# ASSESSMENT OF IMPACT DAMAGE THRESHOLDS IN FRUITS AND VEGETABLES

*BY*

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STATE.

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# DECLARATION

I declare that this project work was carried out by me under the supervision of Engr. P.A. Idah

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PGD/AGRIC ENG/2001/157

# CERTIFICATION

This is to certify that this project work on the measurement of impact damage thresholds on fruits and vegetables was carried out by Emeh, Boniface Enedoh of Agricultural Engineering Department, Federal University of Technology, Minna, Niger State.

In partial fulfilment of the requirements for the award of post Graduate Diploma in Agricultural Engineering.

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Engr. P.A. Idah
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# DEDICATION.

This project work is dedicated, first and foremost, to God Almighty for his protection especially from road hazards along Abuja- Minna road and to my dearly beloved wife Mrs. Lawrencia UK Emeh for her encouragement and support throughout the programme.

# ACKNOWLEDGEMENT

To God be the glory who made it possible for me to be alive up to this day. I wish to appreciate my unalloyed gratitude to the able supervisor of this project, Engr. Peter A. Idah of the Department of Agricultural Engineering, Federal University of Technology, Minna, for all the sacrifices in terms of time and materials toward making this project a reality. May God in His infinite mercy bless you in a special way, Amen.

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# ABSTRACT.

This project involves the assessment of impact damage thresholds in fruits and vegetables with tomato fruits as a case study. Impact testing machine developed by Ajisegiri et al (2003) was used in carrying out the impact tests. Red fresh tomato fruits that have not been subjected to any sort of damage were procured. Their individual weights were determined by weighing them using sensitive electronic weighing balance. The masses of these weighed tomato fruits were sorted out into three groups:- $m_1$ (0g to 30.0g); $m_2$ (30.1g to 60.0g) and $m_3$ (60.1g and above). Three impact surfaces onto which the fruits were dropped were used namely, surface 1 $S_1$, (Smooth Plastic Material), surface II $S_2$ (Serrated Basket Material) and surface III, $S_3$ (Rough Wood Material). The heights of drops were varied as follows: $h_1 = 30cm$, $h_2 = 70cm$, $h_3 = 100cm$, $h_4 = 130cm$, and $h_5 = 160cm$. Five fruits samples were selected from each of the mass groups and dropped from these heights unto each of the surfaces. After the drop of each sample, the sample was assessed to determine the nature of possible damage sustained and record made. For the purpose of this experiment, damages were classified as puncture (P), crack (C) and bruise (B). From the traces of marks made on the samples when they impacted on the surfaces smeared with powdered material (granulated chalk), the bruise areas of the impacted samples were determined using measuring tape and graph sheets. The whole exercise was recorded with a video camera with a view to determine the rebound heights of the dropped samples through the calibration pasted on the column of the impact testing machine when the video tape was played. The results of the experiments showing the replications of drops, the various mass samples, type of damage sustained by samples and the rebound heights of samples from various heights were tabulated. From the data obtained, the absorbed energy and the coefficient of restitution were calculated. The results showed that minimum impact energy that will result in cracks on the sample was 0.33195 J. The results also showed that the height of drop and the mass significantly affect the impact energy.

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# CHAPTER ONE.

# INTRODUCTION.

Fruits and vegetables are food items required in human body for a balance diet. Botanically, a fruit is the product of the determinate growth from angiospermous flower or inflorescence after fertilization. To the consumer, fruits are the plant products with aromatic flavors, which are either naturally sweet or normally sweetened before consumption. Horticulturally, a fruit is any plant that is eaten without being cooked (Osueni, 1984)

Fruits are important in the tropics and subtropics due to their carbohydrate and vitamins contributions to the diet. Most fruits contain large quantities of sugars and are high in vitamins such as vitamins A and C which are not in abundance in the staple food of many warm areas. Since fruits are eaten fresh rather than cooked, their vitamin contents are not diminished in the preparation (Rice et al; 1990).

Vegetables on the other hand are soft, edible plant product that may be eaten raw or cooked. Grubben (1977) described vegetables as plant which provides a source of food often low in calories and which are consumed in addition to starchy staple food in order to make them more palatable. Nutritionally vegetables are good sources of vitamin, proteins, minerals, and fibre (Rice et al; 1990).

Vegetables could be grouped into three main categories:

i. Seeds and pods:- This includes tomato, pepper, water melon, egg plant, cucumber, peas, the green peas and the beans.

ii. The bulb, the roots or tubers:- This includes onion, carrot, garlic, potato.

iii. Flowers, buds, stem and leaves:- This includes amaranthus celosia, lettuce, cabbage, etc (Osueni,1984).

Fresh fruits and vegetables are inherently perishable. During the process of distribution and marketing, substantial losses are incurred which range from a light loss of quality to total spoilage. Post –harvest losses may occur at any point in the marketing process, from the initial harvest through assembly and distribution to the final consumer. The causes of losses are many. It may range from physical damage (bruising, abrasion, puncture, cracks etc) to decay and water loss (shriveling).

There is the need to assess and evaluate the causes of these post harvest losses and find means of preventing them. One of the causes of the losses during handling is impact against other fruits, part of containers and other handling equipment. The assessment of impact damage and determination of the thresholds values of impact force that would cause different types of damage in fruits and vegetables become very necessary. In this project, tomato fruits at ripe state will be used in the assessment of the impact damage. Such assessment requires the proper knowledge of the characteristics of the produce in question, hence the need to take close look at tomato fruit.

## TOMATO CROP.

Tomato crop (fruit) is supposed to have originated from both Central and South America (Spur, 1976). The word tomato stems from the word "tomati" and this was the term used by the Indians of Mexico for the crop. The Portuguese introduced it into West Africa between the Sixteenth and Seventeenth century. Since then, it has become the most popular vegetable crop world wide (Nwankiti, 1984).

Tomato is a liquid (not hard) fruit, which is made up of soft mass contained in a mostly elastic skin. The resistance of tomato to impact damage is based on the skin. The fruit has deep green colour, which becomes lighter as it matures; the colour changes to pink and finally becomes reddish when it is fully ripped (Rice et al; 1990).

## POST HARVEST HANDLING OF TOMATO.

Tomato fruit is delicate and highly perishable. It must therefore be carefully handled during and after harvesting. There is considerable "North to South" distribution of tomatoes in Nigeria due to pattern of production. Tomatoes are usually packed in baskets, cardboard boxes, wooden and plastic crates during handling. They are transported by rail in trains or by road in trucks over long distances. Very often, it takes 3 – 5 days to arrive at the final destination.

Most of the mechanical damages especially those resulting from impact take place during this long distance travel. The vehicles on traversing over the irregular road profiles are set on vibrations as a result of the excitation from the potholes and bumps on the roads. It is these vibrations and the resulting impacts that are dissipated as energy in produce, thus resulting to damage. It is therefore necessary to subject this produce to various impact forces in order to determine the threshold values that will initiate or cause different types of mechanical damages. This is with a view to generating relevant information that could be used in the selection of appropriate transport and handling devices that would reduce such impacts.

## OBJECTIVES.

The objectives of this study are therefore –

i. To determine the various heights of fall that will cause different impact damages.

ii. To ascertain the effects of different impact surfaces on fruit damage.

## JUSTIFICATION

The world resources are not equitably distributed thus giving rise to the need to move resources from areas of surplus to areas of lack. Tomato being a very important source of vitamins in human diet need not only be transported to areas of lack, but also ensure it does not lose quality. The need to look into the post-harvest handling of fruits and vegetables, the handling equipment and mechanism become very important. It becomes necessary to study the causes of post harvest quality and quantity losses, how to put a check or at least minimize these losses.

