DETERMINATION OF IMPACT DAMAGE RESISTANCE OF FRESH TOMATO FRUIT

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CERTIFICATION

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DEDICATION

I dedicate this project to God, my family the Mayakis' and also to my niece Mamu.

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Firstly, I give all thanks to my Almighty God for His; protection, provision and strength throughout my period of study.

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ABSTRACT

Most types of food for man is a living or once living organism be it natural or derived. As a living entity food continues to carry on metabolic activities even during storage. These activities are at times enhanced by injuries sustained as a result of mechanical damage particularly impact. In this study the impact damage resistance or susceptibility of some popular cultivars of tomatoes were assessed. Two popular cultivars, Roma VF and Cherry were obtained from the local producers in Minna and subjected to impact using the method of free falling instrumented impact. A twin was used to suspend the fruit at different heights (50, 100, and 150cm) from where the fruits were released on to impact surfaces (bare concrete wall and carton). The energy absorbed and the dynamic yield pressure were computed. The mean impact energy absorbed by the samples were 0.410J and 0.310J for cherry and roma varieties respectively. While the dynamic yield pressures were $184.63N/m^2$ and $380.67N/m^2$ respectively for cherry and roma variety. The effects of variety were highly significant at 5% level of influence as far as these parameters were concerned. The roma variety is much more resistant to impact damage than the cherry. The information obtained are vital in the design of handling systems.

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CHAPTER ONE

1.0 INTRODUCTION

The recognition of an increasing worldwide demand for high quality in fruits and vegetables has grown in recent years. Evidence of severe problems of mechanical damage is increasing, and this is affecting the trade of fruits. The potential market for fresh high quality vegetables and fruits remain restricted due to supply of poor quality products especially in the developing countries. This is the case for local as well as import/export markets, resulting in reduction in the consumption of fresh fruit in favour of other fixed quality products (Ruiz Altisent, 1991) Important factors influencing the shopping behaviour of most consumers are taste/flavour, freshness/ripeness, firmness, appealing look and cleanliness. Sometimes it is difficult to meet up these factors due to the method of harvesting and handling. After harvest, the tomato enter the market chain, progressing from the farm gate to the wholesale market, the retail market and finally to the consumer. It is noted that between 30 and 50% of these are lost during the process as a result of poor handling and inadequate storage facilities (Olorunda and Aboaba, 1978)

Post-harvest handling, packaging, transportation and distribution of fruits and vegetables involve mechanical operations resulting in impact related bruising. Impact has been recognized as the most important cause of damage (bruising) in fruits (Ruiz Altisent, 1991). Excessive compression also causes bruising as do repeated impact. Bruising appears as a result of impact and compressions of the fruits against other fruits, part of the trees, containers, parts of any grading and treatment machinery and on any uncushioned surface. Severity of damage to the fruit is primarily related to height of fall, initial velocity, and number of impact, type of impact surface and size and physical properties of the fruits.

The biological and chemical reactions following mechanical damages do contribute to the problem. It is important to prevent injuries that expose the susceptible internal tissues of plant and animal materials to micro organisms. The degree of infection of mechanically damaged product depends on the nature of the attacking fungi present and the resistance of the product to the invading organism after infection has occurred.

Impact properties are studied ultimately to minimize impact damages to fruits and vegetables. Reduction in bruise along with better handling operation will ensure higher quality commodity at better return on investment, so there is a need to asses the effects of impact damage resistance of fresh tomato with the view to provide data that will help in reducing losses, crops in each area require storage and handling procedures applicable to that area.

1.1 VEGETABLES AND FRUITS.

Fruit, seed-bearing structure of a flowering plant. A fruit is actually a ripened ovary, a component of the flower's female reproductive structure (Encarta Encyclopedia Deluxe 2003). Fruits are widely eaten all over the world. Fruits include; apples, banana, grape, guava, mango, papaya, pineapple, watermelon e.t.c.

Vegetables are also widely eaten and they include; cabbage, carrot, garlic, ginger, okra, onion, peas, potato and tomato. e.t.c.

Vegetable production, like most agricultural commodities are seasonal, it forms about 25% of minor food crops grown in the tropics (Eric and Bani, 1988). In Nigeria, for instance, enormous quantities of vegetables are produced annually (Oyeniran, 1988). The commercial and nutritional importance of food as highlighted by USDA is shown in Fig 1.1.

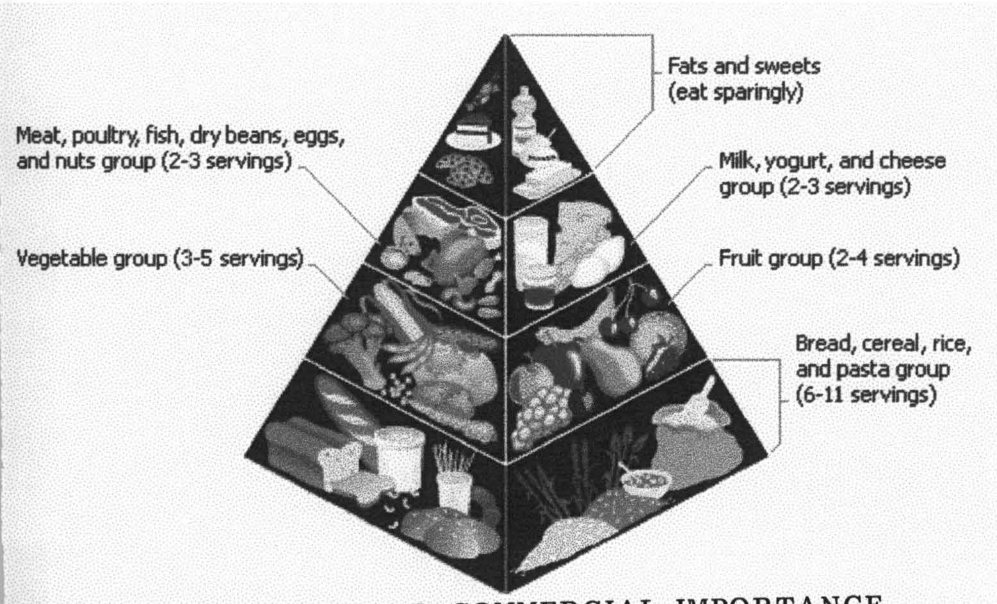

Fig 1.1 NUTRITIONAL AND COMMERCIAL IMPORTANCE
ource: Encarta Encyclopedia

The United States Department of Food Pyramid vides a practical visual guide to healthful eating, indicating the recommended y portions of the basic food groups. In the strictest sense, many of the foods fall under the bottom layers of the pyramid, including grains and vegetables, actually fruits.

