtained at 84.35% moisture content, but highly significant compared to the mean material loss of 4.00% at 68.2% Moisture content. The insignificant difference of the 5.22% and 5.82% levels of material loss at 84.35% and 77.6 % moisture contents suggests that higher materials loss is associated with ginger rhizomes at higher levels of moisture content. The analysis of variance (ANOVA) for material loss is presented in Table 4.14. The result showed that only moisture content had significant effect on material loss at 5% level of significance. Other factors and their interactions were however not significant.

4.2.4 Effect of Moisture Content, Speed and Crop variety on throughput capacity

The results of different moisture content levels on throughput capacity are presented in Table 4.15. The result showed that the highest mean throughput capacity of 71.19gk/hr was observed at 68.2% moisture content. This was followed by a mean throughput capacity of 64.14kg/hr at 84.35% moisture content. The minimum throughput capacity of 60.31Kg/hr was observed at the 77.6% moisture content.

The analysis of Variance (ANOVA) for throughput capacity is presented in Table 4.16. It showed highly significant effect of moisture content and the interaction of Moisture content and speed at 1 and 5% level of significance. The effects of other factors and their interactions was however not significant.

Effect of interaction of moisture content and speed on throughput capacity: The results of the interaction of moisture content and speed are presented in table 4.17. The trend showed no significant increase in throughput capacity of ginger rhizomes with increase in speed. At 84.35% moisture content, the lowest throughput capacity (60.03Kg/hr) was obtained at 284rpm, while the highest (70.9Kg/hr) was obtained. At 77.6% moisture content, there was no significant difference in throughput capacity. The lowest throughput capacity at 68.2% moisture content was obtained at 240rpm while the highest (75.03Kg/hr) was obtained at 284rpm. moisture content. This was followed by a mean throughput capacity of 64.14kg/hr at 84.35% moisture content. The least throughput capacity of 60.31 kg/hr was observed at 77.6% moisture content. The higher throughput capacity at lower moisture content may be due to shrinkage of the ginger rhizomes. As a result many ginger rhizomes enter splitting chamber at a time and are impelled without being split due to their small sizes. The result of the interaction of moisture content and speed on throughput capacity are presented in the trend showed no significant increase in throughput capacity of ginger rhizomes with increase in speed. At 84.35% moisture content, the lowest throughput capacity (60.03kg/hr) was observed at 284-rpm impeller speed, while the highest (70.90kg/hr) was observed at the highest impeller speed (388rpm). At 77.6% moisture content, no significant difference in throughput capacity was observed between impeller speeds.

Table 4.13: Mean material loss at different moisture content

	Moisture content (% wet basis)		
	84.35	77.6	68.2
Material Loss	5.22 ab	5.82 a	4.00 b

Means followed by the same letter are not significantly different.

Table 4.14: Analysis of variance (ANOVA) for material loss

Source of variation	d.f.	s. s	m.s.	v .r.	F < pr
Moisture	2	51.406	25.703	3.48	0.037 *
Speed	4	4.919	1.230	0.17	0.955 ns
Moisture.Speed	8	76.944	9.618	1.30	0.259 ns
Crop variety	1	8.217	8.217	1.11	0.296 ns
Moisture.Crop variety	2	8.465	4.232	0.57	0.567 ns
Speed. Crop variety	4	21.382	5.345	0.72	0.579 ns
Moisture. Speed. Crop Variety	8	62.320	7.790	1.06	0.406 ns
Residual	60	442.793	7.380		
Total	89	676.445			

* = Significant at the 5% level; ns = Not significant

Table 4.15: Mean throughput capacity at different Moisture content.

	Moisture content (% wet basis)		
	84.35	77.6	68.2
Throughput capacity	64.14 b	60.31 c	71.19 a

Means followed by the same letter are not significantly different.

Table 4.16: Analysis of variance (ANOVA) for Throughput capacity

Source of variation	d.f.	s.s.	m.s.	v.r.	F < pr.
Moisture	2	1825.92	912.96	49.11	<0. 001**
Speed	4	159.58	39.89	2.15	0.086 ns
Moisture. Speed	8	612.55	76.57	4.12	<0.001**
Crop_Var	1	32.84	32.84	1.77	0.189 ns
Moisture.Crop_Var	2	205.05	102.53	5.52	0.006 ns
Speed.CroP_Var	4	128.62	32.16	1.73	0.155 ns
Moisture.Speed. Crop_Var	8	275.61	34.45	1.85	0.085 ns
Residual	60	1115.32	18.59		
Total	89	4355.48			

* = Significant at the 5% level; ** = Significant at the 1% level; ns = Not significant

The lowest throughput capacity (66.88kg/hr) at 68.2% moisture content was observed at 240rpm while the highest throughput capacity (75.03 kg/hr) was observed at 284 rpm. The decrease in throughput capacity at other higher impeller speeds was however no significant. There appeared to be generally no significance in throughput capacity of ginger rhizomes at all moisture content levels as shown in Table 4.17. This could be as a result of the limitation capacity of the impeller that allows single ginger rhizomes to be fed into the splitting mechanism on to the cutting blade at a time irrespective of speed of the impeller.

Table 4.17: Interaction of moisture content and speed on mean throughput capacity

Moisture content (%), Wet Basis	Impeller speed (Rpm)				
	240	284	326	345	388
84.35	61.64 def	60.03 f	62.42 def	65.74 cde	70.90 abc
77.6	64.18 def	59.41 f	58.93 f	58.93 f	60.09 ef
88.2	66.88 bcd	75.03 a	70.50 abc	71.44 ab	72.08 ab

Means followed by the same letter are not significant

CHAPTER 5 DISCUSSION

5.1 Physico-Mechanical Properties of Tafin Giwa and Yatsun Biri Ginger Varieties

It was observed that the Tafin Giwa ginger variety had higher axial dimensions (length, width and thickness) compared with the Yatsun Biri ginger variety ($p< 0.01$). This suggests that Tafin Giwa ginger variety has larger physical structure than Yatsun Biri variety. The differences in the physical properties of the two ginger varieties (Table A3) are due to the varietal factors. Nwadikom and Njoku (1988) suggested linkages between variations in physical properties among different varieties of ginger with irregularity in structure of the ginger rhizomes. Erinle (1988) reported the Tafin Giwa ginger as an improved variety with a plump size compared to the local Yatsun Biri variety, which has a smaller physical structure. Furthermore, rhizomes of the Tafin Giwa variety had significantly higher mass ($p<0.01$), volume ($p<0.01$) and density ($p = 0.03$) than those of the Yatsun Biri variety. These variations in physical properties have relevant implications with respect to equipment design, particularly with regard to the size of the splitting chamber; the size of the splitting chamber influences the performance of the equipment with respect to splitting and breakage since adequate consideration for this implies proper sitting of the rhizome in the chamber to enhance splitting and minimize bruising and breakage. The Yatsun Biri ginger variety beign smaller in size was accommodated in the design by averaging the pooled mean thickness of the two ginger varieties.