Most damages to freshly and fragile fruits and vegetables are due to impacts. Impacts may be as a result of vibration, stacking (piling), hitting (dropping) or rubbing against each other of these produce. It therefore becomes important to assess the commencement of this damage; hence the need for the measurement of impact damage threshold in tomato fruits. Such a measure is needed to assess damage resistance response of fruits and vegetables to cultural and conditioning practices, for cultivars development and selection and to more precisely determine the probability of impact damage in handling equipment.

Moreover, impact damages in fruits and vegetables reduce quality and efficiency and increase costs to growers, packers, shippers, and consumers. For example, potato bruising alone cost U.S. growers $150 million, or an average of $10,000 per registered grower in 1985 (Francis et al; 1985). Furthermore, impact damages also reduce the shelf life and international marketability of produce.

In spite of the importance of fruits and vegetables in human diet, its per capital consumption is still relatively low at 100g in developing countries when compared to 200g obtainable in more advanced countries (Grubben, 1977). The use of improved cultivars developed through the assessment of impact damage thresholds would help to increase agricultural production and storage of fruits and vegetables.

Assessment of impact response of fruits and vegetables can produce significant results, which could be used to predict subsequent damages suffered by these fruits and vegetables in transit. Such assessment could further generate basic data that could be used to conceptualize appropriate handling devices that would result in minimum damage to these produce during handling.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### IMPACT DAMAGE IN FRUITS AND VEGETABLES

Fruits and vegetables are very sensitive to impact actions. Impact has been recognized as the most important cause of damage (bruising) in fruits and vegetables (Nwankiti, 1984). Other types of impact damage include skin breaks, spots, rots, decay and deteriorations. Impact damage does not only affect produce appearance, but also provides entrance for decaying organisms and increases rate of respiration and the subsequent moisture loss. The qualitative, quantitative as well as cash value of produce is adversely affected ( Nwankiti, 1984).

Research on mechanical damage in fruits and vegetables with a view to minimizing impact damage has been carried out. The first research on physical properties of fruits was, in fact, directed toward analysing the response to slow or rapid loading of selected fruits (Fridley et al; 1968, Horsefield et al; 1968, Horsefield et al; 1972). From that time on, research has expanded greatly; and different aspects of problem have been approached. These include application of mechanical models for contact (impact) problem, the response of biological tissues to loading devices for dictating damage in machines and equipment, and procedure for sensing bruises in grading and sorting (Altisent, 1991).

Researches to asses impact damage based on the resistance or susceptibility measure on fruits and vegetables were carried out by (Schoorl and Holt, 1977 (a),(b)). This study found that Jonathan Delicious and Granny Smith apples exhibited linear correlation between bruise volume and energy absorbed (E). With these units, the term is more properly called a bruise

susceptibility coefficient (Altisent, 1991). However, the concept is extremely valuable because it provides an objective, repeatable measure of tendency of a given lot of a commodity to sustain mechanical damage, relative to other lots of that commodity and even other commodities.

Altisent (1991) provides an extensive new literature review on impact damages in fruits. In reviewing her own work (Altisent, 1990) and that of others –(Kampp and Nissan, 1990), she concluded that, "neither input nor absorbed energy are in themselves sufficient to predict impact sensitivity of apples and consequently of other fruits". This conclusion is valid because bruise susceptibility varies considerably with the condition of the fruits. The fruit variable conditions that are important, and how they relate to bruise susceptibility are still not well defined.

Brusewitz and Bartsch (1989) found that V/E i.e. (bruise volume/impact energy absorbed) decreased gradually with storage time and consequently with firmness, while others (Hung and Prussia, 1988; Holt and

Schoorl, 1984) found an increasing V/E with a decrease in firmness. This and other conflicts in bruise susceptibility research are yet to be resolved.

Hyde et al (1993) used two methods of impact damage threshold and resistance measurement to assess impact damage thresholds in fruits and vegetables. The first was a conventional threshold method, which used two thin wires to suspend the commodity, forming a 1-m pendulum.

An angular scale calibrated in units of drop height provides a measure of drop and rebound heights. A steel anvil mounted on a masonry wall formed the impact surface and cushioning materials were attached to the anvil when needed. Individual potato tubers, onions or apples of approximately the same mass within commodity 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 were evenly spaced.

The second method used a 3 - meter pendulum and an instrumental anvil fitted with impact force and contact area sensors. Photocells sensed impact and rebound velocities. Computer logging at 20,000 samples per second yielded force and area profiles from which dynamic pressure profiles were calculated. Bruise energy and other absorbed energy were partitioned using multiples impact techniques.

The results from the experiment include bruise thresholds on steel and reference cushioning materials for three commodities (potato tubers, onions and apples). The instrumented pendulum results show promising relationships between dynamic yield pressure (force per unit area), impact profiles, and bruise damage occurrence. (Hyde et al; 1993).

Diener et al (1979) in trying to find solution to impact damage assessment used a decreasing height, multiple–impact (DHMI) technique where fruits were dropped onto a load cell and allowed to bounce successively. They found that rebound time (relative time between successive impacts) increased with successive impacts on the same position with peaches and apples. They speculated that, "Apparently with each successive impact a higher percentage of energy was stored in the elastic form and was thus recoverable in rebound" Diener et al (1979) in Hyde et al (1993).

## 2.1 CAUSES OF IMPACT (MECHANICAL) DAMAGE IN FRUITS AND VEGETABLES.

Impact or mechanical damage in fruits and vegetables in which bruising ranks high appears as a result of impacts and compression of produce against one another, parts of the trees, containers, parts of any grading and treatment machinery and on any uncushioned surface. The severity of damage to the fruits and vegetables is influenced by the following:-

( i ) Height of fall

( ii ) Initial velocity of fall

( iii ) Number of impacts

( iv ) Type of impact surface

( v ) Physical properties of the fruit. (Hyde, 1996).

## 2.2 MEANS OF REDUCING IMPACT DAMAGE

Impact damage can be reduced by the following means:-

1. By improving equipment design and operation:- This could be done by:-

( a ) reduce number and or severity of impacts

( b ) reduce number of drops in handling system

( c ) reduce height of drop in handling system

(d ) keep conveyors full to capacity

( e ) empty out conveyors only when necessary

( f ) add cushioning materials

(g ) remove rigid supports under drops. (Hyde, 1996)

2. By reducing commodity sensitivity: This could be done by :-

( a ) temperature conditioning

( b ) turgor conditioning

( c ) cultivar selection (Hyde, 1996)

## 2.3 METHODS OF IMPACT ASSESSMENT.

Impact (shock) could result from throwing or dropping of packages. It could also be as a result of sudden change of momentum following the starting and stopping of a vehicle containing the package. Impact could equally result from vehicle speeding over rough roads. The effects of such impacts are bruising of packaging and the subsequent bruising of produce contained in the package.

There is no rapid quantitative method of impact damage resistance measurement that currently exists. Such assessment is needed to ascertain response of fruits and vegetables to cultural and conditioning practices, for cultivar development and selection, precisely determine the probability of impact damage in handling equipment. However, various theoretical models have been used to explain and analyse the impact problems as applied to fruits.

The first presented many years ago considers a fruit as an elastic (generally spherical) body and applying the Hertz contact theory further developed by Shingley (Horsfield et al; 1972, Rumsey and Fridley, 1977). This approach has been shown to be the only approximately applicable, but has yielded much interesting information on many fruits especially those classified as hard or rigid fruits.

