# DETERMINATION OF SOME ENGINEERING PROPERTIES OF SUGARCANE *(Saccharum officinarum)*

BY

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## DECLARATION

I hereby declare that this project is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any University or Institution. Information derived from personal communications, published and unpublished works of others were duly referenced in the text.

07/12/2010

Akpadija, Samuel Okhaifoede

Date

# CERTIFICATION

This project entitled "Determination of some engineering properties of Sugarcane *accharum officinarum)*" by Akpadija Samuel Okhaifoede, meets the regulations governing the ward of the degree of Bachelor of Engineering (B.ENG.) of the Federal University of echnology, Minna, and it is approved for its contribution to scientific knowledge and literary resentation.

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## DEDICATION

This Project is dedicated to Almighty God, to my Parent Elder and Deaconess Akpadija for all their love and support throughout my education, and also to my dear sister Rose Mary Akpadija.

## ACKNOWLEDGEMENTS

I am grateful to Almighty God Jehovah, the Alpha and Omega, who despite all odds has let me successfully to the completion of my programme.

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Finally, this work will not be complete without giving appreciation to my lovely friends: Alan Nwankolo, Nnamdi Menkiti, Obiajulu Menkiti, Richard Balogun, Chika Nwajokwu. Thank you for always being there for me.

May God be with you all.

**ABSTRACT**

In this study, selected engineering properties (shape, size, colour, volume, particle density, surface area and compressive strength) of sugarcane was determined at moisture contents of 70.77%. Under approved standard laboratory conditions and using standard methods and instruments, experiments were conducted and results were obtained. The highest value of compressive strength for sugarcane samples with the nodes when placed vertically and horizontally are 5.86KN and 1.72KN respectively, the highest value of compressive strength for sugarcane samples without nodes when placed vertically and horizontally are 4.46KN and 0.95KN. In operations such as crushing and extraction, Sugarcane with nodes requires a high force greater or equals to 5.86KN on the vertical axis and also requires a lesser compressive force greater or equal to 1.72KN on the horizontal axis. Sugarcane without nodes requires a high force greater or equal to 4.46KN on the vertical axis and also requires a lesser compressive force greater or equal to 0.95KN.The coefficient of variation of length, width, thickness, mass and volume are 11.09%, 4.52%, 4.45%, 12.28% and 14.77% respectively. Therefore, these results are important for maximum efficiency in designing equipment required for further processing of Sugarcane and the reduction of mechanical damage to agricultural produce during postharvest handling and processing.

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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background to the Study

Sugarcane is the common name of a species of herb belonging to the grass family. The official classification of sugarcane is *Saccharum officinarum*, and it belongs to the family Gramineae. It is common in tropical and subtropical countries throughout the world. It can grow from eight to twenty feet tall, and is generally about 2 inches thick. Several different horticultural varieties are known, and they differ by their stem color and length (Harris and Staples, 1999).

The common sugarcane has been cultivated since ancient times. The most widely used form of cultivation is by stem cuttings, since many varieties do not produce fertile seeds (Microsoft Encarta Encyclopedia, 1994). According to Helen and Boyel, (1999) this is one of the many species of plants that would not survive without human intervention. It is a very easy, and profitable plant to grow, but does not naturally reproduce very effectively.

The sugarcane was one of the first "cash crops" of early colonial America. It grew plentifully in the southern states, and was a major source of income for many plantations. It is grown readily in the United States in Hawaii, Louisiana, Florida and Puerto Rico. The countries that produce the largest amounts of sugarcane are Brazil, Cuba, Kazakhstan, Mexico, India, and Australia (Microsoft Encarta Encyclopedia, 1994).

Sugarcane is the source of sugar in all tropical and subtropical countries of the world. Estimates for 2000 and 2009 indicate world production of cane sugar was between 40 and 41 million tons. Production in the United States, excluding Puerto Rico, averaged 2,550,000 tons during those years - from 592,000 acres of cane in Hawaii, Florida and Louisiana. Sugar production in Puerto Rico averaged 850,000 tons for the two years.

Several species of Sugarcane are found in Southeast Asia and neighboring islands, and from these cultivated cane probably originated. The sweet juice and crystallized sugar were known in China and India some 2500 years ago. Sugarcane reached the Mediterranean countries in the eighth century A.D., and reached the Americas in early colonial times.

The cane plant is a coarse growing member of the grass family with juice or sap high in sugar content. It is tender to cold, the tops being killed by temperatures a little below freezing. In continental United States, where freezing may occur during the winter, it is mainly planted in late summer or early fall and harvested a year later. In tropical countries it may be planted at almost any time of the year since the plant does not have a rest period. The season of active growth in continental United States is 7 to 8 months while in tropical countries growth is near continuous until harvest. This results in heavier yields of cane and sugar under tropical conditions. For example, yields of cane and sugar per acre in Hawaii, where the cane is grown for about 2 years before harvesting, are from 3 to 4 times yields in Louisiana and Florida from one season's growth (Microsoft Encarta Encyclopedia, 1994).

Sugarcane plants are propagated by planting sections of the stem. The mature stems may vary from 4 to 12 feet or more ill height, and in commercial varieties are from 0.75 to 2 inches in diameter. The stem has joints or nodes as in other grasses. These range from 4 to 10 inches apart along the above-ground section of the stem. At each node a broad leaf rises which consists of a sheaf or base and the leaf blade. The sheaf is attached to the stem at the node and at that point entirely surrounds the stem with edges overlapping. The sheath from one node encircles the stem up to the next node above and may overlap the base of the leaf on the next higher node. The leaf blade is very long and narrow, varying in width from 1 to 3 inches and up to 5 feet or more in length. Also, at each node along the stem is a bud, protected under the leaf sheath. When stem sections are planted by laying them horizontally and covering with soil a new stem grows from the bud, and roots grow from the base of the new stem. The stem branches below ground so several may rise as a clump from the growth of the bud at a node (Faw, 1998).

In planting cane fields, mature cane stalks are cut into sections and laid horizontally in furrows. In continental United States sections with several nodes are laid while in tropical countries sections with 2 or 3 nodes are commonly used - since temperatures for growth are more favorable. Usually only one node on a stem piece develops a new plant because of polarity along the stem piece.

Planting is in rows about 6 feet apart to make possible cultivation and use of herbicides for early weed control. As plants become tall lower leaves along the stems are sbaded and die. These ultimately drop off, so only leaves toward the top remain green and active. Between the nodes the stems have a hard, thin, outer tissue or rind and a softer center. The high-sugar-containing juice is in this center. More than one crop is harvested from a planting. After the first crop is removed two or more so-called stubble crops are obtained. These result from growth of new stalks from the bases of stalks cut near the ground level in harvesting (Faw, 1998).

Sugarcane cannot be easily harvested by machine, so for centuries it has been harvested by hand, using large machete like blades. For this reason sugarcane fields have very large amounts of farm hands, and are a major source of employment throughout South America, Central America, and even the Caribbean. In early America, when the plant was readily harvested, it was a major source of slavery in the south. However, with the advent of abolition, it was found that sugarcane could be imported cheaper than it could be grown (Microsoft Encarta Encyclopedia, 1994). This is why the sugarcane industry in the United States has diminished so sharply since the Civil War.

The primary use for sugarcane is to process sugar, which can then be used in an infinite number of products. The type of sugar produced by sugarcane is called sucrose. This is the most important of all the sugars. Sucrose is used as a sweetening agent for foods and in the manufacture of cakes, candies, preservatives, soft drinks, alcohol, and numerous other foods. Although the use of sugar in the human diet is controversial, sucrose supplies about 13 percent of all energy that is derived from foods (Escalona, 1962).

Over half of the World's sugar supply is derived from the sugarcane (Microsoft Encarta Encyclopedia, 1994). The sugarcane producing countries are not given much credit for supplying the world with a major source of food and nutrition, but they are given plenty of credit for being a world leader in making money. Billions of dollars are generated every year due to the sugarcane plants that are grown in the west alone. Also of significance is the number of jobs that are created every year to harvest the sugarcane plant in small and underprivileged countries (Escalona, 1962).

When sugarcane is harvested it is stripped of its leaves and sent to the sugar factory. At the factory the stems are crushed and shredded by rollers in a process called grinding. During grinding hot water is sprayed over the shredded material to extract the remaining sugar. The solid waste that is left after extraction of the sugar is known as pulp or sugarcane bagasse, which is dried and used as a fuel (Harris and Staples, 1999).