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TOMATO

Tomatoes (Lycopersicum esculentum) are mostly cultivated in the semi-arid ne of Nigeria especially in Borno, Kano, and Kaduna and Bauchi states. They produced both during the rainy season and in dry season under irrigation. matoes are usually harvested between March and May in the north and ptember and October in the south.

Tomato although often called a vegetable, the tomato is actually a true berry, type of fleshy fruit characterized by its soft pulp, thin skin, and many seeds. Cut in half, the tomato displays distinct sections, each representing a separate ovary compartment, or carpel, with many seeds. (Michelle Garrett/Corbis)

; 1.2 Section of a fresh tomato fruit.

1 IMPORTANCE OF TOMATO

Most people eat a mixed diet of foods from plants and animals. Fruits and etables are important sources of essential minerals and vitamins in the human . When eaten together with some root (potato) and leguminous (beans, peas) ps, they provide a proportion of protein requirements as well as variety in our and colour. It is also an important food for body growth and repairs.

Proteins are essential to the building and repair of muscles and organs. Fresh duce is low in protein content although on a dry-weight basis some root crops h as potato as well as leaves of several crops have protein contents appr

Minerals are required for health but only in small amount as compared with energy foods and protein. Sodium, potassium, iron, calcium, phosphorus and many trace elements are essential.

Vitamins are essential for control of chemical reaction in the body. Fruits and vegetables and to a lesser extent tomatoes are important sources of vitamin C and other essentials.

Fibre or "Roughage" is found in larges amount in fresh produce. It plays an important part in the function of digest containing high fibre content is shown by medical studies to reduce susceptibility to diseases.

Vegetables such as fresh tomatoes are good sources of folic acid in the diet and they also contain pectin, which helps to remove waste products from the body. In the absence of an adequate animal protein intake, vegetables are the cheapest and most available source of these micro nutrients.

1.3 STATEMENT OF PROBLEM

Despite the remarkable progress made in increasing food production at the global level, approximately half of the population in the third world do not have access to adequate food supplies. There are many reasons for this, one of which is food losses occurring in the post-harvest and marketing system. Evidence suggests that these losses tend to be highest in those countries where the need for food is greatest.

Both quantitative and qualitative food losses of extremely variable magnitude occur at all stages in the post-harvest system from harvesting, through handling storage, processing and marketing to final delivery to the consumer. About half of what is produced never reaches the consumer (FAO, 1977).

Factors, which are responsible for these damages and losses, include the harvesting, packaging containers, vehicle being used and the bad roads over which the vehicles move for distribution.

According to Tennema,et al (1985), the shelf life of a packed food is controlled by the physical properties and characteristics of the product. These include;

a) Water activity

b) pH value

c) Susceptibility to enzymatic or microbiological deterioration

d) Mechanism of spoilage

e) Requirement for sensitivity to oxygen, light, carbon

f) Oxide and moisture

About 99% of the farmers package harvested tomato fruits in baskets made from palm fronds (Jonah et al, 1996, Williams, 1998). The baskets in turn serve the purpose of handling and transporting the fruit and also as measure of sale. The long distance trips across the country are carried out using lorries, pick up vans, articulated trucks e.t.c. Dry grasses are used to cushion the packed fruits in the baskets. Trades do acknowledge that about 45% losses in quality of the fruits do occur before the fruits reach the destination (Williams, 1998).

One of the major functions of packaging is to ensure safe delivery of a product to the ultimate user in a cost effective manner. During transportation, forces are transmitted to the packages in the form of acceleration produced by vibration and impact. When packages are stacked inside vehicles and warehouses compression forces act on them as well.

As the product moves from harvesting or production areas to the final consumer, mechanical stresses due to drops impacts are transmitted to the product via the outer container and its cushioning media. The number and severity of this transportation damage depend on several factors but the most important are the impact and vibration resulting from the excitation received by the vehicles from the irregular road profiles. The shelf life of the transported fruits also depends on the severity of the damage that the produce is subjected to during transportation. The sensitivity of the produce to impact depends on the properties of the produce. Different cultivars may also react differently to the impact force. It is therefore important to assess the activities of the produce especially the popular cultivars prevalent in the country when subjected to certain impacts so that better conditions of extending the life of the produce can be obtained. Hence this study is intended to evaluate the impact resistance damage of some fresh tomato, cultivars.

1.4 OBJECTIVES

1. To determine impact damage thresholds of tomato on wall and cushioning material (carton).
2. To evaluate the possibility of using dynamic yield pressure, coefficient of restitution, and absorbed energy of the produce as indicators of impact resistance, and hence generate data that can be used to minimize such damage during handling.

1.5 PURPOSE OF STUDY (JUSTIFICATION)

The purpose of this study is to provide some basic information on how to minimize impact damages during the post harvest handling and transportation of tomato. Mechanical damages in agricultural product are due to impact and vibration forces, which include compression forces.

Impact has been recognized as the most important cause of damage (bruising) in fruits (Ruiz Altisent, 19991) Excessive compression also causes bruising as do repeated impact.

After harvest, the tomato enters the market chain, progressing from the farm to the wholesale market, the retail market and finally to the consumer. It is noted that 30 to 50% of these are lost during the process as a result of poor handling and inadequate storage facilities (Olorunda and Aboaba, 1978) There is therefore a need to assess some of the contributing factors, how they influence the rate of deterioration of the produce especially in storage and hence proper solutions to curtail the losses.