In recent years, some testing devices which have been developed to apply and analyse controlled impacts to fruits include :-

( i ) Instrumented pendulums (Holt and Schoorl, 1984; Hughes and Grant, 1987)

( ii ) Free-falling instrumented devices (Chen et al; 1985) and

( iii ) Spring-activated falling rods (Gahtow, 1990)

Chen et al. (1987) and Garcia et al (1988) used an impact testing device consisting of a free-falling impacting rod with a changeable spherical tip, instrumented with a miniature accelerometer (Altisent, 1991).

The reported findings was that the bruise damage measured as the size and/or the volume of the affected fruit tissue was related to input energy (i.e. drop height) using a given variety at a given ripeness stage and physical condition. The relevant impact parameters were maximum deformation (DM), permanent deformation (DP), maximum impulse (IM), maximum impact force (FM) impact duration (T).

Rodriguez and Ruiz (1989) used depth and diameter to evaluate bruise severity in pears of Blanquilla variety. The parameters used include maximum inpact force, maximum impact deformation, permanent deformation, inpact energy, absorbed energy, impact duration, firmness, acidity, soluble solids and soluble solids/acidity ratio. Around 57% of total variation could be explained by these parameters, most of the variation being explained by inpact energy alone.

Bruise volume was also used by various researchers to evaluate bruise severity. Kampp and Nissan (1990) studied the susceptibility to impact, (applied by an instrumented pendulum) of seven varieties of apples. As in results reported by many other researchers, high correlations were found between inpact energy ($E_{abs}$) and bruise volume (V) for the three (early, mid and late harvest) samples of the variety. The important result was, the impact susceptibility can be expressed as regression coefficient in the expression:

$$V = aE_{abs} + b \text{ (a in ml / J; b in ml)} \quad \text{———} (1)$$

The impact susceptibility is different for every sample of every variety. From this and many other similar results, it is concluded that neither input nor absorbed energy are in themselves sufficient enough to predict impact sensitivity of apples and consequently of other fruits. Other parameters like impact process, the response of fruits due to its physical properties and the structure and physiology of the fruits must be included to explain bruising.

Lichtensteiger et al (1988) used drop-testing apparatus where the samples were released from specific heights onto a rigid aluminum plate instrumented with a force transducer. Various types of models (fabricated balls) and red tomatoes were tested. Changing the properties of the shell in relation with the internal material of the tested balls showed that the shell effect is prevalent when the internal material is stiffer than the shell, no shell effect was observed. This result shows that the effect of the skin when testing hard or soft fruit is in fact, relevant in the response to impacts and it will be different for different ripeness stages of the fruits.

Brusewitz and Bartsch (1989) also dropped fruits (five varieties of apples) onto a plate instrumented with a piezoelectric force transducer. They revealed that the relation "bruise volume / absorbed energy" changed gradually with storage time, decreasing with firmness. Other studies however showed different or opposite results (Hung and Prussia; 1988, Holt and Schoorl, 1984) namely an increase in "bruise volume /absorbed energy" with reducing firmness. They also found that impact contact time (T) was closely correlated with decreasing firmness as well as the ratio impact force / contact time. This was in agreement with all the impact parameters research result found so far.

Free fall of instrumented fruits was used by Chen and Yazdani (1989). The degree of bruising of Golden Delicious apples dropped from different heights onto different compacting surfaces (padded differently) could be predicted by multiple regression models based on measured and calculated impact parameters; and Fourier transform coefficient of the impact acceleration curves. The relevant parameters were max. value of force /time rate change (F/T slope), maximum deformation (DM), and absorbed energy (EAB). Further, maximum force (FM) and duration or time of impact (T) was significant in regression equation.

Other researchers on impact assessment include Siyami et al (1988) who used impact table to perform free-fall tests on apples; Timm et al (1989) who used dropping of fruits on impact surface carrying an accelerometer on the opposite side to assess impact; and Ajisegiri et al (2003) who developed and used impact testing machine to evaluate impact response of fruits and vegetables using the concept that energy at impact is a function of the mass of the sample and the height of drop. He expressed the relation as :-

$$E_{ab} = (1 - e^2)wh = (1 - e^2)mgh \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_} (2)$$

(Moshenin, 1978 in Ajisegiri et al .2003)

Where $E_{ab}$ = energy absorbed, e = coefficient of restitution, w = weight of material = mg, m = mass of material, g = acceleration due to gravity (gravitational pull), h = height of drop.

## 2.4 DEVICES FOR ASSESSING IMPACTS IN FRUITS AND VEGETABLES.

There are various devices in recent years, which have been developed to apply and analyse controlled impacts to fruits and vegetables. They include the instrumented pendulum, free-falling instrumented devices and spring activated falling rods. Researchers use various means to approach the assessment. Some use the concept that energy at impact is a function of mass of sample and the height of drop (Ajisegiri et al; 2003), while some use multiple regression models based on measured and calculated impact parameters and Fourier–transform coefficient of the impact acceleration curves (Chen and Yazdani 1989) to predict the degree of bruise.

Some of the impact assessment devices in fruits and vegetables include:-

(i) Impact testing machine (Ajisegiri et al; 2003). This impact-testing machine was developed and fabricated. This machine was used to subject potato tubers to impact damage in order to investigate the stability of potato tubers under certain conditions of temperature and relative humidity. The concept used is that energy at impact is a function of the mass of sample and the drop height.

(ii) Free–falling impact Rod Devices:

Researchers like Chen et al (1987); Gracia et al (1988) used an impact-testing device that consists of a free-falling impacting rod with a changeable spherical tip and a miniature accelerometer to assess the impact response of fruits and vegetables. The impacting rod is dropped through an electromagnetic linkage to impact on the fruit supported on a plat form. A computer is used to assess the response.

(iii) Free-fall of instrumented fruits device (Chen and Yazdani, 1989): Chen and Yazdani (1989) used free-falling of instrumented fruits to assess the impact damage of Golden Delicious apples which were dropped from different heights onto different impacting surfaces by means of electromagnet equiped with computer and accelerometer. The computer assessed the degree of bruising.

(iv) The Hatt-Turner impact machine: The Hatt–Turner machine is used mainly for flexure impact test of wood in which the height of the drop is increased by increments until failure occurs (ASTM, 1976).

(v) The Riehle combination Izod and Charpy tests:- This device consists of a pendulum, a tube, scale and pendulum catch of both high capacity and low capacity (ASTM, 1972).

(vi) A high speed pneumatic apparatus:- This is used for impact test of foods and agricultural products, for studies at fast rates of loading. (Fletcher et al; 1965).

Research on means to prevent or minimize mechanical damage in fruits and vegetables handling is a welcome development the world over. Most damages to freshly fragile fruits and vegetables are due to impact, which may be as a result of vibration, stacking, hitting (dropping) or rubbing against each other of produce. Handling devices, which cause damage in produce, reduce quality and quantity and shorten the shelf life of produce thus bringing about economic loss to the grower. In effect research into devices for impact damage assessment in fruits and vegetables is very necessary for the benefit of both the grower and consumers.

It is in the light of this that this study, which is intended to determine the threshold value of impact force that will cause different forms of mechanical damage in tomato fruits, is desirable. Such assessment will reveal information /data that can be used in the selection of handling devices that will minimize such damages.

# CHAPTER THREE.

## 3.0 MATERIALS AND EQUIPMENT FOR THE ASSESSMENT.

As stated earlier, various testing devices have been in use in recent years with which to apply controlled impacts in fruits and vegetables. However, the equipment in use in this study is an impact-testing machine developed by Ajisegiri et al (2003).

Other materials and equipment required in this assessment include:-

(i) Fresh tomato fruits of red maturity stage.

(ii) Electronic weighing balance which is used for determining the individual masses of the tomatoes and grouping them according to the required mass group.