The raw juice is then heated and spun in a centrifuge at nearly 1500 rotations per minute. The centrifuge walls are pierced with small holes through which a thick syrup is forced out. This syrup is called molasses, and is in itself a very valuable product. The molasses, which ironically is a waste product of sugar refining, can be sold as syrup, to flavor rum and other foods, to feed animals, or even as an additive for ethyl alcohol. Molasses is even used in processed tobaccos (Harris and Staples, 1999).

After bagasse and molasses are separated from the sugar, the sugar is sent to the refinery. Here sugar is redissolved, decolorized, and recrystallized into the desired size. After the refinery the finished product is established in the form of powdered, granulated, and lump sugars. Brown sugar is also a product created in the refinery. This is simply sugar that has residual molasses in it. Sugar is not only a well known home food additive, but also plays a large role in industrial fermentation. Sugar is a raw material used in the fermentation of ethyl alcohol, butyl alcohol, glycerin, citric acid, and levulinic acid. Sugar is also an ingredient in many soaps, and can be converted into industrial resins (Harris and Staples, 1999).

The difficulty encountered in getting sugarcane to reproduce has begun to cause a global dilemma. World overpopulation, coupled with an increase in the industrial use of sugar has opened the eyes of many scientists. The demand for sugar is greatly outpacing the ability to produce sugarcane (Lorenzo and Gonzalez, 2000). While this is beneficial to many sugar producing countries, it is tremendously disastrous for the rest of the world. Cuba, for instance, has seen a fourfold increase in the demand for its sugar, but has actually decreased the number of acres in which it plants sugarcane (Escalona, 1982). This is very important, because Cuba is the United

States' largest supplier of sugar. Continuing this in attention to the global need for commercially processed sugarcane could lead to a world-wide shortage of this sweet substance.

To help curb the world shortage of sugar scientists have begun cultivating sugarcane shoots in laboratories using a temporary immersion system. This system allows for a longer growing season for sugarcane, because the shoots could be planted inside, and then planted and harvested earlier. This might allow for two different harvests in one year, which would double global sugarcane production. Also of much importance is the fact that this temporary immersion system reduces planting costs by 46%, and performs similarly to conventionally grown sugarcane, Finally, by growing sugarcane in a sterile laboratory, the amount of time that sugarcane in exposed to the elements is limited, and therefore chance of healthier plants increases (Lorenzo and Gonzalez, 2000).

Engineering properties are key fundamental factors to the creation of new ideas. To be more precise, it will enhance techno-scientific development with respect to agricultural production. According to Food and Agricultural Organization of United Nations (FAO) report, increasing world population and rising standard of living are the two major pressures on the supply of food. Therefore, the need to address and solve this problem entails getting more food supply through agricultural mechanization to the less food production populace of the world, especially the developing countries including Nigeria. Knowing the engineering properties of agricultural products will enable engineers to design appropriate pre-harvest and post-harvest handling equipment which will in turn boost the production of such a product (Olajide, 1999).

## 1.2 Objectives of the Study

The objective of this project is to determine these selected engineering properties of sugarcane; (shape, size, colour, weight, volume, density, porosity, surface area, angle of repose and compressive strength).

## 1.3 Statement of the Problem

The shortage of processing, preservative machines and equipment for sugarcane, maybe due to the fact that data on the engineering properties of sugarcane required for the design of these machines are insufficient and not available in some cases in Nigeria.

Also, most agricultural products are visco-elastic, therefore, the determination of the engineering properties of biomaterials are difficult and complicated, since they are apparently affected by temperature, moisture content and the rate of loading.

## 1.4 Justification of the Study

The knowledge of the engineering properties is useful for both engineers and food scientist, plant and animal breeders and thus it is important it is important in data collection which are of high relevance in the consideration of the designing and fabrication of processing, preserving, handling, harvesting systems and machines as well as the utilization of harvested and processed sugarcane for different functions and purposes of which the sugarcane had been underutilized, particularly in the developing countries.

## 1.5 Scope of the Study

The project will focus only on the determination of some engineering properties. The results will be useful for those working on design and fabrication of sugarcane juice extractor. Recommendation will be made after the determination and will go a long way to assist future researcher in post-harvest technology of agricultural products.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Sugarcane

Sugarcane is any of six to thirty-seven species (depending on taxonomic system) of tall perennial grasses of the genus *Saccharum* (family Poaceae, tribe Andropogoneae). Native to warm temperate to tropical regions of Asia, they have stout, jointed, fibrous stalks that are rich in sugar, and measure two to six meters (six to nineteen feet) tall. All sugar cane species interbreed, and the major commercial cultivars are complex hybrids (Harris and Staples, 1999).

Sugarcane products include table sugar, Falernum, molasses, rum, cachaça (the national spirit of Brazil), and ethanol. The bagasse that remains after sugarcane crushing may be burned to provide heat and electricity. It may also, because of its high cellulose content, serve as raw material for paper, cardboard, and eating utensils that, because they are by-products, may be branded as "environmentally friendly" (Dawes, 1983). Plate 2.1 shows a sugarcane plant and Plate 2.2 shows a mature sugarcane sticks.

Plate 2.1: Sugarcane Plant

Plate 2.2: Mature Sugarcane Sticks

Today, sugarcane is grown in over 110 countries. In 2008 an estimated 1,743 million metric tons of sugarcane were produced worldwide. Today, about 50 percent of world sugarcane production occurs in Brazil and India as shown in Fig 2.1.

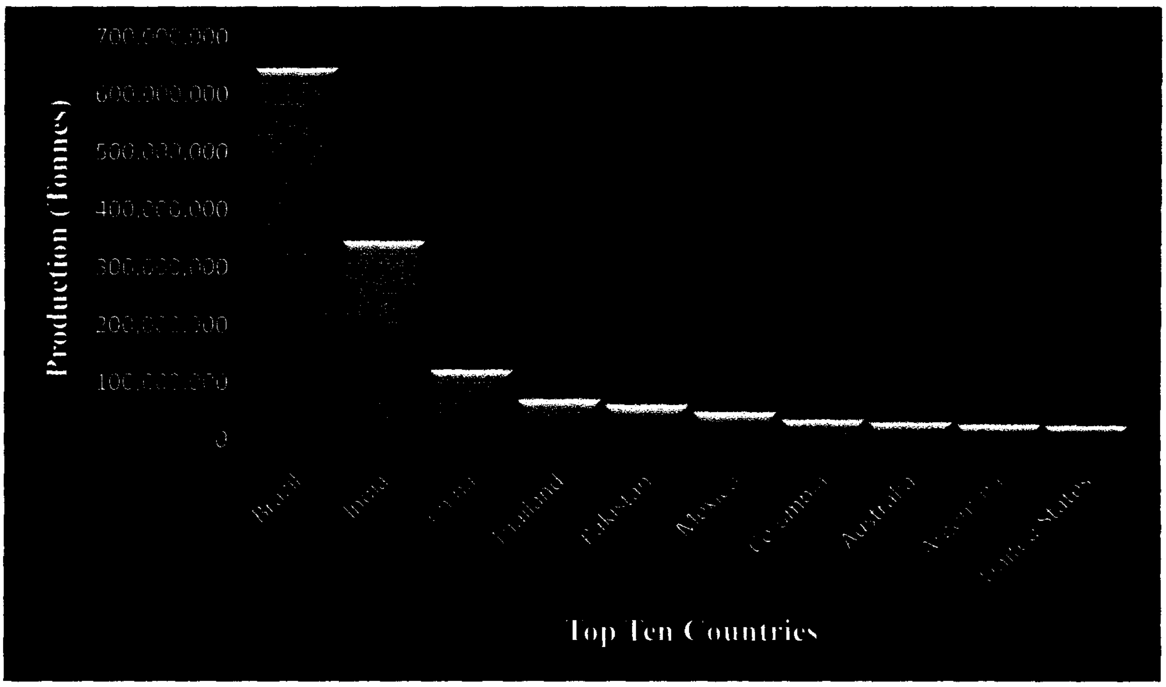


Fig 2.1 Top Ten Sugarcane Producers

### 2.1.1 Origin

Sugarcane is indigenous to tropical South Asia and Southeast Asia. Different species likely originated in different locations with *S. barberi* originating in India and *S. edule* and *S. officinarum* coming from New Guinea. Crystallized sugar was reported 5,000 years ago in India.