A profitable assessment of tomato produced under Fadama Development Programme in Kaduna State where single descriptive statistic and farm budgeting techniques were used for the analysis was carried out. The results showed that total production cost per hectare for tomato was ₦55,967.60 and the total revenue per hectare was ₦ 110,160.00. The net farm profit per hectare was ₦ 54,192.40 while the average profit per hectare was ₦ 45,654.00. (Alamu et al, 2002)

The tomato production trend in Nigeria evaluated in 1997 was;

Production (100 tones) =570

Yield Kg/ha =10,364

Area harvested (1000 ha) =55

(Coker, 2002)

These figures clearly showed that the business of tomato production is not only profitable, but that there are rooms for increase in production if the quality of the produce can be maintained especially during the distribution and marketing.

This study is important as it gives insight into the factors that can affect the qualities like firmness, appearance, shape, and texture e.t.c. of the fruits during handling and storage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 TOMATO PRODUCTION

Fresh tomatoes are produced all over Nigeria. the production figures for various well know fruits and leaf vegetables in Nigeria as recorded in the 1995 annual abstract of statistics of federal office of statistics are given in table 2.1 (Daramola 1998, Williams 1998).

Table 2.1

FRUIT AND VEGETABLES	AREA (1000 HA)	PRODUCTION FIGURE (1000 TONNES)
Tomatoes	2448	1850
Pepper	1240	920
Onion	250	610
Mango	520	1300
Pineapple	120	360
Guava	102	70
Plantain	2004	3075
Banana	420	1620
Paw paw	200	96
Cashew nut	150	216
Leaf vegetables	2760	980

(Daramola, 1998)

The above table revealed that tomato ranked first among the vegetables produced in terms of quantity and second in terms of area of cultivation.

2.2 POST HARVEST LOSSES OF FRESH PRODUCE

The most common causes of post harvest losses in Nigeria include rough handling and inadequate cooling and temperature maintenance. The lack of sorting to eliminate defects before storage and the use of inadequate packaging materials further add to the problem.

The two main objectives of applying post harvest technology to harvested fruits and vegetables are to maintain quality (appearance, texture, flavour, nutritive value and safety) and to reduce losses between harvest and consumption. Effective management during the post harvest period, rather than the level of sophistication of a given technology, is the key in reaching the desired objectives. Principal causes of post harvest losses of fruits and vegetables are shown in Table 2.2

Table 2.2 showed principal causes of post harvest losses and poor quality for various group of fruits and vegetables.

Group	Examples	Principal causes of Post-harvest losses and poor Quality (in order of importance.
Root vegetables	Carrots	Mechanical injuries
	Beats	Improper curing
	Onions	Sprouting and roving
	Garlic	Water loss (shrivelling)
	Potato	Decay
	Sweet Potato	Chilling injury
Leafy vegetables	Lettuce	Water loss (wining)
	Chard	Loss of green colour (yellowing)
	Spinach	Mechanical injuries
	Cabbage	Relatively high respiration rates

	Green Onions	Decay
Flower vegetables	Artichokes	Mechanical injuries
	Broccoli	Yellowing and other discolouration
	Cauliflower	Abscission of florets
Immature fruits vegetables	Cucumbers	Decay
	Squash	Over maturity at harvest
	Egg-plant	Water loss (shrivelling)
	Peppers	Bruising and other mechanical injuries
	Okra	Chilling injury
	Snap-Beans	Decay
Mature - fruits vegetables and fruits	Tomato	Bruising
	Melons	Over-ripeness and excessive softening at harvest
	Citrus	Water loss
	Bananas	Chilling injury (chilling sensitive fruits)
	Mangoes	Compositional changes
	Apples	Decay
	Grapes	
	Stone fruits	

Source: FAO (Rome) 1989

Minimizing rough handling, sorting to remove damaged and diseased produce and effective temperature management will help considerably towards maintaining quality products and reducing storage losses.

2.3 PROPERTIES OF TOMATOES FRUIT AS RELATED TO HANDLING

2.3.1 PHYSICAL PROPERTIES OF TOMATO FRUITS

The physical properties of fresh tomato fruits are important in assessing the fruit quality. These properties determine the consumers' preference or choice. These properties are the external colour, shape, size, texture, smoothness, firmness, and so on.

The fruit quality is mostly determined by the appearance of the skin colour. The skin colour, which is the external colour, is influenced by the pigmentation of both the flesh and skin. The colour pigmentation could be pink, yellow, orange, purple, red, dark yellow etc and varies in different cultivars but most consumers prefer the deep uniform red coloured tomatoes. It has been observed that the concentration of the pigments and hence the colour of fruits are affected during handling and storage. This is due to the prevailing conditions especially temperature. It is vital to improve the conditions under which these produce are handled and stored in order to maintain the quality.

Tomato fruit shape differs greatly among cultivars. They may be spherical, oblate, elongated or pear-like (Messiaen, 1992). The varieties common in Nigeria are quite numerous and were introduced at various years from different sources. These varieties are preferred due to their high fruit-set and tolerance to viral disease (Erinle, 1985). They are Roma, *Roma VF (TI 106), Ronita, Chico, cirio 56, cherry, Earlystone, Gamad F, Ife I, la-Bonita,* and so on. The internal structures of these varieties are quite different but their flavour and texture are not really dependent on their shape. Tomato shape could influence the choice, design construction and nature of the packaging containers. Also it influences the acceptability of the produce.

The size of tomato fruits influences the choice of consumers. The sizes vary greatly, the ranges are grouped as very small which is below 3cm, small (3 – 5cm), medium (5 – 8cm), large (8 – 10cm) and very large (> 10cm). The range of fruits sizes vary among cultivars. Sizes of the fruits are of importance to the quality of the fresh produce. This is due to its influence in the physiological activities of the fruits. It has been observed that the rate of respiration of fruits is determined by the difference in their surface area to their volume ratio and nature of their surface coatings which influence their gas diffusion characteristics (Egharevba, 1995).

Also, tomato fruits sizes are important because they determine the selection, design and construction of packaging containers in the fruit handling and distribution process.

Another important property that influences quality of fresh tomato fruits is the firmness of the fruits. The quality is closely associated with ripeness stage. It also varies greatly among cultivars (Dewulf et al, 1999). Tomato firmness affects its susceptibility to mechanical damage and consequently their handling ability. Most consumers prefer firm fruits, which do not loss too much juice when sliced. Thus, consumers' demand for high – quality products makes it necessary for growers and distributors to set-up an integrated quality control system to monitor the quality of fruits from farm to the consumers. Proper knowledge about the properties are necessary as it will aid better and proper handling of the fresh produce for long distance distribution and subsequent storage.