(iii) Measuring tape, this is used for measuring heights of drops of tomatoes and the heights of rebounds.

(iv) Digital or video camera. This is used in capturing the rebound heights of tomatoes.

(v) Various surfaces of interest:- serrated, rough, smooth e.t.c.

(vi) Trays for collecting tomato samples.

(vii) Paper tape

(viii) Powdered material (granulated chalk)

## 3.1 EQUIPMENT AND METHODS.

As mentioned earlier, the testing device, which is used in this study, is the impact testing machine by Ajisegiri et al (2003). The machine is simple in design and operation. It consists of a platform for holding and releasing of samples, impact surface platform, a supporting stand, a column (adjustable) measuring tape (digital), a box for collecting the falling sample from the platform. It does not require complicated accessories such as transducer, accelerator etc as do some other testing devices. It utilizes the concept that the energy absorbed by the material is a function of the weight of the material and height of fall (drop) as expressed in Equation (2).

The coefficient of restitution (e) can be determined from the relationship-:

$$e = \frac{V_2}{V_1} = \left(\frac{h_2}{h_1}\right)^{1/2} \qquad \text{————} (3)$$

where, $V_1$ and $V_2$ are initial velocity of fall and rebound velocity respectively; $h_2$ and $h_1$ denote the height of rebound and height of drop (fall) in free-fall respectively.

## 3.2 METHOD OF ASSESSMENT

The impact testing machine (Ajisegiri et al; 2003) was cleaned and set on a level floor. The spirit level on the supporting stand was used to determine when the machine became balanced. A paper tape which was calibrated in cm starting from 0cm to 170cm was pasted on the vertical column of the machine with 0cm mark at the same level with the machines impact surface and the 170cm mark at the top part of the column. The first 20cm of the calibrated paper tape was calibrated in multiples of 2cm starting from 0.0cm. This makes for easy and more accurate reading of the rebound heights of samples. The remaining length was calibrated in multiples of 10cm.

For this assessment, three types of impact surfaces and five drop heights were considered. The impact surfaces include:

( i ) Smooth surface denoted by "$S_1$" ; plastic material was used.

( ii ) Serrated surface denoted by "$S_2$" ; basket material was used.

( iii ) Rough surface denoted by "$S_3$" ; wooden material was used.

The heights that were considered starting from the lowest to the topmost were $h_1$ =40cm, h2 = 70cm, $h_3$= 100cm, $h_4$= 130cm, and $h_5$= 160cm.

The samples were red fresh tomato fruits, which have not sustained any sort of injury or rough handled. The fruits were gently weighed by the use of sensitive electronic balance and graded into three groups by mass. The first group of mass denoted by " $M_1$" is made up of tomatoes having weight between 0g to 30.0g; the second mass group denoted by $M_2$ has weights between 30.1g to 60.0g and the third mass group denoted by "$M_3$" contains tomatoes of weight ranging from 60.1g and above. Before the dropping of the samples commenced on each surface, white powdered substance was smeared on the surface such that when the samples impacted on the surface, the white powdered substance make a trace of the portion of the sample in direct contact with the impacting surface.

On each surface (plastic, basket, wood), from each mass group and from each chosen height of drop (40, 70, 100,130, 160cm), five samples were dropped individually by placing such sample on the material holding platform and the trigger handle actuated to release the sample. Forty-five samples were dropped from each chosen drop height; fifteen samples on each surface and five samples from each of the three mass groups. Therefore a total of 225 samples were dropped from the five heights being considered. These dropping exercises were recorded with a video machine with a view to capturing the rebound height of samples after impacting on the surface.

After each drop of the samples, observations of the fruits were made to assess any possible damage and the nature of the damage. For this assessment exercise, the nature of the damage was classified into bruise, crack, and puncture. The result of the observations on the sample dropped upon a particular surface was recorded on a piece of paper tape and pasted on the sample for identification. The bruised surface areas of each of the dented samples as traced out by the contour drawn by the white powdered substance were determined by the use of measuring tape and graph sheets. The bruised areas were then recorded against each sample, the surface onto which it impacted and the drop height.

The videotape used in recording the experiment was later relayed on an audio video machine. By careful observations, the rebound height of each of the sample dropped against a particular surface and from a specified height was read out through the calibrations affixed on the column of the impact-testing machine.

From the relationship as expressed in Eq. (3), the coefficient of restitution , e, could be calculated since the height of drop , $h_1$ , and that of rebound , $h_2$ , are known.

When the coefficient of restitution, e, is determined, the absorbed energy, Eab, can be determined through the relationship as expressed in Eq. (2)

## 3.3 EXPERIMENTAL LAYOUT OF IMPACT ASSESSMENT OF TOMATO FRUITS.

The experimental design used in this assessment was the three-factor, full factorial experiment. The three factors were drop height, impact surface and mass of sample. Five levels of height, namely 40cm, 70cm, 100cm, 130cm, 160cm, were considered. Three impact surfaces:- smooth (plastic), serrated (basket) and rough (wood) and three mass groups ( 0.0 –30.0g, 30.1 – 60.0g, 60.1 & above) were used. The replication was 5 times. Thus, we obtain 5X3X3X5 =225 treatments. The illustration is as shown below in Table 3.1.

**Techniques of analysis:** The data collected were subjected to statistical analysis using completely randomized design (CRD). An analysis of variance (ANOVA) was used to ascertain whether there were significant differences among the means of the samples under different treatments.