Around the eighth century A.D., Arabs introduced sugar to the Mediterranean, Mesopotamia, Egypt, North Africa, and Andalusia. By the tenth century, sources state, there was no village in Mesopotamia that did not grow sugarcane. It was among the early crops brought to the Americas by the Andalusians (from their fields in the Canary Islands), and the Portuguese (Lorenzo and Gonzalez, 2000).

"Boiling houses" in the 17th through 19th centuries converted sugarcane juice into raw sugar. These houses were attached to sugar plantations in the western colonies. Slaves often ran the boiling process, under very poor conditions. Made of cut stone, rectangular boxes of brick or stone served as furnaces with an opening at the bottom to stoke the fire and remove ashes. At the top of each furnace were up to seven copper kettles or boilers, each one smaller and hotter than the previous one. The cane juice began in the largest kettle (Faw, 1998). The juice was then heated and lime added to remove impurities. The juice was skimmed, then channeled to successively smaller kettles. The last kettle, which was called the 'teache', was where the cane juice became syrup. The next step was a cooling trough, where the sugar crystals hardened around a sticky core of molasses. This raw sugar was then shoveled from the cooling trough into hogsheads (wooden barrels), and from there into the curing house (Dawes, 1983).

Sugarcane is still extensively grown in the Caribbean. Christopher Columbus first brought it during his second voyage to the Americas, initially to the island of Hispaniola (modern day Haiti and the Dominican Republic). In colonial times, sugar formed one side of the triangular trade of New World raw materials, European manufactures, and African slaves. France found its sugarcane islands so valuable, it effectively traded its portion of Canada, famously dubbed "a few acres of snow," to Britain for their return of Guadeloupe, Martinique and St. Lucia at the end of the Seven Years' War. The Dutch similarly kept Suriname, a sugar colony in South America, instead of seeking the return of the New Netherlands (New York). Cuban sugarcane produced sugar that received price supports from and a guaranteed market in the USSR; the dissolution of that country forced the closure of most of Cuba's sugar industry. Sugarcane remains an important part of the economy of Guyana, Belize, Barbados, Haiti, along with the Dominican Republic, Guadeloupe, Jamaica, and other islands (Reagan and Flynn, 1986).

Sugarcane production greatly influenced many tropical Pacific islands, including Okinawa and, most particularly, Hawaiʻi and Fiji. In these islands, sugarcane came to dominate the economic and political landscape after the arrival of powerful European and American agricultural businesses, which promoted immigration of workers from various Asian countries to tend and harvest the crop. Sugar was the dominant factor in diversifying the islands' ethnic makeup, profoundly affecting their politics and society.

Brazil is the biggest grower of sugarcane, which goes for sugar and ethanol for gasoline-ethanol blends (gasohol) for transportation fuel. In India, sugarcane is sold as jaggery, and also refined into sugar, primarily for consumption in tea and sweets, and for the production of alcoholic beverages (Reagan and Flynn, 1986).

### 2.1.2 Uses

Some medical and curative properties of sugarcane:

1. Sugarcane juice is great for recharging energy because it contains rich carbohydrate and iron. Green-typed tropical sugarcane is sweetest and juiciest. It is also elephant's favorite.
2. Being a nutritious product containing natural sugars, minerals and organic acids, sugarcane juice has many medicinal properties.
3. It strengthens the stomach, kidneys, heart, eyes, brain and sex organs.
4. The juice is beneficial in fevers. In febrile disorders which causes fever, when there is a great protein loss, liberal intake of sugarcane juice supplies the body with necessary protein and other food elements.
5. Sugarcane is very useful in scanty urination. It keeps the urinary flow clear and helps the kidneys to perform their functions properly. It is also valuable in burning micturation due to high acidity, genorrhoea, enlarged prostate, cyctitis and nepthritis. For better results, it should be mixed with lime juice, ginger juice and coconut water.
6. Mixed with lime juice, it can hasten recovery from jaundice. It is, however, very essential that the juice, must be clean, preferably prepared at home. Resistance is low in hepatitis and any infected beverage could make matters worse.
7. The juice sucked from the sugarcane can prove highly valuable in case of weak teeth due to lack of proper exercise resulting from excessive use of soft foods. It gives a form of

In planting cane fields, mature cane stalks are cut into sections and laid horizontally in furrows. In continental United States sections with several nodes are laid while in tropical countries sections with 2 or 3 nodes are commonly used - since temperatures for growth are more favorable. Usually only one node on a stem piece develops. a new plant because of polarity along the stem piece (Taylor and Francis, 2009).

Planting is in rows about 6 feet apart to make possible cultivation and use of herbicides for early weed control. As plants become tall lower leaves along the stems are sbaded and die. These ultimately drop off, so only leaves toward the top remain green and active. Between the nodes the stems have a hard, thin, outer tissue or rind and a softer center. The high-sugar-containing juice is in this center. More than one crop is harvested from a planting. After the first crop is removed two or more so-called stubble crops are obtained. These result from growth of new stalks from the bases of stalks cut near the ground level in harvesting.

### 2.1.4 Pest

The cane grub can substantially reduce crop yield by eating roots; it can be controlled with Confidor or Lorsban. Other important pests are the larvae of some butterfly/moth species, including the turnip moth, the sugarcane borer (*Diatraea saccharalis*), the Mexican rice borer (*Eoreuma loftini*); leaf-cutting ants, termites, spittlebugs (especially *Mahanarva fimbriolata* and *Deois flavopicta*), and the beetle *Migdolus fryanus*. The planthopper insect *Eumetopina flavipes* acts as a phytoplasma vector, which causes the sugarcane disease ramu stunt (Reagan and Flynn, 1986).

### 2.1.5 Pathogens

Numerous pathogens infect sugarcane, such as Sugarcane Grassy Shoot Disease caused by *Phytoplasma*, Whiptail disease or Sugarcane smut, Pokkah Boeng caused by *Fusarium moniliforme*, and Red Rot disease caused by *Colletotrichum falcatum*. Viral diseases affecting sugarcane include Sugarcane mosaic virus, Maize streak virus, and Sugarcane Yellow Leaf Virus (Faw, 1998).

### 2.1.6 Nitrogen Fixation

Some sugarcane varieties are known to be capable of fixing atmospheric nitrogen in association with the bacterium *Glucoacetobacter diazotrophicus*. Unlike legumes and other nitrogen fixing plants which form root nodules in the soil in association with bacteria, *G. diazotrophicus* lives within the intercellular spaces of the sugarcane's stem (Dawes, 1983).

## 2.2 Sugarcane Production

The production of raw sugar in Nigeria slumped to zero in the early part of this decade. More recently, however, with the privatisation of sugar-producing companies and good management in the refinery business, the Nigerian sugar industry has emerged from this slump. The success of the privatisation process has seen domestic sugar production rise to around 100,000 tons in 2007/2008, up from 80,000 in 2006/2007. With overall sugar consumption in the region of 1.5 million tons, Nigeria is the largest consumer of sugar in Africa apart from South Africa, and the industry is still dependent on raw sugar imports. 90% of Nigeria's sugar is, however, refined in the country, opening the door to increased exports of refined sugar (Dawes, 1983).

The Nigerian government encourages local value addition by maintaining a duty differential of 50% between imports of refined sugar and raw sugar and granting five year tax holidays to refineries. (The tariff differential between imports of refined sugar and raw sugar from the Economic Community of West African States (ECOWAS) and other countries is 15%).

The reorganisation of the industry has been overseen by the National Sugar Development Council (NSDC), set up in 1993. The NSDC has set a target of 70% self-sufficiency in sugar production by 2010 (Faw, 1998).

In 2008 Olam International Limited announced a strategic partnership with the Modandola Group (MG) for investments in sugar refining in Nigeria. This partnership will set up a 750,000 ton per annum capacity sugar refinery with a captive port in Lagos.

The Dangote Sugar Refinery, majority-owned by Nigeria's leading private conglomerate, Dangote Group, is the main sugar plant in Nigeria. It has a production capacity of 1.44 million MT per annum, making it the largest sugar refinery in sub Saharan Africa and second largest in the world. In Nigeria, Kaduna state is the largest sugarcane producing state (Olajide,1999).