The angles of repose of the Tafin Giwa and Yatsun Biri varieties of ginger were statistically at par ($p = 0.197$). This indicates that a hopper designed using the angle of repose of Tafin Giwa can equally and successfully discharge any bulk quantity of

Yatsun Biri ginger variety. The forces of shear requirement for the rhizomes of the Tafin Giwa and Yatsun Biri varieties of ginger were, similarly, at par (p = 0.068), suggesting that equal amount energy may be required for splitting rhizomes of the two varieties of ginger.

5.2 Performance Evaluation of Ginger Splitting Machine

5.2.1 Effect of Moisture Content, Speed and Crop Variety on Splitting Efficiency

Effect of moisture content on splitting efficiency: Within the 68.2 and 77.6% moisture content range, decrease in splitting efficiency was observed to occur with increasing moisture content. However, within the 77.6 and 84.35% moisture content range, splitting efficiency was observed to increase with increasing moisture content. Moisture content is known to have an important effect on the physico-mechanical properties of agricultural materials. High content of moisture is likely to give better softening of the fibres of the ginger rhizomes, making it easier for the knife to destroy the fibers and split the ginger rhizomes. Further more, at higher moisture contents, the fibres are likely to be more loosely packed, permitting better knife penetrability and enhancing splitting efficiency. However, at lower moisture contents, shrinkage of the rhizomes occurs and the fibres become difficult for the blade to cut or penetrate. As a result, most ginger rhizomes escape the splitting chamber as bruised or broken. Kanafojski and Karworski (1976) observed that the drier the plant material the more lignified are its fibres, causing higher resistance to cutting and increasing cutting energy requrement. Simonyan *et al.* (2003) observed a decrease in splitting efficiency of Tafin Giwa ginger from 76.8% to 64.6% with decrease in moisture content from 30% to 22%, dry bases. Balasubramanian *et al.* (1993) also reported a decrease in slicing efficiency of cassava tubers with decrease in moisture content.

Effect of impeller speed on splitting efficiency: Splitting efficiency generally decreased with increase in impeller speed. This finding is supported by the findings of Kepner *et al.* (1978), O'Dogherty (1981) and Chancellor (1988) who observed that the cutting velocity influences the cutting effect on agricultural materials. Balasubramanian *et al.* (1993) also reported a decrease in chip recovery in a cassava slicer with an increase in cutting speed. Also, the rotation of the impeller at high speed causes poor synchronization of product feed with the impeller's speed of operation. This results in the ginger rhizomes being thrown back through the hopper repeatedly, an occurrence that is responsible for some bruising of the final products and breakages in the rhizomes which has negative implications on splitting efficiency.

Effect of crop variety on splitting efficiency: A higher splitting efficiency of 68.1% was obtained with the rhizomes of the Tafin Giwa variety of ginger over the Yatsun Biri variety for which a 54.2% splitting efficiency was recorded. This suggests that crop variety has an important effect on splitting efficiency of ginger rhizomes. Although preliminary laboratory investigations conducted showed that rhizomes of the Tafin Giwa and Yatsun Biri varieties of ginger had non-significantly different shear strengths, there were variations in the physical properties. Size properties play vital role in the effective constraining of the ginger rhizomes in the splitting chamber against the stationery knife, ready for impact by the impeller. Smaller sized ginger rhizomes are disadvantaged in this regard since improper positioning results in incorrect impaction by the impeller. Furthermore, rhizomes that are incorrectly positioned and impacted are incorrectly split, bruised and broken. The Yatsun Biri ginger variety, being smaller in size than the Tafin Giwa variety, is disadvantaged in this regard in the equipment, which was designed to split both varieties. Chen *et al.* (2004) have established that the energy and power requirements for cutting plant stalks are dependent on species, variety, maturity and size.

Effects of interactions of moisture content and crop variety on splitting efficiency: At the first level of interaction, only the effects of moisture content and crop variety were significant ($p<0.01$). At every level of moisture content, splitting efficiency obtained with the Tafin Giwa variety were higher than those obtained with the Yatsun Biri variety, except at the 68.2% moisture content where the splitting efficiency recorded with Yatsun Biri variety were at par with that obtained with the Tafin Giwa variety. When the results were looked up across moisture content for each variety, splitting efficiency for Tafin Giwa variety increased with increasing moisture content, splitting efficiency at the 68.2 and 77.6% moisture contents being at par. While increasing moisture content eases cutting by affording softer and easily cut and penetrable rhizom fibres, the Tafin Giwa rhizomes had varietal advantage over the Yatsun Biri variety with regards to splitting efficiency. These effects worked together to give better splitting efficiencies with the Tafin Giwa variety with increasing moisture contents.

Effects of interactions of speed, moisture content and crop variety on splitting efficiciency: The effects of the interactions of these three factors were significant at the 5% level. The highest splitting efficiencies of 82.1% and 80.1% were obtained with the Tafin Giwa variety at the lowest operational speeds of 240 and 284 rpm, respectively, and at the highest moisture content of 84.35%; these two values of splitting efficiency were at par. Splitting efficiencies at the 326 rpm (which was 74.2%) and at 345 rpm (which was 70.42%) were also at par with the afore mentioned performances; they were similarly obtained with the Tafin Giwa variety at the highest moisture content of 84.35%.

5.2.2 Effect of Moisture Content, Speed and Crop Variety on Percentage of Bruised and Broken Ginger Rhizomes

Effect of moisture content on percentage of bruised and broken ginger: The lowest percentage of bruised and broken ginger in this study was obtained at the highest moisture content. At higher moisture contents, the volume and size of ginger rhizomes are increased. At lower moisture contents, however, ginger rhizomes are shrunken with reductions in rhizome volume and size. Small sized rhizomes are seldom constrained adequately in the splitting chamber to ensure that the impeller correctly impacts upon them against the stationary blade so as to achieve the splitting of the ginger rhizomes. On the contrary, they are positioned in orientations that favour the impeller breaking off the fingers of the rhizome and the rhizome itself into smaller pieces. Furthermore, the shrunken rhizomes are forced out of the splitting chamber through the sides of the stationary blade, with incurred bruises and broken rhizomes. This finding is in agreement with findings by Simonyan *et al.* (2003) who reported lower percentage of damage on Tafin Giwa ginger variety at higher moisture content during slicing.

Effect of crop variety on percentage of bruised and broken ginger: The Yatsun Biri variety of ginger had higher percentage of bruised and broken rhizomes (45.75%) compared with 32.20% obtained for the Tafin Giwa variety. This is attributable to their difference in size in relation to the width of the splitting chamber; the Yatsun Biri variety being of significantly smaller size in comparison to the Tafin Giwa variety. Improper positioning of the smaller sized ginger rhizomes against the stationary blade in the splitting chamber accounted for the higher percentage of bruised and broken ginger recorded for the Yatsun Biri variety.