## TABLE 3.1 Experimental Layout Of Impact Assessment Of Tomato Fruits

| eight 1 | HEIGHT I, $h_1$ = 40cm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| rfaces | Surface 1, ($S_1$) plastic :- smooth | | | Surface 11 ( $S_2$) basket :- serrated | | | Surface 111 ($S_3$) wood:- rough | | |
| ass oups | $M_1$ | $M_2$ | $M_3$ | $M_1$ | $M_2$ | $M_3$ | $M_1$ | $M_2$ | $M_3$ |
| ops – 1 | $h_1 m_1 s_1$ | $h_1 m_2 s_1$ | $h_1 m_3 s_1$ | $h_1 m_1 s_2$ | $h_1 m_2 s_2$ | $h_1 m_3 s_2$ | $h_1 m_1 s_3$ | $h_1 m_2 s_3$ | $h_1 m_3 s_3$ |
| ops – 2 | $h_1 m_1 s_1$ | $h_1 m_2 s_1$ | $h_1 m_3 s_1$ | $h_1 m_1 s_2$ | $h_1 m_2 s_2$ | $h_1 m_3 s_2$ | $h_1 m_1 s_3$ | $h_1 m_2 s_3$ | $h_1 m_3 s_3$ |
| ops – 3 | $h_1 m_1 s_1$ | $h_1 m_2 s_1$ | $h_1 m_3 s_1$ | $h_1 m_1 s_2$ | $h_1 m_2 s_2$ | $h_1 m_3 s_2$ | $h_1 m_1 s_3$ | $h_1 m_2 s_3$ | $h_1 m_3 s_3$ |
| ops –4 | $h_1 m_1 s_1$ | $h_1 m_2 s_1$ | $h_1 m_3 s_1$ | $h_1 m_1 s_2$ | $h_1 m_2 s_2$ | $h_1 m_3 s_2$ | $h_1 m_1 s_3$ | $h_1 m_2 s_3$ | $h_1 m_3 s_3$ |
| ops – 5 | $h_1 m_1 s_1$ | $h_1 m_2 s_1$ | $h_1 m_3 s_1$ | $h_1 m_1 s_2$ | $h_1 m_2 s_2$ | $h_1 m_3 s_2$ | $h_1 m_1 s_3$ | $h_1 m_2 s_3$ | $h_1 m_3 s_3$ |
| ight II | HEIGHT II, $h_2$= 70cm | | | | | | | | |
| ops – 1 | $h_2 m_1 s_1$ | $h_2 m_2 s_1$ | $h_2 m_3 s_1$ | $h_2 m_1 s_2$ | $h_2 m_2 s_2$ | $h_2 m_3 s_2$ | $h_2 m_1 s_3$ | $h_2 m_2 s_3$ | $h_2 m_3 s_3$ |
| ops – 2 | $h_2 m_1 s_1$ | $h_2 m_2 s_1$ | $h_2 m_3 s_1$ | $h_2 m_1 s_2$ | $h_2 m_2 s_2$ | $h_2 m_3 s_2$ | $h_2 m_1 s_3$ | $h_2 m_2 s_3$ | $h_2 m_3 s_3$ |
| ops – 3 | $h_2 m_1 s_1$ | $h_2 m_2 s_1$ | $h_2 m_3 s_1$ | $h_2 m_1 s_2$ | $h_2 m_2 s_2$ | $h_2 m_3 s_2$ | $h_2 m_1 s_3$ | $h_2 m_2 s_3$ | $h_2 m_3 s_3$ |
| ops –4 | $h_2 m_1 s_1$ | $h_2 m_2 s_1$ | $h_2 m_3 s_1$ | $h_2 m_1 s_2$ | $h_2 m_2 s_2$ | $h_2 m_3 s_2$ | $h_2 m_1 s_3$ | $h_2 m_2 s_3$ | $h_2 m_3 s_3$ |
| ops – 5 | $h_2 m_1 s_1$ | $h_2 m_2 s_1$ | $h_2 m_3 s_1$ | $h_2 m_1 s_2$ | $h_2 m_2 s_2$ | $h_2 m_3 s_2$ | $h_2 m_1 s_3$ | $h_2 m_2 s_3$ | $h_2 m_3 s_3$ |
| ight III | HEIGHT III, $h_3$ = 100cm | | | | | | | | |
| ops – 1 | $h_3 m_1 s_1$ | $h_3 m_2 s_1$ | $h_3 m_3 s_1$ | $h_3 m_1 s_2$ | $h_3 m_2 s_2$ | $h_3 m_3 s_2$ | $h_3 m_1 s_3$ | $h_3 m_2 s_3$ | $h_3 m_3 s_3$ |
| ops – 2 | $h_3 m_1 s_1$ | $h_3 m_2 s_1$ | $h_3 m_3 s_1$ | $h_3 m_1 s_2$ | $h_3 m_2 s_2$ | $h_3 m_3 s_2$ | $h_3 m_1 s_3$ | $h_3 m_2 s_3$ | $h_3 m_3 s_3$ |
| ops – 3 | $h_3 m_1 s_1$ | $h_3 m_2 s_1$ | $h_3 m_3 s_1$ | $h_3 m_1 s_2$ | $h_3 m_2 s_2$ | $h_3 m_3 s_2$ | $h_3 m_1 s_3$ | $h_3 m_2 s_3$ | $h_3 m_3 s_3$ |
| ops –4 | $h_3 m_1 s_1$ | $h_3 m_2 s_1$ | $h_3 m_3 s_1$ | $h_3 m_1 s_2$ | $h_3 m_2 s_2$ | $h_3 m_3 s_2$ | $h_3 m_1 s_3$ | $h_3 m_2 s_3$ | $h_3 m_3 s_3$ |
| ops – 5 | $h_3 m_1 s_1$ | $h_3 m_2 s_1$ | $h_3 m_3 s_1$ | $h_3 m_1 s_2$ | $h_3 m_2 s_2$ | $h_3 m_3 s_2$ | $h_3 m_1 s_3$ | $h_3 m_2 s_3$ | $h_3 m_3 s_3$ |
| ight IV | HEIGHT IV, $h_4$ | | | | | | | | |
| ops – 1 | $h_4 m_1 s_1$ | $h_4 m_2 s_1$ | $h_4 m_3 s_1$ | $h_4 m_1 s_2$ | $h_4 m_2 s_2$ | $h_4 m_3 s_2$ | $h_4 m_1 s_3$ | $h_4 m_2 s_3$ | $h_4 m_3 s_3$ |
| ops – 2 | $h_4 m_1 s_1$ | $h_4 m_2 s_1$ | $h_4 m_3 s_1$ | $h_4 m_1 s_2$ | $h_4 m_2 s_2$ | $h_4 m_3 s_2$ | $h_4 m_1 s_3$ | $h_4 m_2 s_3$ | $h_4 m_3 s_3$ |
| ops – 3 | $h_4 m_1 s_1$ | $h_4 m_2 s_1$ | $h_4 m_3 s_1$ | $h_4 m_1 s_2$ | $h_4 m_2 s_2$ | $h_4 m_3 s_2$ | $h_4 m_1 s_3$ | $h_4 m_2 s_3$ | $h_4 m_3 s_3$ |
| ops –4 | $h_4 m_1 s_1$ | $h_4 m_2 s_1$ | $h_4 m_3 s_1$ | $h_4 m_1 s_2$ | $h_4 m_2 s_2$ | $h_4 m_3 s_2$ | $h_4 m_1 s_3$ | $h_4 m_2 s_3$ | $h_4 m_3 s_3$ |
| ops – 5 | $h_4 m_1 s_1$ | $h_4 m_2 s_1$ | $h_4 m_3 s_1$ | $h_4 m_1 s_2$ | $h_4 m_2 s_2$ | $h_4 m_3 s_2$ | $h_4 m_1 s_3$ | $h_4 m_2 s_3$ | $h_4 m_3 s_3$ |
| ight V | HEIGHT V, $h_5$ | | | | | | | | |
| ops – 1 | $h_5 m_1 s_1$ | $h_5 m_2 s_1$ | $h_5 m_3 s_1$ | $h_5 m_1 s_2$ | $h_5 m_2 s_2$ | $h_5 m_3 s_2$ | $h_5 m_1 s_3$ | $h_5 m_2 s_3$ | $h_5 m_3 s_3$ |
| ops – 2 | $h_5 m_1 s_1$ | $h_5 m_2 s_1$ | $h_5 m_3 s_1$ | $h_5 m_1 s_2$ | $h_5 m_2 s_2$ | $h_5 m_3 s_2$ | $h_5 m_1 s_3$ | $h_5 m_2 s_3$ | $h_5 m_3 s_3$ |
| ops – 3 | $h_5 m_1 s_1$ | $h_5 m_2 s_1$ | $h_5 m_3 s_1$ | $h_5 m_1 s_2$ | $h_5 m_2 s_2$ | $h_5 m_3 s_2$ | $h_5 m_1 s_3$ | $h_5 m_2 s_3$ | $h_5 m_3 s_3$ |
| ops –4 | $h_5 m_1 s_1$ | $h_5 m_2 s_1$ | $h_5 m_3 s_1$ | $h_5 m_1 s_2$ | $h_5 m_2 s_2$ | $h_5 m_3 s_2$ | $h_5 m_1 s_3$ | $h_5 m_2 s_3$ | $h_5 m_3 s_3$ |
| ops – 5 | $h_5 m_1 s_1$ | $h_5 m_2 s_1$ | $h_5 m_3 s_1$ | $h_5 m_1 s_2$ | $h_5 m_2 s_2$ | $h_5 m_3 s_2$ | $h_5 m_1 s_3$ | $h_5 m_2 s_3$ | $h_5 m_3 s_3$ |

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1-Types of Mechanical Damage

The results of the impact assessment carried out on riped (red) tomatoes to ascertain the threshold values of impact energy that will result in various types of mechanical damages on the fruit are presented thus. The types of mechanical damage observed by dropping the fruit from various heights onto different impact surfaces are presented in Table 4.1. It can be observed from the result that bruise virtually occurred in the dropped fruit irrespective of the drop height, mass or impact surface.