### 2.2.1 Company Involved In the Utilization of Sugarcane

Some of these companies are as follows;

1. Nigeria Sugar Co Ltd, PMB 65 Jebba, Kwara State, Nigeria
2. Tate Industries Plc, P O Box 1240 Lagos, Lagos State, Nigeria

3. The Nigerian Association of Chambers of Commerce, Industry, Mines and Agriculture P O Box 109 Lagos, Lagos State, Nigeria (Matsuoka, 2006).

### 2.2.2 Economic importance

Sugarcane production offers a great deal to the economy, if exploited to its full potential. It could serve as a means of foreign exchange, thereby increasing the foreign reserve of the economy.

Sugarcane production could also aid the economy to deal with the present increase in unemployment. If sugarcane is present in a large scale production, it would provide job employment for a lot of people within that economy. An example of this can be seen in Plate 2.3.

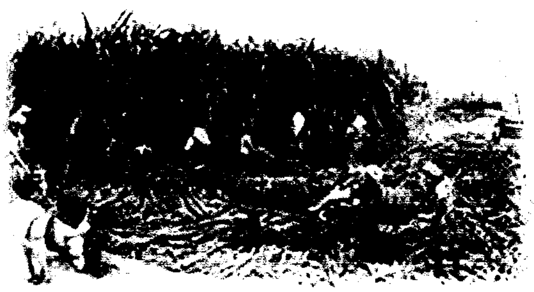

Plate 2.3: Sugarcane serving as a means of employment

### 2.2.3 Sugarcane Large Scale Production

#### 2.2.3.1 Processing

Traditionally, sugarcane processing requires two stages. Mills extract raw sugar from freshly harvested cane, and sometimes bleach it to make "mill white" sugar for local consumption. Refineries, often located nearer to consumers in North America, Europe, and Japan, then produce refined white sugar, which is 99 percent sucrose. These two stages are slowly merging. Increasing affluence in the sugar-producing tropics increased demand for refined sugar products, driving a trend toward combined milling and refining (Taylor and Francis, 2009).

#### 2.2.3.2 Milling

Small rail networks are a common method of transporting cane to a mill. Refineries test newly arrived cane for Brix and trash percentage (Dawes, 1983).

The mill washes, chops, and uses revolving knives to shred the cane. Shredded cane is repeatedly mixed with water and crushed between rollers; the collected juices contain 10–15 percent sucrose, and the remaining fibrous solids, called bagasse, are burned for fuel. Bagasse makes a sugar mill more than energy self-sufficient; surplus bagasse goes in animal feed, in paper manufacture, or to generate electricity for sale. The cane juice is next mixed with lime to adjust its pH to 7. This mixing arrests sucrose's decay into glucose and fructose, and precipitates some impurities. The mixture then sits, allowing the lime and other suspended solids to settle. The clarified juice is concentrated in a multiple-effect evaporator to make a syrup about 60 percent sucrose by weight. This syrup is further concentrated under vacuum until it becomes supersaturated, and then seeded with crystalline sugar. On cooling, more sugar crystallizes from the syrup. A centrifuge separates the sugar from the molasses. Additional crystallizations extract more sugar; the final residue is called blackstrap (Taylor and Francis, 2009).

Raw sugar is yellow to brown. Bubbling sulfur dioxide through the cane juice before evaporation bleaches many color-forming impurities into colorless ones. This *sulfitation* produces sugar known as "mill white", "plantation white", and "crystal sugar". Such sugar is the most commonly consumed in sugarcane-producing countries as shown in Plate 2.4 (Rainy, 2009).

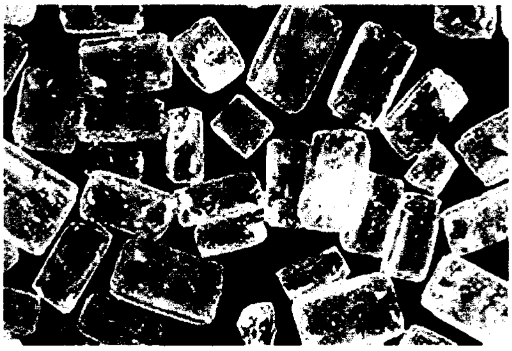

Plate 2.4: Sugar Crystals

#### 2.2.3.3 Refining

Sugar refining further purifies the raw sugar. It is first mixed with heavy syrup and then centrifuged in a process called 'affination'. Its purpose is to wash away the sugar crystals' outer coating, which is less pure than the crystal interior. The remaining sugar is then dissolved to make a syrup, about 70 percent solids by weight (Taylor and Francis, 2009).

The sugar solution is clarified by the addition of phosphoric acid and calcium hydroxide, which combine to precipitate calcium phosphate. The calcium phosphate particles entrap some impurities and absorb others, and then float to the top of the tank, where they can be skimmed off. An alternative to this "phosphatation" technique is 'carbonatation,' which is similar, but uses carbon dioxide and calcium hydroxide to produce a calcium carbonate precipitate (Palmer and Donald 2007).

After filtering any remaining solids, the clarified syrup is decolorized by filtration through activated carbon. Bone char is traditionally used in this role. Some remaining color-forming impurities adsorb to the carbon. The purified syrup is then concentrated to supersaturation and repeatedly crystallized in a vacuum, to produce white refined sugar. As in a sugar mill, the sugar crystals are separated from the molasses by centrifuging. (Harris and Staples, 1999) Additional sugar is recovered by blending the remaining syrup with the washings from affination and again crystallizing to produce brown sugar. When no more sugar can be economically recovered, the final molasses still contains 20–30 percent sucrose and 15–25 percent glucose and fructose.

To produce granulated sugar, in which individual grains do not clump, sugar must be dried, first by heating in a rotary dryer, and then by blowing cool air through it for several days (Helen and Boyel, 1999)

#### 2.2.3.4 Disadvantages of Sugarcane Production

The major disadvantage involved in the production of sugar has to do with the high rate of mosquitoes and other insects that would be attracted to that area due to the sugarcane plantation (Reagan and Flynn, 1986).

## 2.3 Physical properties of Sugarcane

A physical property is any measurable property the value of which describes a physical system's state. The changes in the physical properties of a system can be used to describe its transformations (or evolutions between its momentary states).

An agricultural produce can be measured or perceived without changing its identity. Physical properties can be intensive or extensive. An intensive property does not depend on the size or amount of matter in the produce, while an extensive property does. In addition to extensiveness, properties can also be either isotropic if their values do not depend on the direction of observation or anisotropic otherwise. Physical properties are referred to as observables. They are not modal properties (Microsoft Encarta Encyclopedia, 1994).

### 2.3.1 Shape

This is defined as the form of which the agricultural produce takes with respect to standard shapes. The knowledge of the shape of agricultural produce is vital in the construction and fabrication of processing machines and equipment. Shape is also important in heat and mass transfer calculations, screening solids to separate foreign materials, grading of fruits, vegetables and evaluating the quality of food materials (Mohsenin, 1970).

### 2.3.2 Size

Size is an important physical attribute of foods used in screening solids to separate foreign materials, grading of fruits, vegetables and evaluating the quality of food materials. In fluid flow and heat and mass transfer calculations, it is necessary to know the size of the sample.

Size can be determined using the projected area method. In this method, three characteristics dimensions are defined:

1. Length, which is the longest dimension of the maximum projected area;
2. Width, which is the minimum diameter of the maximum projected area or the maximum diameter of the minimum projected area; and
3. Thickness, which is the shortest dimension of the minimum projected area

Length (L), width (W), and thickness (T) terms are commonly used and they correspond to major, intermediate and minor diameters respectively. The dimensions can be measured using a micrometer or vernier caliper. The micrometer is a simple instrument used to measure distances between surfaces. Most micrometers have a frame, anvil, spindle, sleeve, thimble and ratchet stop. They are used to measure the outside diameters, inside diameters, the distance between parallel surfaces, and the depth of holes. Fig 2.2 shows the representation of the three axes and the three perpendicular dimensions of a sugarcane.