Effect of impeller speed on percentage of bruised and broken ginger: When the effect of speed on the percentage of rhizomes that were bruised was considered, it was observed that the percentages of rhizomes bruised or broken at the lower operational speeds of 240, 284 and 326 rpm were at par and were 31.36, 35.23 and 39.78%, respectively. These were the lowest recorded values and were significantly lower than values obtained at 345 and 388 rpm, which were 46.12 and 42.3%, respectively, and were also at par. Bruising and breakage of ginger rhizomes were higher at the higher speeds and are due to non-synchronization of product feed and impeller action at the higher speeds. Non-synchronization of product feed and impeller action result in the rhizomes being knocked out of the splitting chamber and back through the hopper, repeatedly, leading to bruising and breakage of the ginger rhizomes. It is also necessary for the rhizomes to have sufficient time to attain proper positioning once in the splitting chamber before receiving the impact from the impeller. When this condition is not satisfied, what occurs is that the impeller impacts upon the wrongly oriented rhizome against the stationary cutting blade leading to parts or fingers of the rhizome being forcefully broken off and rhizome being forced out through the openings between the sides of the stationary blade and the walls of the splitting chamber, with severe breakages and bruises incurred on the rhizome.

Effects of interactions of moisture content and crop variety on percentage of bruised and broken ginger: Only the interactions of moisture content with crop variety was significant for the first order interactions. For every level of moisture content, the percentage of bruised and broken ginger rhizomes of the Tafin Giwa variety was significantly less than that recorded with the Yatsun Biri variety; the combination of Tafin Giwa variety and the highest moisture content of 84.35% gave the lowest percentage of bruised and broken ginger, which was 25.39%. Within variety, percentage of bruised and broken ginger reduced with increasing moisture content for the Tafin Giwa variety, although values at the 77.6 and 68.2% moisture contents were at par.

Effects of interactions of moisture content, speed and crop variety on percentage of bruised and broken ginger: When the interaction of the three factors was considered, the trend showed that the Yatsun Biri variety of ginger had significantly higher mean percentage of bruised and broken ginger compared with the Tafin Giwa variety at every impeller speed at moisture contents of 84.35% and 77.6%. However, at the lowest moisture content of 68.2%, the percentages of bruised and broken rhizomes for the two varieties were at par at every speed. The least recorded percentage of bruised and broken ginger, which was 17.93%, was obtained with the Tafin Giwa variety of ginger at the highest moisture content of 84.35% and the lowest operational speed of 240 rpm. The Tafin Giwa variety is favoured for its larger size which enhances proper positioning of the rhizome in the splitting chamber, minimizing bruising and breakage that arise as a function of improper rhizome orientation in the splitting chamber. Normally, higher moisture contents favour larger product size and volume, both of which favour proper positioning of the rhizome on the stationary blade in the splitting chamber, ready for splitting. At the lower speeds, better synchronization of product feed and impeller action is obtained, resulting in less repeated throw-back of rhizomes from the splitting chamber and reductions in the quatities of rhizomes that are bruised and broken.

5.2.3 Effect of Moisture Contents, Speed and Crop Variety on Material Loss

Effect of moisture content on material loss: Of all the factors studied and their interactions, only the main effect of moisture content on material loss was significant. Other factors were however not significant. Material loss was higher at the higher moisture contents of 77.6% and 84.35%, at which material losses of 5.82 and 5.22% were recorded. These two losses were not significantly different. They were, however significantly higher than material loss at the lowest moisture content of 68.2%, which was 4%. Cutting or splitting of ginger rhizomes by impact results in fragmentation of parts of the rhizome. These fragments are thrown against the walls of the splitting chamber and the neck of the hopper at high centrifugal speeds of the impelling assembly. The sticking of the fragments to the walls of the splitting chamber and the lower parts of the hopper result in reductions in product recovery which amount to retention loss. Higher rhizome moisture content, which implies higher moisture content of the fragments, enhances the sticking of the fragments to the walls of the splitting chamber and the lower part of the hopper. Furthermore, some of these fragments are thrown out through the hopper by the action of the impeller as scatter losses.

5.2.4 Effect of Moisture Content, Speed and Crop Variety on Throughput Capacity

Effect of moisture content on throughput capacity: Of all the factors studied for their effects on the throughput capacity of the equipment, only the main effect of moisture content was significant. All the other factors were not significant on throughput capacity. Throughput dropped significantly from 64.14 kg/h at the 84.35% moisture content to 60.31 kg/h at the 77.6% moisture content. Throughput however rose, also significantly, from 60.31 kg/h at the 77.6% moisture content to 71.19 kg/h at the 68.2% moisture content. The significantly highest throughput obtained at the lowest moisture content of 68.2% may not be unconnected with the shrunken rhizomes which are forced out of the splitting chamber between the stationary blade and the walls of the splitting chamber as non-split rhizomes. It is likely that more of the shrunken rhizomes are forced out per unit time than are split rhizomes per unit time, more of which would be obtained at the higher moisture contents.

Effects of interactions of moisture content and speed on throughput capacity: When the interactions of the factors studied for their effects on the throughput capacity were considered, only the effect of the interaction of moisture content with speed was significant. Within moisture content levels, the changes in throughput capacity with changing speeds of operation were generally insignificant. For the rhizomes at 84.35% moisture content, throughput capacity increased insignificantly with increasing speed within the 240 rpm to 345 rpm speed range. Throughput at the highest operational speed was however significantly higher than these, although it was at par with throughput at the 345 rpm speed of operation. The increase in non-synchronization in the flow of ginger rhizomes into the splitting chamber with respect to impeller speed, particularly with increasing operational speed and the consequent repeated throw-back of the fed rhizomes at such speeds appear to have limiting effects on the throughput of the equipment and are thus implicated in this trend. However, Balasubramanian *et al.* (1993), Pasikatan *et al.* (1997) and Savani et al. (2004) who worked on the slicing of cassava, cutting of corn stalks and the shredding of agricultural waste, respectively, reported increases in throughput capacity with increasing operational speed.

CHAPTER 6 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The physical and mechanical properties of ginger rhizomes are essential design parameters that must be determined if mechanization of their processing operations is to be achieved. This study was undertaken to determine the physical and mechanical properties of the two popular varieties of ginger, namely, Tafin Giwa and Yatsun Biri with the sole aim of developing a machine that splits ginger rhizomes longitudinally. The two ginger varieties (Tafin Giwa and Yatsun Biri) showed significant difference in their physical properties.

The ginger splitting machine was developed based on the physical and mechanical properties of the two ginger varieties. The performance of the equipment was investigated at three different moisture contents and at five different impeller speeds. The study showed that splitting efficiency decreased with increase in impeller speed at all moisture contents for both Tafin Giwa and Yatsun Biri ginger varieties. The splitting efficiency was highest for Tafin Giwa (82.09%) at 240rpm and 84.35% moisture content and lowest (57.15%) at 345rpm at 68.2% moisture content. For Yatsun Biri ginger, the splitting efficiency (67.95%) was highest at 240rpm and at 84.35% moisture content and lowest (40.94%) at 345rpm and at 77.6% moisture content.