Cracks on the other hand were prevalent on the samples dropped from 130cm height and above. The crack damage was also prominent among the bigger fruit (40g and above).

### 4.2-Coefficient of restitution"

The results of the coefficient of restitution of the tomato samples used in this study are presented in Table 4.2. The trend showed that the coefficient of restitution ranges from between 0.242- 0.542. The variation noted in the results obtained showed that the coefficient of restitution is not a constant as earlier observed (Mohsenin, 1978) but varies with the velocity of impact. This coefficient is very important because it is employed in the analysis of engineering problems. The value of the coefficient of restitution indicates the degree of elasticity or plasticity in an impact. If the value of e equal to 1, it indicates a perfectly elastic impact; while if it is 0, it implies a perfectly plastic impact. Determining these important engineering properties for the specie of tomato grown in Nigeria is important since such property is used in providing the desired cushioning (selection of padding materials)

## 4.3 IMPACT ENERGY

The results of the average impact energy computed from the data obtained are presented in Table 4.3. The result showed that for the samples of tomatoes within the mass group of 0-30g, the average impact energy from the various heights on plastic, basket and wood materials were 0.2003, 0.1461 and 0.1528 respectively. The average values for the samples (31-60g mass) were 0.3891, 0.3410 and 0.3599 respectively, while those for mass group 3 (60.1 and above) were 0.6220, 0.5636 and 0.5848 respectively.

The results showed that the impact energy is generally high for those samples dropped from height $h_5$ (160cm) irrespective of the impact surfaces as can be seen from Table 4.5. Most of the samples dropped from the height sustained cracks, which actually are points of entry into the produce by spoilage micro-organisms. It is this energy absorbed during handling that actually determines the shelf life of the produce, because the bruise resulting from this impact energy constitutes tissue damage which subsequently leads to deterioration of the produce in storage. It is also noted from the result that the greater the mass of the produce, the higher also is the impact energy, irrespective of the impact surface.

## 4.4 IMPACTS OR BRUISE AREA

The results of the bruise area computed from the experiment are presented in Table 4.4. The results showed that the values of bruise area are generally high for those samples dropped from higher heights, irrespective of the impact surface. It also showed that those for higher masses are also higher. The values of these data are important in computing the dynamic yield pressure (an equivalent of bioyield point) in fruits if the weight, the modulus of elasticity and Poisson ratio are known.

## 4.5 DISCUSSION AND OBSERVATIONS

It is observed from the results that the energy absorbed by the fruits was generally high for those dropped from higher heights and those with larger masses. This result is important because during handling, the fruits generally bounce on each other and the container, and the energy absorbed in this process constitutes the mechanical damage. This energy which can be obtained from the momentum (mv) depends on the mass of the produce. It is also important to note that the resulting force (ma) also depends on the acceleration and the mass. It is thus important to know how this energy is influenced by mass with the view to selecting appropriate velocity and acceleration when handling various masses of fruits that will result in minimal damage.

The information obtained here could help in dropping fresh riped tomatoes from heights that could cause various mechanical damage.

The results showed that cracks in the fresh produce occurred generally when the samples are dropped from a height of 100cm and above. The cracks in produce provide entry point for the spoilage micro-organisms which usually cause deterioration in form of rots. Thus the information could be used in the process of designing handling systems especially in the processing lines that will avoid dropping fruits from heights that will result in such damages.

The data obtained from the bruised area in this study could be used to determine the dynamic yield pressure (an equivalent of bioyield point) for the fruits if the modulus of elasticity and Poisson ratio are known. The knowledge of such data is important if such produce is being subjected to dead load such as the case when they are stacked during handling.

It is believed that knowing the engineering properties such as coefficient of restitution (e) obtained in this study for specific specie of produce, is important if proper solutions are to be provided to curtail the mechanical damage during handling.

The data obtained were subjected to statistical analysis to actually ascertain the effects of height, mass and impact surfaces on the values of impact energy and bruise area. The ANOVA is presented in Table 4.6. The results showed that height and mass have significant effect on the impact energy absorbed by the produce at 5% level of significance.

## TABLE 4.1: TYPES OF DAMAGE SUSTAINED BY SAMPLES OF VARIOUS MASSES DROPPED FROM DIFFERENT HEIGHTS ON TO DIFFERENT SURFACES

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SURFACE I, S1: PLASTIC | | | | | | | | | | |
| | | HEIGHT I, h1 = 30 CM | | | | | | | | | | |
| DROP | M1 | Type of damage | | | M2 | Type of damage | | | M3 | Type of damage | | |
| | | P | C | B | | P | C | B | | P | C | B |
| 1 | 16.5 | - | - | - | 43.7 | | | B | | | | B |
| 2 | 21.5 | - | - | - | 37 | - | - | - | | | | B |
| 3 | 18.4 | - | - | - | 41 | - | - | - | | - | - | - |
| 4 | 26.0 | - | - | - | 48 | | | B | | - | - | - |
| 5 | 14.5 | - | - | - | 34 | | | B | | | | B |
| | | SURFACE II, S2 BASKET | | | | | | | | | | |
| 1 | 13 | - | - | - | 39 | | | B | | | | B |
| 2 | 28 | - | - | - | 50.8 | | | B | | - | - | - |
| 3 | 21 | | | B | 35 | - | - | - | | | | B |
| 4 | 24 | - | - | - | 44 | | | B | | | | B |
| 5 | 15 | - | - | - | 38 | - | - | - | | | | B |
| | | SURFACE III, S3 WOOD | | | | | | | | | | |
| 1 | 17 | - | - | - | 56 | | | B | | | | B |
| 2 | 26 | - | - | - | 43 | | | B | | | | B |
| 3 | 15 | - | - | - | 37 | - | - | - | | - | - | - |
| 4 | 18 | - | - | - | 40 | - | - | - | | | | B |
| 5 | 23 | - | - | - | 58 | | | B | | - | - | - |
| | | HEIGHT II h2 = 70CM: S1 – PLASTIC | | | | | | | | | | |
| 1 | 20 | - | - | - | 38 | | | B | 74 | | | B |
| 2 | 18 | - | - | - | 53 | | | B | 68 | | | B |
| 3 | 16 | - | - | - | 45 | - | - | - | 71 | | | B |
| 4 | 14 | - | - | - | 36 | | | B | | | | B |
| 5 | 17 | - | - | - | 52 | | | B | | - | - | - |
| | | HEIGHT II, h2 = 70 CM: S2 – BASKET | | | | | | | | | | |
| 1 | 15 | | | B | 48 | P | | | 85 | | | B |
| 2 | 18 | - | - | - | 59 | | | B | 73 | | | B |
| 3 | 27 | - | - | - | 41 | - | - | - | 70 | | | B |
| 4 | 23 | - | - | B | 51 | | | B | 65 | | | B |
| 5 | 26 | - | - | B | 44 | | | B | 83 | | | B |
| | | HEIGHT II H2 S3 – WOOD | | | | | | | | | | |
| 1 | 13 | - | - | - | 57 | - | - | B | 72 | - | C | - |
| 2 | 24 | - | - | B | 48 | - | - | B | 84 | - | - | B |
| 3 | 26 | - | - | B | 43 | - | - | B | 71 | - | - | B |
| 4 | 16 | - | - | - | 39 | - | - | B | 68 | - | - | B |
| 5 | 14 | - | - | - | 46 | - | - | B | 72 | - | - | B |