2.3.2 CHEMICAL PROPERTIES OF TOMATO FRUITS.

Chemical properties of fresh tomato fruits influence the changes in the fruit during the process of post harvest activities. Thus, it is of great importance in the study of the fruit handling.

Chemical constituents of the fresh produce do influence the changes. These constituents play major roles in their ripening and also in their quality during handling and transportation. The changes in these chemical components in fruits and vegetables results mostly from the reaction that occurred when the produce are detached from the plants. These chemical constituents are water, sugars, proteins, fibres, vitamins, minerals, lipids, organic acid, and so on. These constituents have different compositions in the fruits (Table 2.3)

The compositions of some of the chemical constituents are shown in table 2.3.

Table 2.3 chemical constituents of tomato fruits

CONSTITUENTS	COMPOSITIONAL VALUES FOR 100g
Water	93.7
Carbohydrate (sugar)	4.64
Protein	0.85
Lipid (fat)	0.33
Fibre	1.1

Source (USDA Research, 1997).

Due to the high water content of most fruits and vegetables (about 80%) like melons, lettuce, citrus, tomato, cucumber, etc, they are highly susceptible to damages during handling. Water loss from the produce does occur under severe handling and storage conditions. These cause weight loss, nutritional loss and loss in quality value. This loss is estimated to be more than 40 – 50% in the tropics and sub-tropics (Egharevba, 1995). Apart from the water content, other components which are active when the fruit is detached from the plant spontaneously react with each others causing loss of colour, flavour, and so on.

Since it has been noted that the changes that occur in the fruits as they are been handled are influenced by the interactions of the chemical constituents, it is essential to have a firm knowledge of these properties so as to minimize the effects of subsequent interactions of these constituents and hence improve the tomato quality.

2.3.3 BIOLOGICAL PROPERTIES OF TOMATO FRUITS.

The structural composition of the fruit is of importance as it determines the strength of the produce. The anatomy of the tomato fruits as shown in fig. 2.4 gives more insight about the tomato structure.

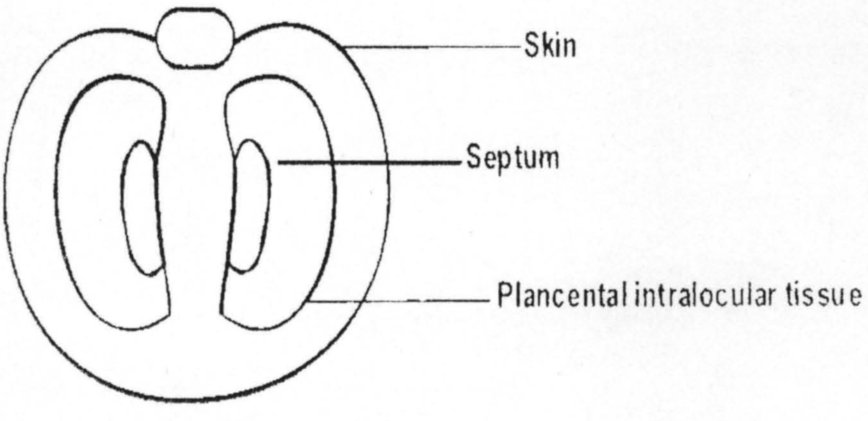

Figure 2.4 Tomato Fruit Tissue

Source: Coombe (1976)

Tomato fruits are composed of the flesh (pericarp walls and skin) and pulp (placenta and locular tissue including seeds). The pericarp consists of an exocarp, which is the skin, a mesocarp, which is the parenchyma, and an exocarp (a single – celled layer), which lines the locules. The mesocarp(i.e. the parenchyma) consists of cellulose, hemicellulose and pectin (these are all polysaccharides). These polysaccharides confer rigidity (strength) to the pericarp walls and determine the cell shape. Also, the interaction between the rigidity of the walls and tugor (internal hydrostatic pressure) of the tomato cells provides the mechanical support to the fruit. It has been noted that the arrangement of the parenchyma is another factor that influences mechanical strength of tomato (Abott et al, 2002).

The resistance of tomato fruit depends on the flesh firmness and hence the internal structure (Altisent, 1991). Retention of substantial amount of their liquids depends on the skin, which also affects their resistance to damage (Ajisegiri, 2002).

2.3.4 BIOCHEMICAL PROPERTIES OF TOMATO FRUITS.

Biochemical activities in fruits and vegetables arise mostly when the organic components react, giving undesirable results like deterioration in flavour, taste, colour, firmness, and so on. Thus, the biochemical properties of tomato fruits are important, as far as post harvest activities are concerned. This is because most of these undesirable reactions take place spontaneously. The biochemical property has to do with the way and rate at which these constituents react of which relative humidity; temperature and the maturity stage of the produce are influencing factors. Some of the changes that occur in the tomato fruit during the course of its biochemical activities are:

- Loss of chlorophyll
- Conversion of starch to sugars which weakens the cell walls, thus, affecting the firmness and resistance to mechanical damage (Egharevba. 1995)
- Increase in ratio of citric acid to maltic acid
- Increase in glutanic acid
- Synthesis of pigments such as 3-carotene and lycopene.

Understanding these biochemical activities of fresh fruits and vegetables like tomato can help in providing suitable condition that will reduce theses change during handling and storage of the produce. This can be done through provision of appropriate handling conditions that will minimize the rate at which these changes occur.

2.3.5 BIOLOGICAL AND CHEMICAL REACTIONS FOLLOWING MECHANICAL DAMAGES.

The cause of all infectious diseases stems from infestation, incubation and then healing and rehabilitation of the infested part. Certain types of fungi secrete toxins that penetrate disrupt and kill the host cells resulting in rots. Such infection does occur when the produce has openings that allow the entry of the spoilage organisms. It's important to prevent injuries that expose the internal tissues of plant and animal materials. The degree of infection of mechanically damaged products depends on the nature of the attacking fungi present and the resistance of the product to the invading organism after infection has occurred.