Percentage of bruised and broken ginger increased with increasing speed at all speeds and with decrease in moisture content. The lowest percentage of bruised and broken Tafin Giwa and Yatsun Biri ginger (17.93% and 32.05%) were obtained at 240rpm and at a high moisture content of 84.35%. The highest values of percentage bruised and broken were however obtained at 42.85% at 345rpm and 68.2% moisture content for Tafin Giwa and 50.90% at 388rpm at 68.2% for Yatsun Biri ginger varieties respectively.

Material loss decreased with decrease in moisture content. The highest material loss (5.82%) was obtained at 77.6% moisture content, while the lowest (4.00%) was recorded at 68.2% moisture content.

Throughput capacity showed no significant increase with increase in speeds and with decrease in moisture content.

The operating condition of the machine to obtain maximum splitting efficiency with minimum percentage of bruise and broken ginger, and with low material loss and low throughput capacity was observed at 84.35% moisture content at an impeller speed of 240rpm for both Tafin Giwa ginger and Yatsun Biri ginger respectively.

6.2 Conclusions

Based on this study, the following conclusions have been drawn:

1. The Tafin Giwa ginger variety had larger size and volume than the Yatsun Biri ginger variety. These physical properties had significance in the design

of the splitting machine and particularly in the performances recorded for each variety while testing the machine; the larger size and volume of the Tafin Giwa variety favoured better equipment performance.

2. The splitting machine was efficient in longitudinal splitting of the two ginger varieties considered in this study, indicating an improvement over the previous prototypes in terms of splitting efficiency and throughput capacity.

3 The splitting efficiency of the machine on both ginger varieties decreased with increase in the impeller speed at all moisture content levels.

4 At the same speed, the splitting efficiency of the machine on Tafin Giwa ginger was higher than that of Yatsun Biri ginger at all moisture content levels.

5 The percentage of bruised and broken rhizomes incurred for the two ginger varieties increased with increase in impeller speed at all moisture content levels. Minimal bruising and breakage of ginger rhizomes can be obtained by operating the equipment at the lowest possible operational speed favouring high splitting efficiency. The 240-rpm speed satisfied this condition as was established for the range of speeds considered in this study.

6. The percentage of bruised and broken rhizomes incurred on the Yatsun Biri ginger variety was higher than that of the Tafin Giwa variety at all moisture content levels. As low as 17.93 and 32.05% could be obtained by splitting the Tafin Giwa and Yatsun Biri varieties at 84.35% moisture content.

7. Material loss for both ginger varieties was in the range of 4.00-5.82%.

8. At critical splitting speed of the impeller (240 rpm), the machine performance on Tafin Giwa variety of ginger gave a splitting efficiency of 82.1%, percentage of bruised and broken ginger rhizomes of 17.93%, Material loss

of 6.46% and throughput capacity of 67.51 kg/h respectively were obtained at 84.35% moisture content. Using the Yatsun Biri variety under the same conditions, the performance of the machine gave a splitting efficiency of 67.95%, percentage of bruised and broken ginger rhizomes of 32.03%, Material loss of 5.77% and equipment throughput of 55.76 kg/h.

6.3 Recommendations

1. The impeller speed of 240rpm and moisture content of 84.4% produced the optimum performance of the machine for both Tafin Giwa and Yatsun Biri ginger varieties in terms of high splitting efficiency, low percent bruised and broken rhizomes, low material loss and high through put capacity. The best condition for splitting Tafin Giwa and Yatsun Biri ginger varieties should therefore be immediately after harvest when the moisture is still high.
2. Future designs of the splitting chamber should accommodate a range of sizes of rhizomes of the two ginger varieties. also include the rate of feed of rhizomes into the splitting chamber, as this would significantly affect the performance of the equipment.
3. Modifications in the width of the splitting chamber will have significant effect on the performance of the machine, particularly for the Yatsun Biri variety of ginger and other small-sized ginger varieties that may be available. Studies in this line should be considered in the future.

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APPENDIX A

Physico-Mechanical Properties Data

Table A1: Physical and Mechanical Properties of Tafin Giwa Ginger

Sample No	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Volume (m)	Density (g/cm^3)	Angle of Repose (Degree)	Shear force (N)
1	9.72	09.40	02.16	56.00	50	1.120	31.93	95
2	11.23	09.02	02.27	74.66	70	1.070	31.52	95
3	13.00	06.55	02.32	75.45	50	.0940	31.18	140
4	10.92	07.56	02.35	71.84	70	1.030	31.43	86
5	08.93	08.43	01.86	46.14	60	0.990	30.32	105
6	08.90	05.94	02.52	52.92	60	0.880	30.32	84
7	14.30	06.15	02.75	81.30	130	0.630	21.18	110
8	09.64	05.94	02.12	49.52	30	1.650	29.93	135
9	09.03	05.92	02.44	51.04	65	0.790	29.71	86
10	10.84	05.45	02.64	60.36	50	1.210	29.76	76
11	10.00	06.22	02.23	52.50	50	1.050	29.93	95
12	11.44	07.74	02.12	56.68	50	1.130	30.46	75
13	00.95	06.63	02.33	58.95	48	1.230	30.64	94
14	11.43	06.54	02.16	62.84	60	1.050	31.33	74
15	12.00	06.50	02.26	73.96	200	0.370	21.42	139
16	12.40	08.25	02.44	91.29	95	0.960	28.23	145
17	09.20	06.54	02.12	43.29	50	0.870	26.64	77
18	11.52	06.23	02.26	53.72	60	0.900	31.16	50
19	12.05	06.05	02.82	66.64	60	1.110	30.83	96
20	09.86	07.54	02.33	65.25	60	1.090	31.17	105
21	09.56	05.35	02.25	58.10	70	0.830	30.38	87
22	11.25	08.02	02.62	110.02	105	1.050	29.47	75
23	11.04	06.85	02.55	91.64	90	1.020	31.32	86
24	08.90	07.32	02.26	63.68	60	1.060	31.13	97
25	09.04	06.93	02.57	64.52	55	1.170	29.94	92
Total	266.15	173.07	58.55	1632.31	1748	26.26	759.5	2397
Mean	10.65	6.92	2.34	65.29	69.92	1.05	30.38	95.90
Std dev	1.41	1.06	0.22	15.46	33.58	230.08	1.13	22.72