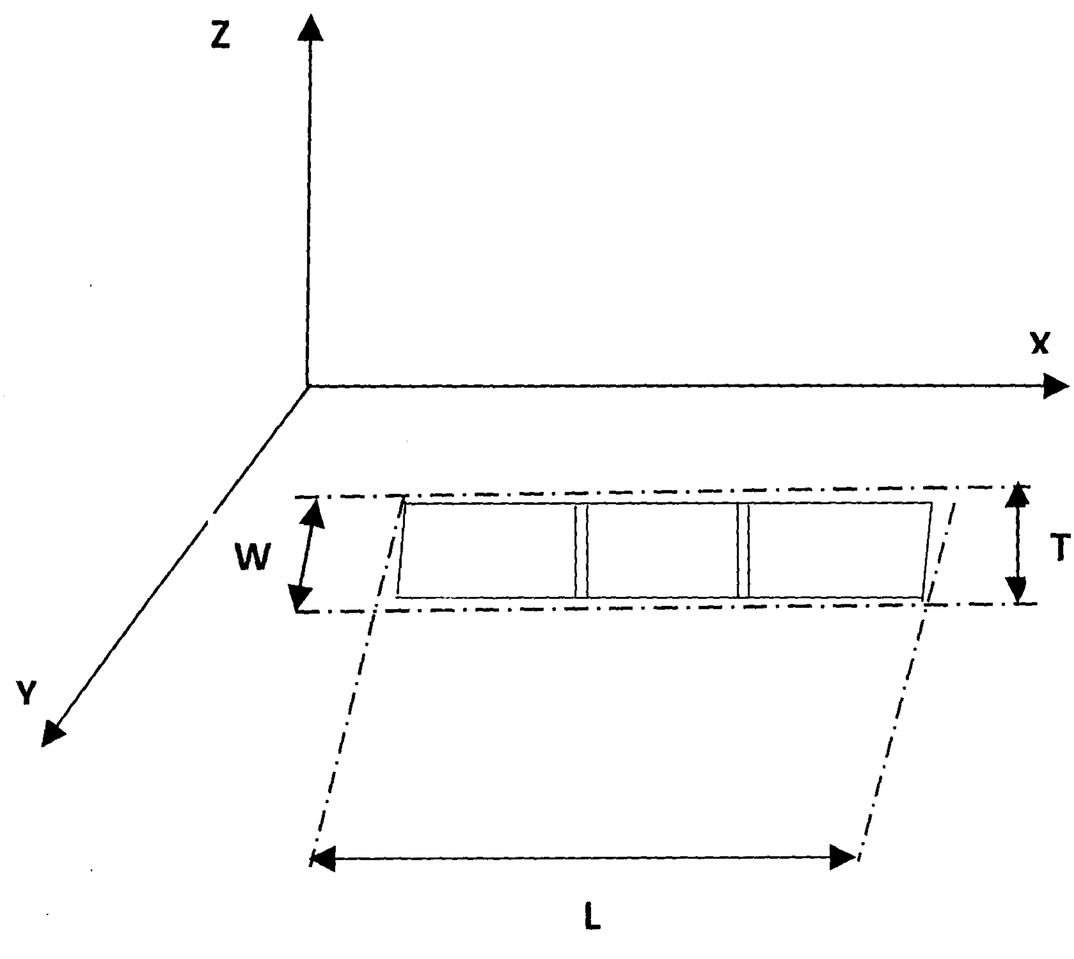


Fig 2.2 Representation of the three dimensions of sugarcane.

Axial dimension in terms of length ($D_1$), width ($D_2$), and thickness ($D_3$), which their means, can be used to evaluate arithmetic mean diameter (AMD), the geometric mean diameter (GMD), square mean diameter (SMD), equivalent diameter (EQD), and the aspect ratio (AR) of the samples using the equations (Mohsenin, 1986)

$$\text{AMD} = \text{A} = \frac{1}{3}[D_1 + D_2 + D_3] \tag{2.1}$$

$$GMD = B = [D_1 \times D_2 \times D_3]^{\frac{1}{3}} \tag{2.2}$$

$$\text{SMD} = \text{C} = \frac{\sqrt{D1\,D2 + D2D3 + D3D1}}{3} \tag{2.3}$$

$$\text{EQD} = \frac{A+B+C}{3} \tag{2.4}$$

$$\text{AR} = \frac{D2}{D1} \tag{2.5}$$

### 2.3.3 Colour

Colour is one of the important quality attributes in foods. Although it does not necessarily reflect nutritional, flavour, or functional values, it determines the acceptability of a product by consumers. It maybe desirable to follow the changes in colour of a product during storage, maturation, processing and so forth. Colour is often used to determine the ripeness of fruits.

Colour is a perceptual phenomenon that depends on the observer and the conditions in which the colour is observed. It is a characteristic of light, which is measurable in terms of intensity and wavelength. Colour of a material becomes visible only when light from a luminous object or source illuminates or strikes the surface. Colour can be determined using a colorimeter or even using the natural white light. Surface colour and appearance are valuable physical properties for selective separation in the field as subsequent handling and processing.

### 2.3.4 Volume and Density

Volume is defined as the amount of three dimensional space occupied by an object, usually expressed in units that are the cubes of length units, such as cubic inches and cubic centimeters, or in units of liquid measure, such as gallons and litres. In the SI system, the unit of volume is $m^3$.

Volume is a very important quality attribute in the food industry. Volume of solids can be determined by using the following methods:

1. Volumes of solids can be determined experimentally by liquid, gas, or solid displacement methods.
2. Volumes can be measured by the image processing method. An image processing method has been recently developed to measure volume of ellipsoidal agricultural products
3. Volume can be calculated from the characteristic dimensions in case of objects with regular shape.

Quality of food materials can be assessed by measuring their densities. Density data of foods are required in separation processes, such as centrifugation and sedimentation and in pneumatic and hydraulic transport of powders and particulates. In addition, measuring the density of liquid is required to determine the power required for pumping. It is also an important physical property to be considered in the fabrication of processing machinery (Mohsenin, 1986).

Density can be calculated after measuring the mass and volume of the object because it is defined as the mass per unit volume. In the SI system, the unit of density is $kg/m^3$.

### 2.3.5 Weight

This can be defined as the quality of heaviness in things, determined by their mass or quantity of matter as acted on by the force of gravity that counteracts efforts to lift or move them.

In handling and processing of agricultural produce, the weight of the produce plays an important role such that it should be critically considered by agriculturalist and engineers. This is the effect of the earth's gravitational force on the mass of agricultural produce. It is usually expressed as the product of the (kg) and the constant of the earth's gravitational pull ($m/s^2$). Its SI unit is Newton (N) and it is mathematically expressed as:

$$w = mg \qquad (2.6)$$

where;

w - weight

m - mass

g - acceleration due to gravity

### 2.3.7 Moisture content

The moisture content of a produce simply indicate the amount of water present in that agricultural produce and this, is great importance to both food scientist and agricultural engineers as it helps in determining certain adaptation and resistance to processing stages such as drying, bagging, storage, cooking and even consumption. It can be expressed in dry or wet basis.

$$M_c = \frac{w_i - w_f}{w_i} \times 100 \qquad (2.7)$$

where:

$m_c$ - moisture content, % dry basis

$w_i$ - initial weight of sample, kg

$w_f$ - final weight of sample, kh

## 2.4 Mechanical Properties

### 2.4.1 Compressive Strength

Compressive strength is the capacity of agricultural produce to withstand axially directed pushing forces. When the limit of compressive strength is reached, the produce is crushed. The compressive strength of a produce is that value of uniaxial compressive stress reached when the produce fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied (Harris and Staples, 1999).

### 2.4.2 Hardness

Hardness is the measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong intermolecular bonds, however the behavior of agricultural produce under force is complex, therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness.

Hardness is dependent on ductility, elasticity, plasticity, strain, strength, toughness, viscoelasticity, and viscosity (Palmer and Donald, 2007).

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Selection of material

The agricultural crop used in determining these engineering properties is Sugarcane *Saccharum officinarum* and 50 pieces of the specimen was used during the experiment (Narsi, 2006). The Sugarcane was obtained from Kure Market, Minna, Niger state, within the month of October.

### 3.2 Preparation of the materials

The 50 samples were cleaned to remove foreign matter, dust and dirt. For the experiment, samples were randomly selected and extra care was ensured to select good sugarcane without any sign of blemish, so as to eliminate getting incorrect results.

### 3.3 Methods

Summary of methods used is given in the Table 3.1:

Table 3.1 Summary of methods

| Parameter | Method used | Instruments/Material/Trademarks |
|---|---|---|
| 1. Moisture content | Oven-drying method | Townson & Mercer electric oven |
| 2. Size | Measurement of dimensions | Vernier caliper, 12cm, 0.002cm accuracy |
| 3. Geometric mean diameter | Mathematical formula i.e. $D_g=(LWT)^{1/3}$ | |
| 4. True density | Toluene displacement method | Toluene, sinker, inextensible string, $1000cm^3$ cylinder |
| 5. Surface Area | Mathematical formula i.e. $\pi(D_g)^2$ | |

### 3.4 Moisture content determination

The moisture content was determined using the oven dried method at $105^0C$ for 24 hours until constant weight was achieved (ASAE, 2003). The weight loss of the samples was recorded and the moisture determined in percentage. The moisture content was calculated using equation 2.7.