Mechanical injuries in the form of cutting, cracking, peeling and bruising which result in the crushing of tissues in fresh fruits and vegetables under load produce a darkening of the tissues called browning of which are of two kinds. There is the enzymatic browning which occurs when injured tissue is exposed to air; e.g. in apple, pear, banana, grape, and so on. The air supply for enzymatic browning is provided either by intercellular air such as the case of internal browning of apples or direct exposure to atmosphere. Non enzymatic browning occurs in processed food such as fruit juices and in dried fruits. Assessment of the impact resistance of the tomato can provide useful data that will minimize such opening resulting from much damage.

2.4 TOMATO PACKAGING AND TRANSPORTATION

PACKAGING/PACKAGING MATERIAL

PACKAGING

Packaging of fresh fruits and vegetables has a great significance in reducing the wastage. Packaging provides protection from physical damage during storage, transportation and marketing. There are variety of packages, packing materials and inserts available.

There are two types of packaging. The first is when produce is packed into small retail units. Ideal container for packing fruits and vegetables should have the following attributes. They are easy to handle, they provide good protection form mechanical damage, they have adequate ventilation and they are convenient for merchandising. They should also be inexpensive and easily degradable or recyclable (Janet et al, 2000). Many kinds of containers have been used but the "ideal" is yet to be found. Users often put economic considerations first in selecting containers. Fancy containers such as fibreboard boxes or wooden or plastic crates, are often used for high-value product. Inexpensive containers such as bamboo baskets or nylon net sacs are used for low-priced produce. Methods of packaging can affect the stability of products in container during shipping and influence how much the container protects their quality. In fibreboard boxes for example, delicate and high-priced products are often packed in trays, while other products are simply put in the box in groups.

Pre-packaging or consumer packaging generally provides additional protection for the products. It is also convenient for retailers as well as customers and therefore adds value to produce.

Most fresh produce for market is made up of large number of small units of similar size, which must be packaged in amounts convenient to be handled by one person. This is best achieved by using containers.

Large commercial quantities of produce need better packaging in order to minimize losses and achieve the most economical use of transport.

The aim is to protect the produce from damage in handling, transport, and storage.

Packages of standard size can reduce the need for repeated weighing and can facilitate handling, stacking and loading

Damages suffered by package produce include those: from injuries such as:

- **Cuts or punctures**

This results from sharp objects piercing package, staples or nail protruding in container.

- **Impact (shock)**

This occurs as a result of throwing or dropping of Packages,

sudden starting or stopping of vehicle, causing load movement, speeding vehicle on rough road.

- **Compression**

This caused by Flimsy or over sized containers, container over stacked too high.

- **Vibration (shaking)**

Resulting from vibration of the Vehicle itself caused by exertion on roads.

Other cause of damages to produce packages include those from environment such as

- **Heat damage**
- **Chilling or freezing damage**
- **Moisture and free-water damage and also from chemical contamination, insect damage, human and animal damage**

PACKAGING MATERIALS

In developing countries like Nigeria and some developed countries, the common packaging system used for fresh fruits and vegetables are baskets made from palm fronts or bamboo, jute bags and cartons. Other improvised packaging containers used initially in packaging imported or locally manufactured goods are also being used. These containers could be made of metal, plastic and wood (Karen, 1991; Idah et al, 1996; Oladapo, 1994). A brief description of some of these packaging materials is given below.

Basket

Baskets and other traditional containers are made from bamboo, rattan, straw, palm leaves, and so on.

Disadvantages are:

- They are difficult to clean when contaminated with decay organisms;
- They lack rigidity and bend out of shape when stacked for long distance transportation;
- They load badly because of their shape;
- They cause pressure damage when tightly filled; and
- They often have sharp edges or splinters causing cut and puncture damage.

Wood

Sawn wood is often used to make re-usable boxes or crates but less so recently because of cost. Wooden boxes are rigid and re-usable and if made to a standard size, stack well on trucks.

Disadvantages are:

- They are difficult to clean adequately;
- They are heavy and costly to transport; and
- They often have sharp edges splinters and protruding nails, requiring some form of liner to protect the content.

Cardboards (Moulded Plastics)

Re-usable boxes moulded from high-density polyethene are widely used for transporting produce. They are strong, rigid, smooth, easily cleaned.

Disadvantages are:

- They require a light organisation and control for use in a regular go-and-return service;
- They deteriorate rapidly when exposed to sunlight;
- They often have many alternative uses (as wash tubs) and are subject to high pilferage rates; and
- They can be produced economically only in large numbers but are still costly.

2.5 TRANSPORTATION

Transportation is a big and often the most important factor in the making of fresh produce. The farms are situated in the rural areas, whereas the produce consumers reside in the major towns. This calls for transportation of the fresh produce from the farm to the urban centres where the markets are and further interstate and international movements. Transport needs could be categorized into on-farm movement (i.e. movement within the farm) and off-farm movement (movement outside the farm).

Transportation of fresh tomato produce is inevitable, because tomato is grown in large quantity in the semi-arid zone and Northern Guinea Savannah areas of Nigeria and the consumers are scattered all over the country. Losses directly attributed to transport conditions could be high. The goal of every person concerned with transportation should be that the produce be kept in the best possible condition during transportation and that the haulage of produce be quick and efficient. To this end, produce should be properly packaged and properly handled on a suitable vehicle.

CAUSES OF DAMAGE IN THE COURSE OF TRANSPORTATION INCLUDE:

Mechanical damage; which could be:

i. Careless handling of packaged produce during loading and unloading;

ii. Vibration (shaking) of the vehicle, especially on bad roads;

iii. Fast driving and poor condition of the roads; and

iv. Poor slowage, which allow packages in transit to sway

v. Over heating. This can occur not only from external source but also from heat generated by the produce within the package itself. Overheating promotes natural breakdown and decay; and increases the rate of water loss from produce. The causes of overheating include:

1. The use of closed vehicle without ventilation;
2. The lack of adequate ventilation of the package themselves; and
3. Exposure of the package to the sun while awaiting transportation or while truck are queuing to unload at their destination.