|  |  | HEIGHT III h3 = 100 CM S1 – PLASTIC |  |  |  |  |
|---|---|---|---|---|---|---|
| 1 | 18 | - - - | 48 | - - B | 75 | - C - |
| 2 | 22 | - - - | 58 | - C - | 68 | - - B |
| 3 | 27 | - - B | 44 | - - B | 84 | - - B |
| 4 | 14 | - - - | 36 | - - B | 72 | - C - |
| 5 | 25 | - - B | 38 | - - B | 71 | - - B |
|  |  | HEIGHT III, h3, S2 - BASKET |  |  |  |  |
| 1 | 22 | - - B | 52 | - - B | 68 | - - B |
| 2 | 16 | - - - | 456 | - - B | 67 | - - B |
| 3 | 13 | - - - | 48 | - - B | 65 | - - B |
| 4 | 17 | - - B | 36 | - - B | 79 | - - B |
| 5 | 16 | - - - | 41 | - - B | 72 | - - B |
|  |  | HEIGHT III h3 S2 - WOOD |  |  |  |  |
| 1 | 14 | - - - | 59 | - - B |  | B |
| 2 | 18 | - - - | 58 | - - B |  | C |
| 3 | 23 | - - - | 46 | - - B |  |  |
| 4 | 29 | - - - | 48 | B |  | - - - |
| 5 | 13 | - - - | 36 | - C - |  | - - B |
|  |  | HEIGHT IV H4 = 130 CM S1 – PLASTIC |  |  |  |  |
| 1 | 22 | - - B | 41 | - - B | 85 | - - B |
| 2 | 16 | - C - | 46 | - - B | 72 | - C - |
| 3 | 14 | - - - | 49 | - C - | 66 | - C - |
| 4 | 18 | - - - | 38 | - C - | 74 | - - B |
| 5 | 13 | - - - | 56 | - - B | 69 | - - B |
|  |  |  |  | H4 |  | S2 – BASKET |
| 1 | 18 | - - B | 42 | - - B | 81 | - - B |
| 2 | 23 | - - B | 45 | - - B | 64 | - - B |
| 3 | 15 | - - B | 56 | - - B | 92 | - - B |
| 4 | 18 | - - B | 38 | - - B | 78 | - - B |
| 5 | 23 | - - B | 42 | - - B | 68 | - - B |
| 5 | 16 | - - B | 46 | - - B | 80 | - - B |
|  |  |  |  | H5 = 160 CM |  | S1 – PASTIC |
| 1 | 15 | P - - | 55 | - C - | 68 | - C - |
| 2 | 18 | - - B | 48 | - C - | 78 | - C - |
| 3 | 22 | - - B | 53 | - - B | 71 | - C - |
| 4 | 16 | - - B | 51 | - C - | 75 | - C - |
| 5 | 21 | - - B | 56 | - C - | 69 | - C - |
|  |  |  |  | H5 |  | S2 – BASKET |
| 1 | 23 | - - B | 38 | - - B | 70 | - - B |
| 2 | 28 | - - B | 42 | - C - | 78 | - C - |
| 3 | 14 | - - B | 52 | - - B | 81 | - - B |
| 4 | 19 | - - B | 48 | - - B | 69 | - - B |
| 5 | 21 | - - B | 37 | - - B | 75 | - - B |

|  |  |  |  |  |  | H5 |  |  |  | S3 – WOOD |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Type of damage |  |  |  | Type of damage |  |  |  | Type of damage |  |  |
| DROP | M1 | P | C | B | M2 | P | C | B | M3 | P | C | B |
| 1 | 26 | - | - | B | 40 | - | C | - | 65 | - | C | - |
| 2 | 14 | - | - | B | 43 | - | C | - | 68 | P | C | B |
| 3 | 16 | - | - | B | 33 | - | - | B | 66 | P | C | B |
| 4 | 24 | - | - | B | 42 | - | C | - | 88 | P | C | B |
| 5 | 19 | - | - | B | 38 | - | C | - | 69 | - | C | - |

**KEY**

|  |  |
|---|---|
| **P** | **Puncture** |
| **C** | **Crack** |
| **B** | **Bruise** |
| **H** | **Height of drop** |
| **S** | **Surface of impact** |

## TABLE 4.2: MEAN VALUES OF COEFFICIENT OF RESTITUTION (e) OBTAINED BY DROPPING SAMPLES FROM DIFFERENT HEIGHTS UNTO DIFFERENT SURFACES

| HEIGHTS (CM) | SURFACES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S1- PLASTIC | | | S2-BASKET | | | S3-WOOD | | |
| | M1 | M2 | M3 | M1 | M2 | M3 | M1 | M2 | M3 |
| H1 = 40 CM | 0.268 | 0.30 | 0.316 | 0.33 | 0.274 | 0 .242 | 0.298 | 0.31 | 0.248 |
| H2 = 70 CM | 0.31 | 0.316 | 0.322 | 0.382 | 0.446 | 0.454 | 0.342 | 0.36 | 0.36 |
| H3 = 100 CM | 0.374 | 0.352 | 0.344 | 0.510 | 0.468 | 0.478 | 0.338 | 0.386 | 0.412 |
| H4 = 130 CM | 0.36 | 0.416 | 0.408 | 0.522 | 0.488 | 0.564 | 0.372 | 0.432 | 0.462 |
| H5 | 0.468 | 0.45 | 0.366 | 0.542 | 0.504 | 0.464 | 0.476 | 0.486 | 0.408 |

## TABLE 4.3: AVERAGE IMPACT ENERGY ABSORBED BY THE SAMPLES DROPPED FROM DIFFERENT HEIGHTS UNTO DIFFERENT SURFACES.

| HEIGHTS (CM) | SURFACES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1- PLASTIC | | | | S2-BASKET | | | | S3-WOOD | | | |
| | M1 | M2 | M3 | AVERAGE | M1 | M2 | M3 | AVERAGE | M1 | M2 | M3 | AVERAGE |
| H1 = 40 CM | 0.072 | 0.1454 | 0.2620 | (0.1598) | 0.070 | 0.015[illegible] | 0.2838 | (0.16930 | 0.0710 | 0.1632 | 0.2478 | (0.1607) |
| H2 = 70 CM | 0.118 | 0.2772 | 0.4472 | (0.2808) | 0.1274 | 0.2672 | 0.4214 | (0.2720) | 0.1128 | 0.2788 | 0.4390 | (0.2769) |
| H3 = 100 CM | 0.179 | 0.3856 | 0.6402 | (0.4016) | 0.1222 | 0.3420 | 0.5316 | (0.3319) | 0.1688 | 0.4122 | 0.5684 | (0.3831) |
| H4 = 130 CM | 0.1836 | 0.4832 | 0. 7818 | (0.4829) | 0.1776 | 0.43[illegible] | 0.6646 | (0.4251) | 0.1716 | 0.4642 | 0.7484 | (0.4614) |
| H5 | 0.2244 | 0.6542 | 0.9788 | (0.6191) | 0.2334 | 0.5086 | 0.9164 | (0.5528) | 0.2396 | 0.4810 | 0.9204 | (0.5470) |
| AVERAGE | 0.20028) | (0.38912) | (0.6220) | (0.3888) | (0.14612) | (0.3110) | (0.56356) | (0.3502) | 0.15276 | 0.35988 | 0.58482 | (0.3658) |