## 3.5 Determination of the physical properties

### 3.5.1 Shape determination

To determine the shape of the sugacane, tracing of the longitudinal and lateral cross sections of the material, when a projector was focused to obtain a sharp boundary on a cardboard paper. This was compared with the shapes listed on a charted standard (Mohsenin, ed. 1986). Using the standard charts, descriptive terms were used to define the shape of the product over twenty replicates.

### 3.5.2 Size Determination

To determine the size of the sugarcane 30 samples were selected at random (Narsi, 2006), according to Mohsenin, the mutually perpendicular axes ($D_1$) and ($D_3$) referred to as length and width, and the thickness ($D_3$) were measured using Vernier Caliper reading to 0.02mm precision. The values for $D_1$, $D_2$ and $D_3$ were used to evaluate arithmetic mean diameter (AMD), the geometric mean diameter (GMD), square mean diameter (SMD), equivalent diameter (EQD) and the aspect ratio (AR) of the materials under investigation using equations 2.1 to 2.5 respectively.

### 3.5.3 Colour determination

The colour is that part of white light that is reflected when light falls on them. To determine the colour of the product, a colorimeter and a standard munsell system of colour measurement was used. In this system all colours are described by the three attributes of hue, value and Chroma. The colour of the product is compared with the colour chips.

### 3.5.4 Geometric Mean Diameter

This was computed using the equation (Mohsenin, 1970):

$$Dg = (LWT)^{1/3}$$

Where Dg is geometric mean diameter, L is the length or dimension along the longest axis in mm; W is the width or dimension along the longest axis perpendicular to L in mm and T is the intermediate diameter or thickness dimension along the longest axis perpendicular to both L and W in cm.

### 3.5.5 Measurement of volume

Toluene ($C_6H_5CH_3$) displacement method was used to determine the volume of the products due to the irregular shapes of the product. The material were first weighed on a platform scale in air and then forced into Toluene inside a measuring cylinder of capacity of $1000cm^3$ by means of a thread. The sugarcane was immersed in the toluene noting the final level to which the toluene rose. The difference between the final and initial levels gives the volume of the sugarcane.

### 3.5.6 Determination of particle density

This is obtained by diving the sample mass measured by the electronic weighing balance by the volume determined by toluene displacement method.

### 3.5.7 Determination of Surface Area

The surface area of the seeds was found by analogy with a sphere of the same geometric mean diameter, using the following equation cited by Tunde-Akintunde and Akintunde (2007).

$S_a = \pi \, GMD^2$

Where:

$S_a$ - surface area, $mm^2$

GMD - geometric mean diameter, mm

### 3.5.8 Weight of products

The weight of the sample selected for the experiment was determined using the electronic weighing machine. Result obtained for 30 replicates (Narsi, 2006).

### 3.5.9 True density

This is the ratio of mass and true volume. Volume of the sugarcane samples was determined by toluene ($C_6H_5CH_3$) displacement method. Toluene was used as it is absorbed to a lesser extent than water and has a low surface tension thereby enabling it to flow smoothly over the sugarcane surface (Mohsenin, 1970).

Toluene was poured into a measuring cylinder of capacity of $1000cm^3$. The sugarcane was immersed in the toluene noting the final level to which the toluene rose. The difference between the final and initial levels gives the volume of the sugarcane.

The mass of each sugarcane was obtained using an electronic balance with sensitivity of 0.001g. The true density was calculated using the relationship:

$$\rho_t = \frac{Mass}{True\ volume}$$

Where $\rho_t$ - true density

## 3.6 Determination of the mechanical property

### 3.6.1 Compressive Strength

This test was carried out using a Universal Material Testing Machine (100kN) (Norwood Instrument Ltd. Huddersfield, Great Britain. Model no: Cat.Nr.261) at the Strength of Material Laboratory with 0.1kn sensitivity, Mechanical Engineering Department, Ahmadu Bello University, Zaria. The machine consists of a fitted Hydraulic hand pump and an Electric digital box which has a load indicator for measuring the amount of load or force exerted. Pressure is applied by the upper arm pressing down on the product which is placed centrally on the bottom platen, which remains stationary. Sensors attached to the load cells of the machine measure the variations in pressure applied on the product and the dimensions of the product till it fails. All details are saved in the computer system that has been interfaced with the machine. Plate 3.1 shows sugarcane samples that was used and Plate 3.2 shows the Universal Material Testing Machine.

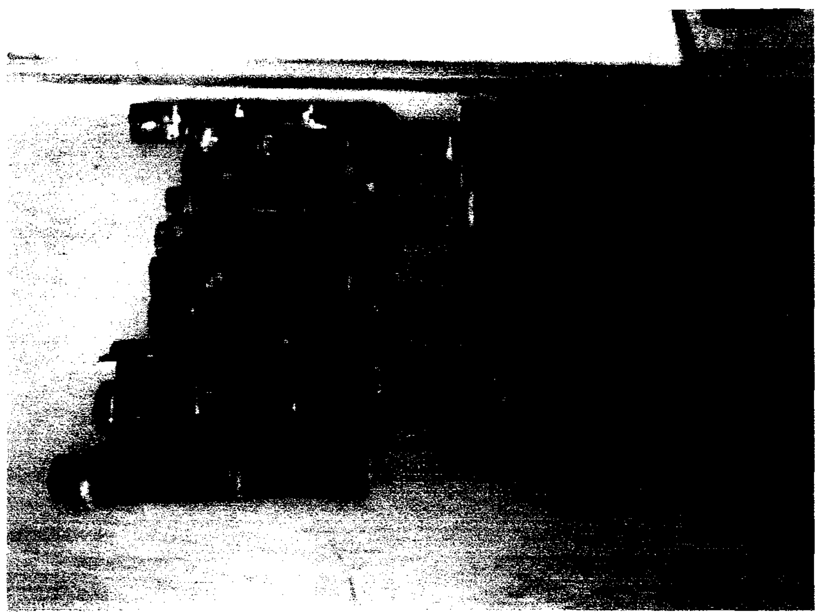

Plate 3.1: Sugarcane Samples

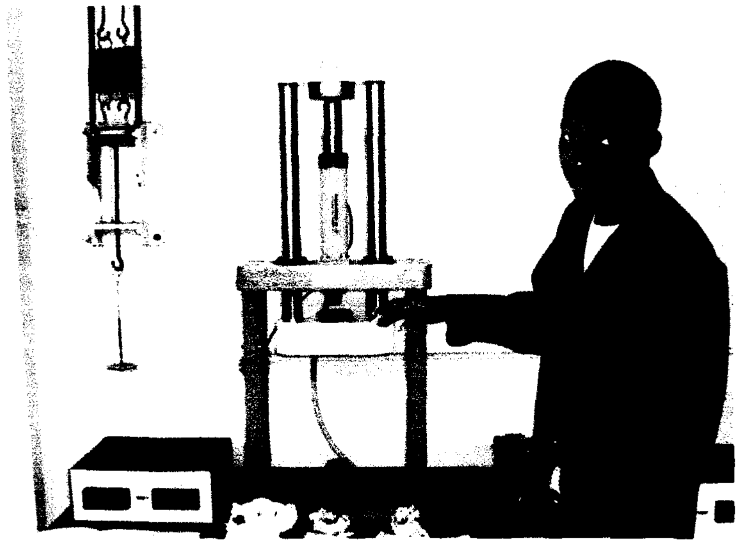

Plate 3.2 Universal Material Testing Machine

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 Presentation of result on physical properties

#### 4.1.1 Moisture content

The result of the experiment are presented in tables and at predetermined moisture contents for the samples used. The weight of the samples before and after drying is shown in Table 4.1 and the moisture content for are shown in Table 4.2.