Of all these factors, the impact energy received by the fresh produce in transit is of great concern because the subsequent shelf life of the produce depends on this. It is this aspect as it affects the stability of the produce that is the focus of this study.

2.6 IMPACT DAMAGE

One of the most common causes of mechanical damage to agricultural products is shock and impact during mechanical handling.

Mechanical injury to fresh fruits often occurs during harvesting, hauling and packaging resulting in cuts and bruises of different severity (Margarita, 1991).

Severity of damage to the fruit is primarily related to: i) height of fall (ii) initial velocity (iii) number of impacts (iv) type of impact surface and size and (v) physical properties of the fruit, related or not to maturity. This problem can be studied from the concept of impact (Margarita, 1991).

The concept of impact is differentiated from the case of static rapid loading by the fact that the forces created by the collision are exerted and removed in a very short period of time (duration of impact) and that the collision produced stress waves which travel away from the region of contact. It has been pointed out that to date no general impact theory has been developed. The bases of current theories were laid by St.Venant who proposed the wave theory, and Hertz who introduced the contact phenomenon for elastic bodies (Mohsenin, 1978). Also, theoretical models have been used to explain and analyse the impact problem as applied to fruits. The first one was presented many years ago and consists of considering a fruit as an elastic (generally spherical) body and applying the Hertz contact theory further developed by shigley (Horsfield et al, 1972, Rumsey and Fridley, 1977).

In the determination of impact damage resistance of fresh tomato fruits, the properties of the produce itself are extremely important because everything else depends on them. The bruise resistance or its inverse susceptibility are also important.

Current measures of bruise resistance or its inverse, susceptibility, are limited in that they do not give a quantitative measure of the bruise resistance of each individual fruit or vegetable (Margarita R.A,1991). These methods generally rely on either bruise indexing or bruise thresholding. Bruise indexes are obtained by dropping a known weight from a known height onto the commodity or by tumbling a group of the commodity in a tumbling barrel or other "handling damage simulator." The bruise index is then judged from the amount, colour, and / or size of bruise that results, often by subjective estimation of the relative amount of bruise on an arbitrary index scale.

2.7 THRESHOLDS

Bruise thresholds were obtained by dropping groups of uniform size commodity from known heights onto standardized impact surfaces and noting the percentage of individuals in each group that show bruising (Hyde et al, 1992). Such measurements are more widely applicable than bruise index values, and they are invaluable in conjunction with instrumented sphere evaluation of handling equipment, (Zapp et al, 1990, Schulte et al, 1992; Mathew, 1992; Mathew and Hyde, 1992). However, such thresholds are a statistical measure and don't provide quantitative bruise resistance values for individual fruits and vegetables. However, this concept is extremely valuable because it provides an objective, repeatable measure of the tendency of a given lot of a commodity to sustain mechanical damage, relative to other lots of that commodity and even relative to other commodities (Hyde et al, 1992).

2.8 DYNAMIC YIELD PRESSURE (DYP)

A method was developed that will directly and simultaneously measure both force and contact area profiles during impact. These two variables allow calculation of dynamic yield pressure (DYP) (force per unit area), which may be thought of as the dynamic analogue of bio- yield point familiar in Quasi-static property measurement (Hyde et al, 1992). Such measurement may ultimately be used to evaluate cultivars, evaluate cultural and conditioning practices, provide guidelines for handling equipment design and operation, and sort fruit or vegetables according to damage resistance. Hitherto, such information are lacking about the popular cultivars of tomato produced in Nigeria. Hence the need for this study.

2.9 SCIENTIFIC BASIS FOR USE OF DYNAMIC YIELD PRESSURE

A damaging impact can be separated into four phases (Mohsenin, 1986):

1. Initial elastic deformation: No permanent damage occurs to the impact area, so Hertz contact theory can be applied. This phase is very small.
2. Onset of plastic deformation: Permanent damage occurs as the pressures during the impact exceed the dynamic yield pressure (DYP) of the tissue.
3. Full plastic deformation: damage continues until the impact pressure falls below the dynamic yield pressure.
4. Elastic rebound: The commodity releases the elastic stresses stored during impact.

If we define bruising as permanent impact damage, then such damage occurs only when the dynamic yield pressure is exceeded. It follows that higher DYP will give a measure of impact damage resistance of fruits and vegetables. (This assumes the bruise to be a confined, incompressible fluid). In this current study therefore, the impact resistance of some popular cultivar of tomatoes produced in Nigeria would be assessed with a view to provide useful data that will assist designers, handlers and distributors on ways of reducing impact damage to the produce during handling.

CHAPTER THREE

3.0 MATERIALS AND METHODS

One of the most common causes of damage to agricultural product is shock and impact during mechanical handling. Impact results from throwing or dropping of produce packaging, starting or stopping of vehicle over rough roads.

A more useful method of applying impact loads is to drop the commodity onto a flat, well-supported, repeatable surface of interest, either hard or cushioned. The disadvantage compared to other methods is that the mass of the sample must be accounted for, but the advantage is that the impact is much closer to that occurring in real handling system. Also, use of flat surface, in addition to being more typical of a real handling system, does not introduce artificial stress concentration within the specimen (Hyde, 1996).

3.1 INSTRUMENTATION

Instrumented pendulum, free-falling instrumented device, twin and other impact testing equipment such as weighing balance, measuring tape, moisture content determination equipment (oven) were used for this experiment.

3.2 MATERIALS

Two (2) varieties of tomatoes, Cherry and Roma VF of red maturity stages were selected.

3.3 METHODOLOGY

The two varieties of fresh tomato being selected were freshly harvested cleaned, graded and weighed one after the other using a weighing balance.