Table A2: Physical and Mechanical Properties of Yatsun Biri Ginger

Sample No	Length (cm)	Width (cm)	Thickness (cm)	Weight (g)	Volume (m)	Density (g/cm^3)	Angle of Repose (Degree)	Shear force (N)
1	8.44	5.14	1.94	29.80	37	0.805	31.1	95
2	9.94	2.88	1.86	18.16	19	0.956	29.9	75
3	7.93	3.97	2.02	24.68	26	0.949	27.7	112
4	8.16	5.17	1.64	27.71	30	0.924	29.2	130
5	6.94	5.46	1.73	27.37	29	0.944	30.1	96
6	10.96	4.37	1.85	26.95	30	0.898	28.4	155
7	4.44	4.05	1.92	22.45	32	0.702	29.9	80
8	8.41	3.12	1.67	21.66	30	0.722	31.7	102
9	7.69	4.53	1.92	28.97	30	0.966	31.1	77
10	9.41	6.05	1.84	19.58	20	0.979	28.4	89
11	9.84	5.18	1.97	34.49	40	0.862	31.4	78
12	8.86	3.98	1.78	23.30	25	0.932	29.3	67
13	8.93	3.92	1.64	21.58	30	0.719	31.4	86
14	5.05	3.22	1.56	12.99	25	0.520	29.1	58
15	6.16	4.89	2.13	27.64	30	0.921	29.5	92
16	7.84	3.99	1.98	23.11	30	0.770	31.6	102
17	8.99	4.96	1.97	23.99	25	0.960	29.3	53
18	9.41	6.05	1.76	32.49	38	0.855	27.3	80
19	8.58	4.37	1.57	19.12	20	0.956	27.6	72
20	6.44	3.74	1.73	16.58	20	0.829	31.7	80
21	7.52	4.34	1.74	16.68	20	0.834	31.3	80
22	9.67	4.17	1.62	15.67	16	0.979	29.8	92
23	7.74	3.72	1.69	13.68	15	0.912	27.4	75
24	8.77	6.78	1.87	38.00	40	0.950	31.4	17
25	8.74	4.63	2.42	47.67	50	0.953	29.3	64
Total	204.86	112.68	84.91	614.32	707	21.797	744.9	1967
Mean	8.20	4.51	1.83	24.60	28.30	0.972	29.79	84.30
Std dev	1.48	0.93	0.19	7.83	8.19	0.11	1.45	24.73

Table A3: T-test for Physico-Mechanical Properties of Tafin Giwa (TG) and Yatsun Biri (YB) Varieties of Ginger

	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
TG (Length)	10.65	1.44						
YB (Length)	8.20	1.51	25	2.45	2.47	4.965	24	0.000045 **
TG (Width)	6.92	1.08						
YB (Width)	4.51	0.95	25	2.42	1.49	8.081	24	0.000000 **
TG (Thickness)	2.38	0.26						
YB (Thickness)	1.83	0.19	25	0.54	0.31	8.846	24	0.000000 **
TG (Mass)	65.3	15.8						
YB (Mass)	24.6	7.99	25	40.72	19.97	10.195	24	0.000000 **
TG (Volume)	69.9	34.3						
YB (Volume)	28.3	8.36	25	41.64	36.2	5.759	24	0.000006 **
TG (Density)	0.99	0.23						
YB (Density)	0.87	0.11	25	0.13	0.28	2.303	24	0.030250 *
TG (Surface)	27.9	5.47						
YB (Surface)	19.4	4.97	25	8.53	8.32	5.127	24	0.000030 **
TG (Angle of Repose)	30.3	1.14						
YB (Angle of Repose)	29.8	1.45	25	0.53	2.01	1.325	24	0.197578 ^{ns}
TG (Shear Force)	95.9	23.2						
YB (Shear Force)	84.3	26.0	25	11.6	30.4	1.908	24	0.068440 ^{ns}

TG = Tafin Giwa; YB = Yatsun Biri; ns = Not Significant; * = Significant at the 5% level; ** = Significant at the 1% level

Appendix B
Performance data of the ginger splitting machine

S/N	TRM	REP	COMB	MC	SPEED	CROP	Q_f	Q_o	Q_{bb}	Q_{csu}	Q_l	TIME
1	T1	1	M1S1C1	84.35	240	C1	500	446	74.05	371.95	54	24.72
2	T2	1	M1S1C2	84.35	240	C2	500	466.31	117.78	348.53	33.69	31
3	T3	1	M1S2C1	84.35	284	C1	500	448.28	93.53	362.62	51.72	27.68
4	T4	1	M1S2C2	84.35	284	C2	500	488.1	133.35	354.75	11.9	28.2
5	T5	1	M1S3C1	84.35	326	C1	500	464.65	159	305.65	35.35	30.81
6	T6	1	M1S3C2	84.35	326	C2	500	470.46	174.95	295.51	29.54	27.63
7	T7	1	M1S4C1	84.35	345	C1	500	489.5	132.14	357.36	10.5	25.31
8	T8	1	M1S4C2	84.35	345	C2	500	471.01	245.29	225.72	28.99	28.65
9	T9	1	M1S5C1	84.35	388	C1	500	491.8	130.74	361.01	8.2	27.87
10	T10	1	M1S5C2	84.35	388	C2	500	471.42	191.28	280.14	28.58	23.69
11	T11	1	M2S1C1	77.6	240	C1	500	456.19	122.49	373.7	43.81	26.88
12	T12	1	M2S1C2	77.6	240	C2	500	477.45	241.31	236.14	22.55	25.14
13	T13	1	M2S2C1	77.6	284	C1	500	445.76	138.39	307.37	54.24	25.21
14	T14	1	M2S2C2	77.6	284	C2	500	471.37	205.6	265.77	28.63	28.2
15	T15	1	M2S3C1	77.6	326	C1	500	485.6	183.2	302.24	14.4	28.17
16	T16	1	M2S3C2	77.6	326	C2	500	491.09	292.88	198.21	8.91	31.39
17	T17	1	M2S4C1	77.6	345	C1	500	467.45	157.43	310.02	32.55	25.4
18	T18	1	M2S4C2	77.6	345	C2	500	451.56	214.14	237.42	48.44	27.61
19	T19	1	M2S5C1	77.6	388	C1	500	479.6	192.24	287.36	20.4	25.17
20	T20	1	M2S5C2	77.6	388	C2	500	434.35	262.51	171.84	65.65	28.83
21	T21	1	M3S1C1	68.2	240	C1	500	488.54	115.89	372.65	11.46	23.75
22	T22	1	M3S1C2	68.2	240	C2	500	478.15	106.56	371.59	21.85	25.81
23	T23	1	M3S2C1	68.2	284	C1	500	489.89	154.05	335.84	10.11	21.67
24	T24	1	M3S2C2	68.2	284	C2	500	481.3	144.81	335.49	18.7	24.32
25	T25	1	M3S3C1	68.2	326	C1	500	492.12	126.05	366.07	7.88	25.72
26	T26	1	M3S3C2	68.2	326	C2	500	475.76	240.53	235.23	24.24	25.94
27	T27	1	M3S4C1	68.2	345	C1	500	485.9	238.39	247.51	14.1	25.09
28	T28	1	M3S4C2	68.2	345	C2	500	488.46	251.63	236.83	11.54	23.02
29	T29	1	M3S5C1	68.2	388	C1	500	484.48	175.04	309.44	15.52	24.88
30	T30	1	M3S5C2	68.2	388	C2	500	491.63	271.99	219.64	8.37	22.9
31	T31	2	M1S1C1	84.35	240	C1	500	475.92	83.35	392.57	24.08	26.89
32	T32	2	M1S1C2	84.35	240	C2	500	473.24	182.8	290.44	26.76	30.05
33	T33	2	M1S2C1	84.35	284	C1	500	482.43	84.92	397.51	17.57	29.15
34	T34	2	M1S2C2	84.35	284	C2	500	466.38	183.2	283.18	33.62	30.8
35	T35	2	M1S3C1	84.35	326	C1	500	486.44	104.05	384.39	13.56	29.69
36	T36	2	M1S3C2	84.35	326	C2	500	445.8	239.96	205.84	54.2	22.59
37	T37	2	M1S4C1	84.35	345	C1	500	474.11	123.14	350.97	25.89	26.77
38	T38	2	M1S4C2	84.35	345	C2	500	471.26	302.76	168.5	28.74	23.73
39	T39	2	M1S5C1	84.35	388	C1	500	494.35	175.27	319.08	5.65	25.88
40	T40	2	M1S5C2	84.35	388	C2	500	471.78	175.99	295.79	28.22	22.05
41	T41	2	M2S1C1	77.6	240	C1	500	485.99	112.37	373.62	14.01	25.14
42	T42	2	M2S1C2	77.6	240	C2	500	481.89	243.59	238.3	18.11	29.58
43	T43	2	M2S2C1	77.6	284	C1	500	484.52	185.18	299.34	15.48	29.62
44	T44	2	M2S2C2	77.6	284	C2	500	479.3	237.83	241.47	20.7	30.22
45	T45	2	M2S3C1	77.6	326	C1	500	457.43	169.04	288.9	42.57	28.52
46	T46	2	M2S3C2	77.6	326	C2	500	460.45	206.05	254.4	39.55	28.62