Table 4.1 Weight of Sugarcane Samples before and after drying

| S/No | Weight of sample(before drying) $W_1$(g) | Weight of sample(after drying) $W_2$(g) | Moisture Content (%) |
|---|---|---|---|
| 1. | 272.54 | 79.66 | 70.80 |
| 2. | 333.85 | 97.58 | 70.90 |
| 3. | 378.65 | 110.68 | 70.70 |
| 4. | 386.84 | 113.07 | 70.75 |
| 5. | 427.49 | 124.95 | 70.65 |
| 6. | 375.95 | 109.89 | 70.80 |
| 7. | 387.50 | 113.27 | 70.75 |
| 8. | 364.73 | 106.61 | 70.78 |
| 9 | 348.33 | 101.82 | 70.69 |
| 10. | 383.51 | 112.10 | 70.90 |
| 11. | 391.00 | 114.29 | 70.87 |
| 12. | 279.23 | 81.62 | 70.79 |
| 13. | 291.33 | 85.16 | 70.70 |
| 14. | 332.41 | 97.16 | 70.75 |
| 15. | 298.22 | 87.17 | 70.75 |
| 16. | 282.53 | 82.58 | 70.78 |
| 17. | 313.94 | 91.76 | 70.68 |
| 18. | 331.20 | 96.81 | 70.70 |
| 19. | 441.08 | 128.93 | 70.74 |
| 20 | 369.27 | 107.94 | 70.75 |
| 21. | 303.19 | 88.62 | 70.79 |
| 22. | 382.75 | 111.88 | 70.70 |
| 23. | 401.72 | 117.43 | 70.65 |
| 24. | 376.12 | 109.94 | 70.75 |
| 25. | 365.92 | 106.96 | 70.85 |
| 26. | 335.12 | 97.96 | 70.70 |
| 27. | 311.87 | 91.16 | 70.86 |
| 28. | 290.38 | 84.88 | 70.76 |
| 29 | 322.57 | 94.29 | 70.75 |
| 30. | 405.18 | 118.43 | 70.80 |
| Averge | 378.65 | 110.68 | 70.77 |

Table 4.2: Moisture Contents for the Sugarcane Samples

| | |
|---|---|
| Weight of sample (before drying) $W_1$(g) | 378.65 |
| Weight of sample (after drying) $W_2$(g) | 110.68 |
| Weight of water removed, $W_3(g) = W_1 - W_2$ | 267.97 |
| Moisture content (%db) $= \frac{W_1 - W_2}{W_1} \times 100$ | 70.77 |

This information is of importance to food scientists and processing engineers to assist them in processing stages such as bagging, and storage.

### 4.1.2 Shape and Colour

The traced projected boundary outlines of the samples were compared with charted standard. The shape of some of the sugarcane samples was found to be oblong and cylindrical.

The colour of the sugarcane sample is purple at surface and whitish inside.

### 4.1.3 Measured Parameters

The means, standard deviations and coefficient of variation of the measured values of length $D_1$, width $D_2$, thickness $D_3$, of 20 Sugarcane samples are presented in the tables 4.3 to 4.5.

Table 4.3: Mass, Length, Width, Thickness of measured parameters of 20 Sugarcane sample

| Specimen | Mass (g) | Length (mm) | Width (mm) | Thickness (mm) |
|---|---|---|---|---|
| **1.** | 272.54 | 197.0 | 42.1 | 44.1 |
| **2.** | 333.85 | 227.0 | 42.5 | 44.5 |
| **3.** | 378.65 | 236.0 | 45.4 | 47.9 |
| **4.** | 386.84 | 255.0 | 42.3 | 44.8 |
| **5.** | 427.49 | 255.0 | 45.1 | 47.6 |
| **6.** | 375.95 | 295.0 | 40.5 | 42.5 |
| **7.** | 387.50 | 260.0 | 43.0 | 45.5 |
| **8.** | 364.73 | 260.0 | 39.5 | 41.5 |
| **9** | 348.33 | 260.0 | 41.2 | 43.7 |
| **10.** | 383.51 | 300.0 | 38.4 | 40.9 |
| **11.** | 391.00 | 270.0 | 41.6 | 43.6 |
| **12.** | 279.23 | 220.0 | 37.1 | 39.6 |
| **13.** | 291.33 | 206.0 | 41.9 | 44.4 |
| **14.** | 332.41 | 200.0 | 44.6 | 46.6 |
| **15.** | 298.22 | 186.0 | 43.1 | 45.6 |
| **16.** | 282.53 | 193.0 | 42.0 | 44.0 |
| **17.** | 313.94 | 225.0 | 41.7 | 44.2 |
| **18.** | 331.20 | 215.0 | 41.8 | 44.3 |
| **19.** | 441.08 | 265.0 | 44.8 | 47.3 |
| **20** | 369.27 | 260.0 | 40.7 | 43.2 |
| **21.** | 303.19 | 212.0 | 42.3 | 44.3 |
| **22.** | 382.75 | 245.5 | 43.9 | 46.4 |
| **23.** | 401.72 | 275.0 | 42.6 | 45.1 |
| **24.** | 376.12 | 260.0 | 41.0 | 43.5 |
| **25.** | 365.92 | 280.0 | 40.3 | 42.3 |
| **26.** | 335.12 | 245.0 | 39.1 | 41.6 |
| **27.** | 311.87 | 203.0 | 43.0 | 45.5 |
| **28.** | 290.38 | 189.5 | 42.3 | 44.8 |
| **29** | 322.57 | 220.0 | 41.8 | 44.3 |
| **30.** | 405.18 | 262.5 | 42.8 | 45.3 |

Table 4.4: Lengths, volumes, and Mass of measured parameters of 30 Sugarcane sample

| Specimen | Mass (g) | Length (mm) | Initial Volume (ml) | Final Volume (ml) | Volume (ml) |
|---|---|---|---|---|---|
| **1.** | 117.03 | 142.49 | 160 | 270 | 110 |
| **2.** | 111.29 | 135.83 | 163 | 270 | 108 |
| **3.** | 112.34 | 135.72 | 165 | 273 | 105 |
| **4.** | 111.55 | 129.16 | 165 | 270 | 105 |
| **5.** | 107.71 | 128.49 | 170 | 270 | 100 |
| **6.** | 107.65 | 128.94 | 175 | 275 | 100 |
| **7.** | 104.88 | 130.79 | 173 | 262 | 99 |
| **8.** | 105.76 | 128.39 | 175 | 273 | 98 |
| **9.** | 103.87 | 127.83 | 175 | 270 | 95 |
| **10.** | 100.35 | 127.58 | 173 | 288 | 95 |
| **11.** | 99.83 | 127.29 | 168 | 262 | 95 |
| **12.** | 100.87 | 126.57 | 170 | 263 | 93 |
| **13.** | 100.44 | 123.56 | 169 | 260 | 92 |
| **14.** | 96.54 | 123.62 | 173 | 262 | 92 |
| **15.** | 97.89 | 125.31 | 165 | 255 | 90 |
| **16.** | 95.47 | 125.76 | 168 | 258 | 90 |
| **17.** | 93.05 | 126.21 | 170 | 260 | 90 |
| **18.** | 96.18 | 114.78 | 172 | 260 | 87 |
| **19.** | 92.47 | 120.71 | 168 | 253 | 85 |
| **20.** | 90.31 | 123.89 | 170 | 265 | 85 |
| **21.** | 87.31 | 118.85 | 170 | 250 | 85 |
| **22.** | 94.22 | 109.62 | 173 | 262 | 84 |
| **23.** | 90.06 | 113.41 | 171 | 254 | 82 |
| **24.** | 87.56 | 121.58 | 170 | 250 | 80 |
| **25.** | 87.05 | 116.11 | 170 | 250 | 80 |
| **26.** | 87.08 | 116.43 | 173 | 250 | 78 |
| **27.** | 86.59 | 111.28 | 175 | 250 | 75 |
| **28.** | 84.87 | 103.48 | 170 | 250 | 75 |
| **29.** | 84.64 | 101.06 | 173 | 250 | 73 |
| **30.** | 82.68 | 90.84 | 170 | 250 | 70 |

Table 4.5: Means, standard deviation and coefficients of variation of measured parameters of Sugarcane samples

| S/No | Measured Parameters | Unit | Maximum Value | Minimum Value | Mean | Standard Deviation | Coefficient of Variation (%) |
|---|---|---|---|---|---|---|---|
| 1. | Length | mm | 300.0 | 186.0 | 239.25 | 32.291 | 11.09 |
| 2. | Width | mm | 45.4 | 37.1 | 41.95 | 1.898 | 4.52 |
| 3. | Thickness | mm | 47.9 | 39.6 | 44.29 | 1.931 | 4.35 |
| 4. | Mass | g | 117.03 | 82.68 | 97.492 | 11.968 | 12.28 |
| 5. | Volume | ml | 110 | 70 | 89.50 | 13.218 | 14.77 |

### 4.1.4 Calculated Parameters

The means, standard deviation and coefficient of variation of the calculated values are shown below in table 4.6.