For the determination of the thresholds and dynamic yield pressure, a twin was used to suspend the sample (Hyde et al, 1993) forming a 150cm pendulum. A measuring tape was placed horizontally as a scale calibrated in units of drop height to provide the measure of drop and rebound heights, and the wall was used as one of the impact surface. Cushioning material (carton) was attached to the wall when required. Individual tomatoes of varying masses within sample were dropped from each of several drop heights, the lowest height intended to bruise less than 10% of the individuals, the highest height to bruise 100%, and the intermediate height was evenly spaced. After the individual samples were subjected to impact, the impact area of each sample was also determined since the force transducer which was suppose to measure the impact force was not available. The force was computed using the formula;

$F=mg$... (1)

Where

F= impacting force (N)

m=mass of tomato (g)

g=acceleration due to gravity (m/s)

Since the materials were released freely under gravity, knowing the force and the area of impact, the dynamic yield pressure (DYP) which is a measure of impact resistance was computed from;

$DYP=F/A$... (2)

Where

DYP=Dynamic yield pressure

F=impacting force (N)

A=area (m^2)

Similarly, the energy absorbed was computed from;

$E=mg\,(1-e^2)\,h$................................ (3)

Where

E=energy absorbed (j)

m=mass (g)

g=acceleration due to gravity (m/s)

e=coefficient of restitution

h=height of fall

Also the coefficient of restitution was computed using the formula;

$$e=V_2/V_1= (h_2/h_1)^{1/2} \qquad (4)$$

Where

e=coefficient of restitution

h_2=rebound height

h_1=height of fall

The experiment was conducted using the experimental layout in Table 3.1

Table 3.1

IMPACT ASSESSMENT: EXPERIMENT LAYOUT WITH "WALL" AS IMPACT SURFACE

	h1					h_2					h_3				
Variety	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5
	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
V_A	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$
	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$
V_B	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$

Table 3.2

IMPACT ASSESSMENT: EXPERIMENT LAYOUT WITH "CARTON" AS IMPACT SURFACE

	h1					h_2					h_3				
Variety	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5
	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
V_A	$V_AM_1h_1$	$V_AM_2h_1$	$V_AM_3h_1$	$V_AM_4h_1$	$V_AM_5h_1$	$V_AM_1h_2$	$V_AM_2h_2$	$V_AM_3h_2$	$V_AM_4h_2$	$V_AM_5h_2$	$V_AM_1h_3$	$V_AM_2h_3$	$V_AM_3h_3$	$V_AM_4h_3$	$V_AM_5h_3$
	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$
	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$
V_B	$V_BM_1h_1$	$V_BM_2h_1$	$V_BM_3h_1$	$V_BM_4h_1$	$V_BM_5h_1$	$V_BM_1h_2$	$V_BM_2h_2$	$V_BM_3h_2$	$V_BM_4h_2$	$V_BM_5h_2$	$V_BM_1h_3$	$V_BM_2h_3$	$V_BM_3h_3$	$V_BM_4h_3$	$V_BM_5h_3$

Table 3.1

Note:

$V_aM_1h_1$........ Means variety A (Cherry) of mass 1 dropped at height 1 (50cm) with wall as impact surface.

$V_aM_2h_2$........ Means variety A (Cherry) of mass 2 dropped at height 2 (100cm) with wall as impact surface.

$V_aM_3h_3$........ Means variety A (Cherry) of mass 3 dropped at height 3 (150cm) with wall as impact surface.

$V_BM_1h_1$........ Means variety A (Roma) of mass 1 dropped at height 1 (50cm) with wall as impact surface.

$V_BM_2h_2$........ Means variety A (Roma) of mass 2 dropped at height 2 (100cm) with wall as impact surface.

$V_BM_3h_3$........ Means variety A (Roma) of mass 3 dropped at height 3 (150cm) with wall as impact surface.

Table 3.2

$V_aM_1h_1$........ Means variety A (Cherry) of mass 1 dropped at height 1 (50cm) with carton as impact surface.

$V_aM_2h_2$........ Means variety A (Cherry) of mass 2 dropped at height 2 (100cm) with carton as impact surface.

$V_aM_3h_3$........ Means variety A (Cherry) of mass 3 dropped at height 3 (150cm) with carton as impact surface.

$V_BM_1h_1$........ Means variety A (Roma) of mass 1 dropped at height 1 (50cm) with carton as impact surface.

$V_BM_2h_2$........ Means variety A (Roma) of mass 2 dropped at height 2 (100cm) with carton as impact surface.

$V_BM_3h_3$........ Means variety A (Roma) of mass 3 dropped at height 3 (150cm) with carton as impact surface.

The ANOVA was used to assess whether there are significance differences among the means of the various parameters of samples dropped from different heights on to different surfaces

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 ABSORBED ENERGY

The result of the impact energy absorbed by the samples of the two varieties dropped from different height of drops are presented in Tables 4.1. The results showed that the mean energy absorbed by the samples dropped from 50, 100 and 150cm on the bare wall are 0.226J, 0.404J and 0.508J respectively while the values for those dropped on the carton are 0.380J, 0.442J and 0.504J respectively for variety A (cherry). Similarly the mean values for variety B (roma VF) are 0.138J, 0.346J and 0.376J for those impacted on the wall and 0.162J, 0.362 and 0.474J for those impacted on the carton.

These data obtained from the experiment were subject to statistical analysis to ascertain the effects of the three factors namely height of drops, variety and impact surface on the energy absorbed. The result of the analysis of variance (ANOVA) is as in Table 4.2. The results showed that height of drop and varieties have significant effects on the absorbed energy at 5% level of confidence. The effects of the impact surface are not statistically significant.

Table 4.1 Impact energy absorbed by the samples dropped from various heights (Joules)

Variety	WALL			CARTON		
	H1	H2	H3	H1	H2	H3
	0.27	0.38	0.52	0.16	0.45	0.5
	0.27	0.38	0.46	0.09	0.42	0.51
	0.17	0.45	0.52	0.2	0.47	0.49
	0.24	0.37	0.51	0.2	0.44	0.51
A	0.18	0.44	0.53	1.25	0.43	0.51
Mean	0.226	0.404	0.508	0.38	0.442	0.504
	0.14	0.39	0.47	0.15	0.33	0.42
	0.14	0.32	0.38	0.19	0.41	0.51
	0.13	0.39	0.37	0.16	0.35	0.49
	0.14	0.32	0.34	0.15	0.41	0.44
B	0.14	0.31	0.32	0.16	0.31	0.51
Mean	0.138	0.346	0.376	0.162	0.362	0.474

Variety A=Cherry and Variety B=Roma

Mean of variety A=0.410J and Mean of variety B=0.310J

Table 4.2 ANOVA for the results of energy absorbed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.824[a]	9	9.159E-02	4.385	.000
Intercept	7.783	1	7.783	372.683	.000
HEIGHT	.595	2	.298	14.252	.000
VARIETY	.153	1	.153	7.327	.009
SURFACE	4.428E-02	1	4.428E-02	2.120	.152
HEIGHT * VARIETY	2.064E-02	2	1.032E-02	.494	.613
HEIGHT * SURFACE	1.001E-02	2	5.007E-03	.240	.788
VARIETY * SURFACE	1.042E-03	1	1.042E-03	.050	.824
Error	1.044	50	2.088E-02		
Total	9.652	60			
Corrected Total	1.868	59			

Level of significance (5%) that is,Alpha=0.05

i) if significance (probability value) > 5%, P>0.05, it has no significant effect

ii) if P<0.05, it has significance.