47	T47	2	M2S4C1	77.6	345	C1	500	470.04	172.48	297.56	29.96	29.1
48	T48	2	M2S4C2	77.6	345	C2	500	466.81	293.51	173.3	33.19	30.21
49	T49	2	M2S5C1	77.6	388	C1	500	456.98	150.06	306.92	43.02	25.03
50	T50	2	M2S5C2	77.6	388	C2	500	491.28	254.23	237.05	8.72	30.51
51	T51	2	M3S1C1	68.2	240	C1	500	463.38	177.58	285.8	36.62	25.06
52	T52	2	M3S1C2	68.2	240	C2	500	469.64	102.59	367.05	30.36	26.28
53	T53	2	M3S2C1	68.2	284	C1	500	481.05	193.16	287.89	18.95	23.89
54	T54	2	M3S2C2	68.2	284	C2	500	475.19	192.85	282.34	24.81	22.74
55	T55	2	M3S3C1	68.2	326	C1	500	494.64	142.26	352.38	5.36	26.47
56	T56	2	M3S3C2	68.2	326	C2	500	468.94	221.99	246.95	31.06	23.74
57	T57	2	M3S4C1	68.2	345	C1	500	489.66	188.33	301.33	10.34	25.3
58	T58	2	M3S4C2	68.2	345	C2	500	482.09	253.26	228.83	17.91	24.2
59	T59	2	M3S5C1	68.2	388	C1	500	482.47	209.29	273.18	17.53	24.58
60	T60	2	M3S5C2	68.2	388	C2	500	488.4	267.19	204.21	11.6	22.48
61	T61	3	M1S1C1	84.35	240	C1	500	481.22	94.65	386.86	18.78	23.45
62	T62	3	M1S1C2	84.35	240	C2	500	473.93	152.92	321.01	26.07	30.23
63	T63	3	M1S2C1	84.35	284	C1	500	467.2	107.55	359.65	32.8	28.2
64	T64	3	M1S2C2	84.35	284	C2	500	497.39	186.8	310.59	2.61	27.21
65	T65	3	M1S3C1	84.35	326	C1	500	489.71	108.98	380.73	10.29	26.73
66	T66	3	M1S3C2	84.35	326	C2	500	458.2	172.71	285.49	41.8	26.2
67	T67	3	M1S4C1	84.35	345	C1	500	464.06	165.99	298.07	35.94	28.3
68	T68	3	M1S4C2	84.35	345	C2	500	490.1	286.62	203.39	9.9	24.73
69	T69	3	,M1S5C1	84.35	388	C1	500	459.53	169.9	289.63	40.47	22.74
70	T70	3	M1S5C2	84.35	388	C2	500	486.91	145.43	341.48	13.09	24.45
71	T71	3	M2S1C1	77.6	240	C1	500	476.25	200.96	275.29	23.75	24.49
72	T72	3	M2S1C2	77.6	240	C2	500	484.09	237.26	246.83	15.91	30.37
73	T73	3	M2S2C1	77.6	284	C1	500	484.61	150.77	333.84	15.39	28.99
74	T74	3	M2S2C2	77.6	284	C2	500	473.93	295.11	178.82	26.07	30.2
75	T75	3	M2S3C1	77.6	326	C1	500	481.55	155.6	325.95	18.45	28.83
76	T76	3	M2S3C2	77.6	326	C2	500	483.8	279.17	204.63	16.2	29.31
77	T77	3	M2S4C1	77.6	345	C1	500	479.71	188.91	290.8	20.29	28.45
78	T78	3	M2S4C2	77.6	345	C2	500	470.58	314.77	155.81	29.42	31.39
79	T79	3	M2S5C1	77.6	388	C1	500	458.16	130.75	327.41	41.84	26.22
80	T80	3	M2S5C2	77.6	388	C2	500	439.21	221.62	217.59	60.79	30.94
81	T81	3	M3S1C1	68.2	240	C1	500	484.37	183.49	300.88	15.63	29.28
82	T82	3	M3S1C2	68.2	240	C2	500	469.2	132.15	337.05	30.8	24.1
83	T83	3	M3S2C1	68.2	284	C1	500	483.63	149.12	334.51	16.37	23.85
84	T84	3	M3S2C2	68.2	284	C2	500	454.57	181.06	273.51	45.43	21.3
85	T85	3	M3S3C1	68.2	326	C1	500	490.61	220.5	270.11	9.39	24.27
86	T86	3	M3S3C2	68.2	326	C2	500	486.57	210.32	276.25	11.43	22.77
87	T87	3	M3S4C1	68.2	345	C1	500	473.7	194.34	279.36	26.3	23.15
88	T88	3	M1S4C2	68.2	345	C2	500	459.23	215.9	243.33	40.77	24.5
89	T89	3	M3S5C1	68.2	388	C1	500	470.55	223.45	247.1	29.45	24.35
90	T90		M1S5C2	68.2	388	C2	500	473.48	258.83	214.65	26.52	25.57

Appendix C

Analysis of Variance for the Performance Data of the Ginger Splitting Machine

SPLIT_EFF = Splitting Efficiency (%)

%BRUISED = Percentage of Bruised or Broken Ginger (%)

MAT_LOSS = Material Loss (%)

THRUPUT_CAP = Throughput Capacity (kg/hour)