Table 4.6: Means, standard deviation and coefficients of variation of some physical properties (calculated) of Sugarcane

| S/No | Calculated Parameters | Unit | Maximum Value | Minimum Value | Mean | Standard Deviation | Coefficient Of Variation (%) |
|---|---|---|---|---|---|---|---|
| 1. | Arithmetic Mean Diameter | mm | 131.1 | 87.57 | 108.49 | 12.04 | 7.45 |
| 2. | Geometric Mean Diameter | mm | 87.73 | 64.89 | 76.32 | 4.91 | 6.43 |
| 3. | Square Mean Diameter | mm | 57.89 | 41.81 | 49.98 | 3.76 | 3.93 |
| 4. | Equivalent Diameter | mm | 92.24 | 64.76 | 78.26 | 6.90 | 5.94 |
| 5. | Aspect Ratio | dec | 0.15 | 0.19 | 0.18 | 0.06 | 0.34 |
| 6. | Particle Density | $g/cm^3$ | 1.06 | 1.18 | 1.09 | 0.91 | 2.56 |
| 7 | Weight | N | 1.15 | 0.81 | 0.96 | 0.12 | 0.37 |
| 8 | Surface Area | $mm^2$ | 24190.27 | 13234.26 | 18307.17 | 75.77 | 129.95 |

### 4.1.5 Discussion of result on physical properties

The results from Table 4.3 to 4.5 show that the length ($D_1$), width ($D_2$) and thickness ($D_3$) for the sugarcane have mean values of 239.25mm, 41.95mm, and 44.29mm respectively. With this, the product can be effectively graded. In the design of machine for processing or extraction, the knowledge of different dimensions is important so as to minimize wastage or breakage while grading, peeling and cleaning.

The result from Table 4.6 reveals that the mean values of the weight and the volume 0.96N and 89.50ml respectively. The weights of agricultural products are quite essential in the design of cleaning equipment using aerodynamic forces, also practical application of mass is in the design of cleaning equipment for separation, conveying and elevating unit operations. The weight and mass of the sugarcane is a useful index in measuring the relative amount of dockage or foreign material in a given lot of material.

The result on Table 4.6 shows the means, standard deviation and coefficient of variation of calculated values of calculated parameters of the sugarcane. AMD has a mean of 108.49mm, GMD has a mean of 76.32mm, SMD has a mean 49.98mm and ED has a mean of 78.26mm. The arithmetic mean and geometric mean can also be used in the determination of the average diameter of sugarcane.

Aspect ratio and particle density ranged from 0.15 to 0.19 and 1.06 $g/cm^3$ to 1.18 $g/cm^3$ and mean values of 0.18 and 1.09 $g/cm^3$ respectively. The particle or true density of agricultural products have been reported to play significant importance in the design of silos and storage bins, maturity and quality evaluation of products which are essential to sugarcane marketing.

**4.2 Presentation of results on mechanical properties**

Table 4.7: Vertical Analysis with the node

| S/no | Diameter (mm) | Length (mm) | Load (KN) | Compressive Extension(mm) |
|---|---|---|---|---|
| 1 | 48 | 115 | 3.42 | 2.12 |
| 2 | 40 | 150 | 4.22 | 4.08 |
| 3 | 44 | 134 | 5.25 | 6.17 |
| 4 | 46 | 115 | 5.73 | 8.04 |
| 5 | 48 | 115 | 5.86 | 10.03 |

Table 4.8: Vertical Analysis without the node

| S/no | Diameter (mm) | Length (mm) | Load (KN) | Compressive Extension(mm) |
|---|---|---|---|---|
| 1 | 40 | 110 | 2.54 | 2.01 |
| 2 | 42 | 90 | 3.35 | 3.99 |
| 3 | 43 | 125 | 3.87 | 6.08 |
| 4 | 44 | 80 | 4.21 | 8.02 |
| 5 | 45 | 75 | 4.46 | 9.90 |

Table 4.9: Horizontal Analysis with the node

| S/no | Diameter (mm) | Length (mm) | Load (KN) | Compressive Extension(mm) |
|---|---|---|---|---|
| 1 | 41 | 52 | 0.98 | 0.49 |
| 2 | 45 | 60 | 1.01 | 1.01 |
| 3 | 44 | 67 | 1.16 | 1.50 |
| 4 | 43 | 50 | 1.52 | 2.10 |
| 5 | 44 | 63 | 1.72 | 2.50 |

Table 4.10: Horizontal Analysis without the node

| S/no | Diameter (mm) | Length (mm) | Load (KN) | Compressive Extension(mm) |
|---|---|---|---|---|
| 1 | 45 | 65 | 0.52 | 0.51 |
| 2 | 43 | 42 | 0.64 | 1.10 |
| 3 | 46 | 45 | 0.75 | 1.52 |
| 4 | 41 | 64 | 0.87 | 2.11 |
| 5 | 44 | 72 | 0.95 | 2.51 |

### 4.2.1 Discussion of Results on Mechanical Properties

With the anvil height set on the Universal Material Testing Machine. For the 5 sugarcane samples, the sugarcane was placed in vertical position such that the nodes of the sugarcane are both at the bottom and at the top. The compressive load at break is 3.42 KN, 4.22 KN, 5.25 KN, 5.73 KN, and 5.86 KN. The sugarcane sample was also placed in a vertical position without the nodes present. The compressive load breaks at 2.54 KN, 3.35 KN, 3.87 KN, 4.21 KN and 4.46 KN. Result from Table 4.7 and 4.8 shows that the greater the compressive load, the higher the extension. Compressive load of the sugarcane sample with the nodes is greater when compared to that its counterpart without nodes. This shows that the compressive load is higher due to the presence of the nodes. Result from Table 4.9 and 4.10 shows that when the sugarcane was placed in horizontal position with the nodes present, the compressive load at break is 0.98 KN, 1.01 KN, 1.16 KN, 1.52 KN, 1.72 KN and without the nodes, the compressive load breaks at 0.52 KN, 0.64 KN, 0.75 KN, 0.87 KN and 0.95 KN when the sugarcane was placed in horizontal position. With this results, this shows that compressive load on the vertical axis is greater when compared to that of the horizontal axis.

The likelihood of fracture of a particle under tension or compression depends on the applied macroscopic stress and the size of the particle. A farm product machine designer needs knowledge of the compressive strength of sugarcane for process design and handling. The compressive load is an important parameter that must be considered for maximum efficiency of the operations.

CHAPTER FIVE

# 5.0 CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The physical and mechanical properties of Sugarcane including shape, size, colour, mass, volume, density, surface area and compressive strength were determined at 70.77% moisture content. Therefore consideration should be given before designing or fabricating, because most of its constituent is made up liquid substance. The dimensions, volumes, mass and surface area varies with sizes. Mass and volume of food materials and agricultural products play an important role in the design of storage bins. From the experiment conducted sugarcane had a cylindrical shape with its particle densities greater than its aspect ratio, Densíties have been of interest in breakage susceptibility and hardness studies. In operations such as crushing and extraction, Sugarcane with nodes requires a high force greater or equals to 5.86KN on the vertical axis and also requires a lesser compressive force greater or equal to 1.72KN on the horizontal axis. Sugarcane without nodes requires a high force greater or equal to 4.46KN on the vertical axis and also requires a lesser compressive force greater or equal to 0.95KN.Also the knowledge of compressive strength is of great importance to engineers handling agricultural products.

All these parameters obtain from proper assessment of the experiment done on sugarcane, the values and data obtained from the physical and mechanical properties of sugarcane which was ascertain that they are useful in design of post harvest handling and processing operations.

## 5.2 Recommendations

The following are recommended for further research

- Determination of the engineering properties of other varieties of sugarcane should be encouraged.
- The government should establish institutions and programs that would carry out more in-depth research and utilization of the sugarcane and usefulness in pharmaceutical and medical research.
- Other engineering properties of sugarcane such as chemical properties should be worked on to acquire comprehensive information in design parameters.

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