The results in the table above shows that the effect of drop height and variety are highly significant at Alpha=0.05. however, there is no significant effect of impact surface, since p>0.05.

4.2 DYNAMIC YIELD PRESSURE

The results of the computed dynamic yield pressure for the samples of the tomato varieties used in this experiment is shown in Table 4.3. The results revealed that the samples used for the experiment have average values of DYP of 184.63 N/M^2 and 380.67N/M^2 for variety A (cherry) and B (roma) respectively. The analysis showed (Table 4.4) that these values are significantly different at 5% level of confidence. It is noted (Hyde et al, 1993) that the higher the value of dynamic yield pressure, the more resistance the produce to impact damage.

Table 4.3 Calculated dynamic yield pressure for the samples of tomato dropped on to the two surfaces from various heights. (N/M^2)

	WALL			CARTON		
Variety	H1	H2	H3	H1	H2	H3
	317.77	133.32	239.99	215.47	127.04	337.86
	200.37	150.19	125.3	125.4	158.16	227.47
	146.38	120.05	112.75	192.53	248.35	137.78
	233.56	102.73	183.62	311.6	265.06	108.13
A	270.12	128.66	143.12	169.28	152.26	154.6
mean	233.64	126.99	160.956	202.856	190.174	193.168
	390.66	110.79	194.94	669.68	322.53	143.21
	288.14	197.24	163.47	506.93	738.39	192.9
	335.01	188.43	229.36	684.85	539.55	153.64
	625.1	161.7	219.11	817.5	885.63	146.64
B	644.05	191.41	153.46	700.71	722.38	102.78
mean	456.593	169.914	192.068	675.934	641.696	147.834

Variety A=Cherry and Variety B=Roma

Mean DYP of variety A=184.63N/M^2 and Mean DYP of variety B=380.67 N/M^2

Table 4.4 ANOVA of results of dynamic yield pressure

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1933568[a]	9	214840.8	17.546	.000
Intercept	4793524	1	4793524	391.487	.000
HEIGHT	478517.6	2	239258.8	19.540	.000
VARIETY	576488.9	1	576488.9	47.082	.000
SURFACE	210931.3	1	210931.3	17.227	.000
HEIGHT * VARIETY	334932.1	2	167466.1	13.677	.000
HEIGHT * SURFACE	191427.8	2	95713.898	7.817	.001
VARIETY * SURFACE	141269.9	1	141269.9	11.538	.001
Error	612219.2	50	12244.385		
Total	7339310	60			
Corrected Total	2545787	59			

Alpha=0.05 (if $p<0.05$, it has significance, if $p>0.05$, it has no significant effect)

4.3 DISCUSSION

The essence of this work is to produce some useful information concerning some popular varieties of fresh tomato grown in the country regarding their susceptibility to impact damage during handling. The results showed that the energy absorbed by the samples dropped from various heights on to two impact surfaces differ significantly between the two varieties (Cherry and Roma) used in this study. The mean impact energy absorbed by variety A (cherry) is 0.410J while that of variety B (Roma) is 0.310J. The mean absorbed energy also differed significantly for the samples dropped from heights.

It was observed during the experiment that visible cracks on the samples started occurring when they were dropped from the 150cm heights on to both wall and carton. The average energy absorbed at this height were 0.504J and 0.474J for variety A (Cherry) and B (Roma) respectively. The results are significant because in the course of handling, it is the energy absorbed as a result of impact and vibration that normally determines the extent of mechanical damage to the produce (Ogut et al, 1999). The cracks resulting from the impact predisposes the produce to other infections and hence reduce the shelf life of the produce. The information can therefore be employed by produce handlers, designers of handling systems and transporters on how high the produce should be dropped in the course of handling so as not to cause these damages.

The information obtained on the dynamic yield pressure (which is measure of both force and contact area) profiles during impact is useful in the evaluation of cultivars, cultural practices, conditioning and providing guidelines for handling equipment for the produce. It is actually a measure of impact damage resistance of the produce. From the results obtained, (Table 4.3) it can be seen that the Roma variety is more resistant to impact damage than the Cherry variety because it has been shown that the higher the dynamic yield pressure the more resistant the produce to impact damage or the lower the dynamic yield pressure the more susceptible the produce to impact damage (Hyde et al, 1993). The information obtained is also useful to handlers at all sages on the kind of compression the produce should be subjected to or the amount of pressure load that the produce can withstand.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

An assessment of impact damage resistance of two popular varieties of tomato grown in the country has been conducted with a view to providing useful information to designers, handlers and transporters of this produce. It can be concluded from the result that of the two varieties investigated, the Roma variety seem more resistant than the Cherry variety. In other words the Roma variety is much more resistant to impact damage than the Cherry variety because the value of dynamic yield pressure is higher than that of Cherry.

5.2 RECOMMENDATION

1. There is need for adequate apparatus such as force transducer, electronic weighing balance and calibrated anvil to make the experiment of this nature more accurate.
2. There should be a departmental farm, where such experiment can be carried out to avoid difficulties in transporting fruits to the laboratory thereby avoiding damages due to impact and vibrations before experiments are carried out.

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Appendix A

Plate 3.1 Cherry variety

Plate 3.2 Roma variety

Appendix B

Plate 3.3 Tomato being held at a drop height

Plate 3.4 Tomato being released from a drop height.