Table B1: Analysis of variance for splitting efficiency data

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MOISTURE	2	1755.2	877.6	21.45	<.001
SPEED	4	2604.77	651.2	15.92	<.001
MOISTURE.SPEED	8	624.28	78.04	1.91	0.075
CROP_VAR	1	4335.99	4336	106.0	<.001
MOISTURE.CROP_VAR	2	833.37	416.7	10.19	<.001
SPEED.CROP_VAR	4	306.94	76.74	1.88	0.126
MOISTURE.SPEED. CROP_VAR	8	772.69	96.59	2.36	0.028
Residual	60	2454.30	40.91		
Total	89	13687.55			

Tables of means for splitting efficiency

Variate: SPLIT_EFF
Grand mean 61.11

Table B2: Mean splitting efficiency (%) at different moisture contents (%)

MOISTURE	84.35	77.6	68.2
SPLIT_EFF	66.99	56.35	59.98

Table B3: Mean splitting efficiency (%) at different operational speeds (rpm)

SPEED (rpm)	240	284	326	345	388
SPLIT_EFF	69.13	64.84	60.24	53.88	57.44

Table B4: Mean splitting efficiency (%) for interactions of speed with moisture contents (%)

	SPEED				
MOISTURE	240	284	326	345	388
84.35	75.02	72.69	65.64	56.07	65.54
77.6	61.08	57.35	55.17	52.18	55.98
68.2	71.30	64.48	59.93	53.40	50.80

Table B5: Mean splitting efficiency (%) obtained for the different ginger varieties

CROP_VAR	C1	C2
SPLIT_EFF	68.05	54.17

Table B6: Mean splitting efficiency (%) for interactions of moisture contents (%) with crop variety

	CROP_VAR	
MOISTURE	C1	C2
84.35	74.76	59.23
77.6	66.54	46.16
68.2	62.85	57.11

Table B7: Mean splitting efficiency (%) for interactions of speed with crop variety

	CROP_VAR	
SPEED	C1	C2
240	73.66	64.61
284	70.83	58.85
326	68.48	52.01
345	63.66	44.10
388	63.61	51.27

Table B7: Mean splitting efficiency (%) for interactions of moisture content, speed and crop variety

		CROP_VAR	
MOISTURE	SPEED	C1	C2
84.35	240	82.09	67.95
	284	80.09	65.28
	326	74.18	57.10
	345	70.42	41.73
	388	66.99	64.08
77.6	240	72.20	49.97
	284	66.54	48.16
	326	64.36	45.97
	345	63.42	40.94
	388	66.18	45.79
68.2	240	66.69	75.90
	284	65.86	63.10
	326	66.89	52.96
	345	57.15	49.65
	388	57.67	43.94

Table B8: Standard errors of means, Standard errors of differences of means and Least significant differences of means (5% level) for splitting efficiency

STAT	MOISTURE	SPEED	MOISTURE SPEED	CROP_VAR	MOISTURE CROP_VAR	SPEED CROP_VAR	MOISTURE SPEED CROP_VAR
rep.	30	18	6	45	15	9	3
d.f.	60	60	60	60	60	60	60
e.s.e.	1.168	1.507	2.611	0.953	1.651	2.132	3.693
s.e.d.	1.651	2.132	3.693	1.348	2.335	3.015	5.222
l.s.d.	3.303	4.264	7.386	2.697	4.671	6.031	10.446

Table B9: Stratum standard errors and coefficients of variation for splitting efficiency

d.f.	s.e.	cv%
60	6.396	10.5

Table B10: Analysis of variance for data on percentage of bruised and broken ginger

Source of variation	d.f.	s.s.	m.s.	v.r.	Fpr.
MOISTURE	2	1807.78	903.89	23.31	<.001
SPEED	4	2431.06	607.76	15.67	<. 001
MOISTURE.SPEED	8	645.09	80.64	2.08	0.052
CROP_VAR	1	4133.37	4133.37	106.58	<. 001
MOISTURE.CROP_VAR	2	803.08	401.54	10.35	<. 001
SPEED.CROP_VAR	4	360.06	90.01	2.32	0.067
MOISTURE.SPEED. CROP_VAR	8	688.75	86.09	2.22	0.038
Residual	60	2327.01	38.78		
Total	89	13196.20			

Tables of means for percentage of bruised and broken ginger

Variate: %_BRUISED
Grand mean 38.97

Table B11: Mean percentage of bruised and broken ginger at different moisture contents

MOISTURE	84.35	77.6	68.2
%_BRUISED	33.08	43.94	39.90

Table B12: Mean percentage of bruised and broken ginger at different operational speeds (rpm)

SPEED	240	284	326	345	388
%_BRUISED	31.36	35.25	39.78	46.12	42.36

Table B13: Mean percentage of bruised and broken ginger for interactions of speed with moisture contents (%)

			SPEED		
MOISTURE	240	284	326	345	388
84.35	24.99	27.61	34.43	43.92	34.46
77.6	40.38	42.65	44.85	47.82	44.02
68.2	28.70	35.49	40.07	46.60	48.62

Table B14: Mean percentage of bruised and broken ginger obtained for the different ginger varieties

CROP_VAR	C1	C2
%_BRUISED	32.20	45.75

Table B15: Mean splitting efficiency (%) for interactions of moisture contents (%) with crop variety

	CROP_VAR	
MOISTURE	C1	C2
84.35	25.39	40.77
77.6	34.05	53.84
68.2	37.15	42.65

Table B16: Mean percentage of bruised and broken ginger for interactions of speed with crop variety

	CROP_VAR	
SPEED	C1	C2
240	27.32	35.39
284	29.37	41.13
326	31.57	47.99
345	36.34	55.89
388	36.39	48.34

Table B17: Mean percentage of bruised and broken ginger for interactions of moisture content, speed and crop variety

		CROP_VAR	
MOISTURE	SPEED	C1	C2
84.35	240	17.93	32.05
	284	20.50	34.72
	326	25.95	42.90
	345	29.58	58.27
	388	33.00	35.92
77.6	240	30.72	50.03
	284	33.46	51.84
	326	35.66	54.03
	345	36.58	59.06
	388	33.82	54.21
68.2	240	33.31	24.10
	284	34.14	36.83
	26	33.11	47.04
	345	42.85	50.35
	388	42.33	54.90

Table B18: Standard errors of means, Standard errors of differences of means and least significant differences of means (5% level) percentage of bruised and broken ginger

STAT	MOISTURE	SPEED	MOISTURE SPEED	CROP_VAR	MOISTURE CROP_VAR	SPEED CROP_VAR	MOISTURE SPEED CROP_VAR
Rep.	30	18	6	45	15	9	3
d.f.	60	60	60	60	60	60	60
e.s.e.	1.137	1.468	2.542	0.928	1.608	2.076	3.596
s.e.d.	1.608	2.076	3.596	1.313	2.274	2.936	5.085
l.s.d.	3.216	4.152	7.192	2.626	4.549	5.872	10.171

Table B19: Stratum standard errors and coefficients of variation. Variate: %_BRUISED

d.f.	s.e.	cv%
60	6.228	16.0

Table B20: Analysis of variance for data on Material Loss (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MOISTURE	2	51.406	25.70	3.48	0.037
SPEED	4	4.919	1.230	0.17	0.955
MOISTURE.SPEED	8	76.944	9.618	1.30	0.259
CROP_VAR	1	8.217	8.217	1.11	0.296
MOISTURE.CROP_VAR	2	8.465	4.232	0.57	0.567
SPEED.CROP_VAR	4	21.382	5.345	0.72	0.579
MOISTURE.SPEED. CROP_VAR	8	62.320	7.790	1.06	0.406
Residual	60	442.793	7.380		
Total	89	676.445			

Tables of means for material loss

Variate: MAT_LOSS
Grand mean 5.01

Table B21: Mean material loss (%) at different moisture contents (%)

MOISTURE	84.35	77.6	68.2
MAT_LOSS	5.22	5.82	4.00

Table B22: Mean material loss (%) at different operational speeds (rpm)

SPEED	240	284	326	345	388
MAT_LOSS	5.20	4.95	4.60	5.05	5.26

Table B23: Mean material loss (%) for interactions of speed with moisture contents (%)

			SPEED		
MOISTURE	240	284	326	345	388
84.35	6.11	5.01	6.16	4.67	4.14
77.6	4.60	5.35	4.67	6.46	8.01
68.2	4.89	4.48	2.98	4.03	3.63

Table B24: Mean material loss (%) obtained for the different ginger varieties

CROP_VAR	C1	C2
MAT_LOSS	4.71	5.32

Table B25: Mean material loss (%) for interactions of moisture contents (%) with crop variety

	CROP_VAR	
MOISTURE	C1	C2
84.35	5.13	5.30
77.6	5.74	5.90
68.2	3.27	4.74

Table B26: Mean material loss (%) for interactions of speed with crop variety

	CROP_VAR	
SPEED	C1	C2
240	5.38	5.02
284	5.17	4.72
326	3.49	5.71
345	4.57	5.53
388	4.94	5.59

Table B27: Mean material loss (%) for interactions of moisture content, speed and crop variety

		CROP_VAR	
MOISTURE	SPEED	C1	C2
84.35	240	6.46	5.77
	284	6.81	3.21
	326	3.95	8.37
	345	4.82	4.51
	388	3.62	4.66
77.6	240	5.44	3.77
	284	5.67	5.03
	326	5.03	4.31
	345	5.52	7.40
	388	7.02	9.01
68.2	240	4.25	5.53
	284	3.03	5.93
	326	1.51	4.45
	345	3.38	4.68
	388	4.17	3.10

Table B28: Standard errors of means, Standard errors of differences of means and Least significant differences of means (5% level) for material loss

STAT	MOISTURE	SPEED	MOISTURE SPEED	CROP_VAR	MOISTURE CROP_VAR	SPEED CROP_VAR	MOISTURE SPEED CROP_VAR
rep.	30	18	6	45	15	9	3
d.f.	60	60	60	60	60	60	60
e.s.e.	0.496	0.640	1.109	0.405	0.701	0.906	1.568
s.e.d.	0.701	0.906	1.568	0.573	0.992	1.281	2.218
l.s.d.	1.403	1.811	3.137	1.146	1.984	2.562	4.437

Table B29: Stratum standard errors and coefficients of variation for material loss

d.f.	s.e.	cv%
60	2.717	54.2

Table B30: Analysis of variance for throughput capacity data

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MOISTURE	2	1825.92	912.96	49.11	<.001
SPEED	4	159.58	39.89	2.15	0.086
MOISTURE.SPEED	8	612.55	76.57	4.12	<.001
CROP_VAR	1	32.84	32.84	1.77	0.189
MOISTURE.CROP_VAR	2	205.05	102.53	5.52	0.006
SPEED.CROP_VAR	4	128.62	32.16	1.73	0.155
MOISTURE.SPEED. CROP_VAR	8	275.61	34.45	1.85	0.085
Residual	60	1115.32	18.59		
Total	89	4355.48			

Tables of means for throughput capacity

Variate: THRUPT_CAP
Grand mean 65.21

Table B31: Mean throughput capacity (kg/hour) at different moisture contents (%)

MOISTURE	84.35	77.6	68.2
THRUPT_CAP	64.14	60.31	71.19

Table B32: Mean throughput capacity (kg/hour) at different operational speeds (rpm)

SPEED	240	284	326	345	388
THRUPT_CAP	64.23	64.82	63.95	65.37	67.69

Table B33: Mean throughput capacity (kg/hour) for interactions of speed with moisture contents (%)

	SPEED				
MOISTURE	240	284	326	345	388
84.35	61.64	60.03	62.42	65.74	70.90
77.6	64.18	59.41	58.93	58.93	60.09
68.2	66.88	75.03	70.50	71.44	72.08

Table B34: Mean throughput capacity (kg/hour) obtained for the different ginger varieties

CROP_VAR	C1	C2
THRUPT_CAP	65.82	64.61

Table B35: Mean throughput capacity (kg/hour)) for interactions of moisture contents (%) with crop variety

	CROP_VAR	
MOISTURE	C1	C2
84.35	63.78	64.51
77.6	63.05	57.57
68.2	70.62	71.75

Table B36: Mean throughput capacity (kg/hour) for interactions of speed with crop variety

	CROP_VAR	
SPEED	C1	C2
240	67.05	61.42
284	65.24	64.41
326	63.12	64.78
345	65.62	65.12
388	68.07	67.31

Table B37: Mean throughput capacity (kg/hour) for interactions of moisture content, speed and crop variety

		CROP_VAR	
MOISTURE	SPEED	C1	C2
84.35	240	67.51	55.76
	284	59.17	60.88
	326	59.74	65.10
	345	64.14	67.34
	388	68.35	73.45
77.6	240	66.90	61.47
	284	60.91	57.92
	326	59.98	57.89
	345	61.70	56.16
	388	65.74	54.44
68.2	240	66.72	67.04
	284	75.63	74.43
	326	69.64	71.36
	345	71.02	71.86
	388	70.11	74.05

Table B38: Standard errors of means, Standard errors of differences of means and Least significant differences of means (5% level) for throughput capacity

STAT	MOISTURE	SPEED	MOISTURE SPEED	CROP_VAR	MOISTURE CROP_VAR	SPEED CROP_VAR	MOISTURE SPEED CROP_VAR
rep.	30	18	6	45	15	9	3
d.f.	60	60	60	60	60	60	60
e.s.e.	0.787	1.016	1.760	0.643	1.113	1.437	2.489
s.e.d.	1.113	1.437	2.489	0.909	1.574	2.032	3.520
l.s.d.	2.227	2.875	4.979	1.818	3.149	4.065	7.042

Table B39: Stratum standard errors and coefficients of variation for throughput capacity

d.f.	s.e.	cv%
60	4.311	6.6