**Unit of Energy absorbed is in Joules**

## TABLE 4.4: MEAN BRUISE AREAS COMPUTED BY DROPPING SAMPLES FROM DIFFERENT HEIGHTS ON TO DIFFERENT SURFACES.

| HEIGHTS (CM) | SURFACES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S1- PLASTIC | | | S2-BASKET | | | S3-WOOD | | |
| | M1 | M2 | M3 | M1 | M2 | M3 | M1 | M2 | M3 |
| H1 = 40 CM | 00 | 6 | 13.8 | 00 | 10.8 | 16.4 | 00 | 10 | 13.3 |
| H2 = 70 CM | 00 | 19.18 | 19.4 | 5.2 | 13 | 1 9.6 | 5.2 | 19.2 | 19.0 |
| H3 = 100 CM | 6 | 16.2 | 19.6 | 5.4 | 16.2 | 18.4 | 00 | 20.2 | 18.52 |
| H4 = 130 CM | 5.2 | 18.1 | 26.2 | 14 | 17.8 | 22.6 | 14 | 16.4 | 26 |
| H5 = 160 CM | 13.6 | 20.6 | 21.9 | 13.6 | 23.5 | 23.5 | 13 | 23.8 | 19 |

## TABLE 4.5 AVERAGES VALUES FOR THE SAMPLES DROPPED FROM DIFFERENT HEIGHTS

| | **Eabs** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S1 | | | S2 | | | S3 | | |
| **Height** | M1 | M2 | M3 | M1 | M2 | M3 | M1 | M2 | M3 |
| **h1** | 0.072 | 0.1454 | 0.262 | 0.07 | 0.1502. | 0.2838 | 0.071 | 0.1632 | 0.2478 |
| **Average** | 0.1598 | | | 0.168 | | | 0.1607 | | |
| | | | | | | | | | |
| **h2** | 0.118 | 0.2772 | 0.4472 | 0.1274 | 0.2672 | 0.4214 | 0.1128 | 0.2788 | 0.439 |
| **Average** | 0.2808 | | | 0.272 | | | 0.2769 | | |
| | | | | | | | | | |
| **h3** | 0.179 | 0.3856 | 0.6402 | 0.1222 | 0.342 | 0.5316 | 0.1688 | 0.4122 | 0.5684 |
| **Average** | 0.4013 | | | 0.3319 | | | 0.3831 | | |
| | | | | | | | | | |
| **h4** | 0.1836 | 0.4832 | 0.7818 | 0.1776 | 0.433 | 0.6646 | 0.1716 | 0.4642 | 0.7484 |
| **Average** | 0.4829 | | | 0.4251 | | | 0.4614 | | |
| | | | | | | | | | |
| **h5** | 0.2244 | 0.6542 | 0.9788 | 0.2334 | 0.5086 | 0.9164 | 0.2396 | 0.481 | 0.9204 |
| **Average** | 0.6191 | | | 0.5528 | | | 0.547 | | |

## 4.6. TESTS OF BETWEEN – SUBJECTS EFFECTS

Dependent Variable: Absorbed Energy Determination.

| SOURCE | Type III sum of squares | Df | Mean square | F | Sig |
|---|---|---|---|---|---|
| Model | 8.717[a] | 29 | .301 | 344.689 | .000 |
| MASS | 1.444 | 2 | .722 | 827.896 | .000 |
| HEIGHT | .903 | 4 | .226 | 258.809 | .000 |
| SURFACE | 1.146E-02 | 2 | 5.729E-03 | 6.570 | .008 |
| MASS* HEIGHT | .243 | 8 | 3.039E-02 | 34.846 | .000 |
| MASS * SURFACE | 3.570E-03 | 4 | 8.925E-04 | 1.023 | .425 |
| HEIGHT *SURFACE | 1.135E-02 | 8 | 1.419E-03 | 1.627 | .194 |
| ERROR | 1.395E-02 | 16 | 8.721E-04 | | |
| TOTAL | 8.731 | 45 | | | |

a. R Squared = .998(Adjusted R Squared .996)

**Post Hoc Tests**

**MASS**

**Homogenous Subsets**

## 4.6 CONCLUSION AND RECOMMENDATIONS.

### 4.6.1 CONCLUSION

To avoid cracks in fruits, such fruits should not be dropped from heights greater than 100cm (1m) for riped Roma variety of tomato fruits. It can therefore be concluded that average minimum energy that will result in cracks is about 0.33195 Joules for Roma VF variety.

### 4.6.2 RECOMMENDATIONS

The following recommendations are hereby made:

(i) For easy accessibility to samples of high degree of good conditions, and to ensure that the required variety is procured, the school or department should set up farms where samples for such experiments will be procured without having to travel long distances.

(ii) The department should purchase its own equipment such as electronic weighing balance to save students from the stress of looking for where to carry out weighing of samples.

(iii) A good and better impact testing machine, which should have some accessories like transducer, computer, accelerometer etc. should be purchased for the department for more accurate assessment and for comparison with the existing one.

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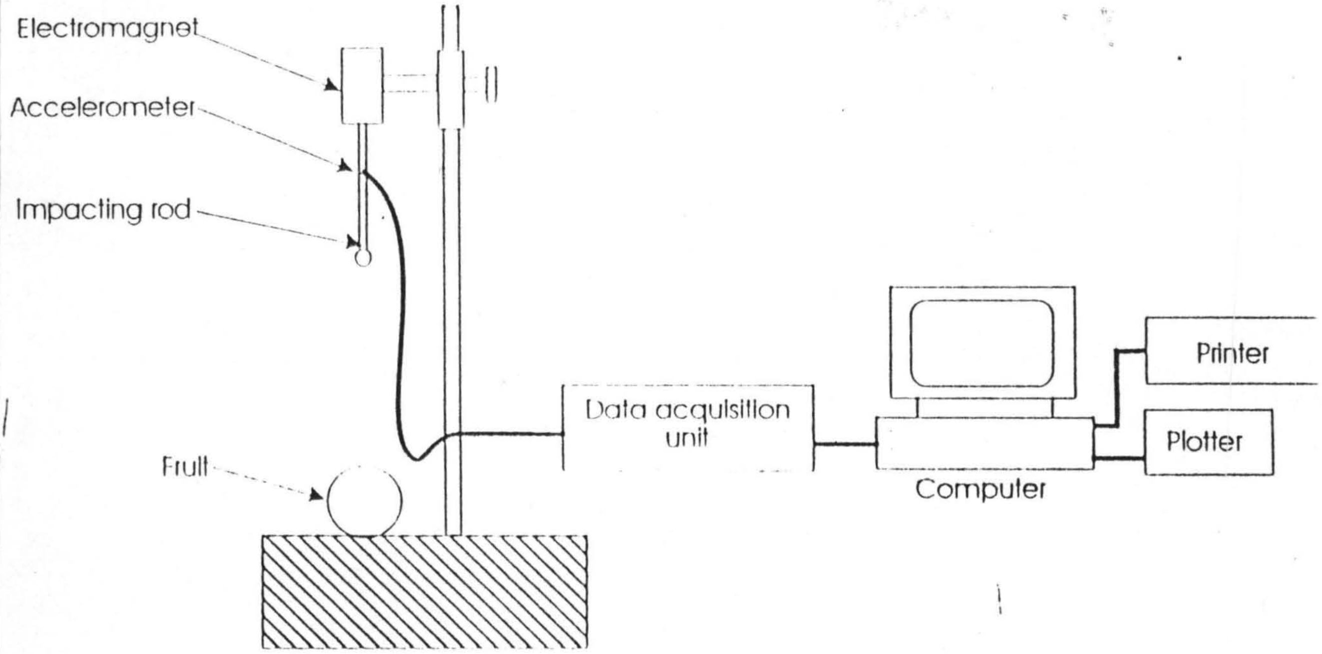
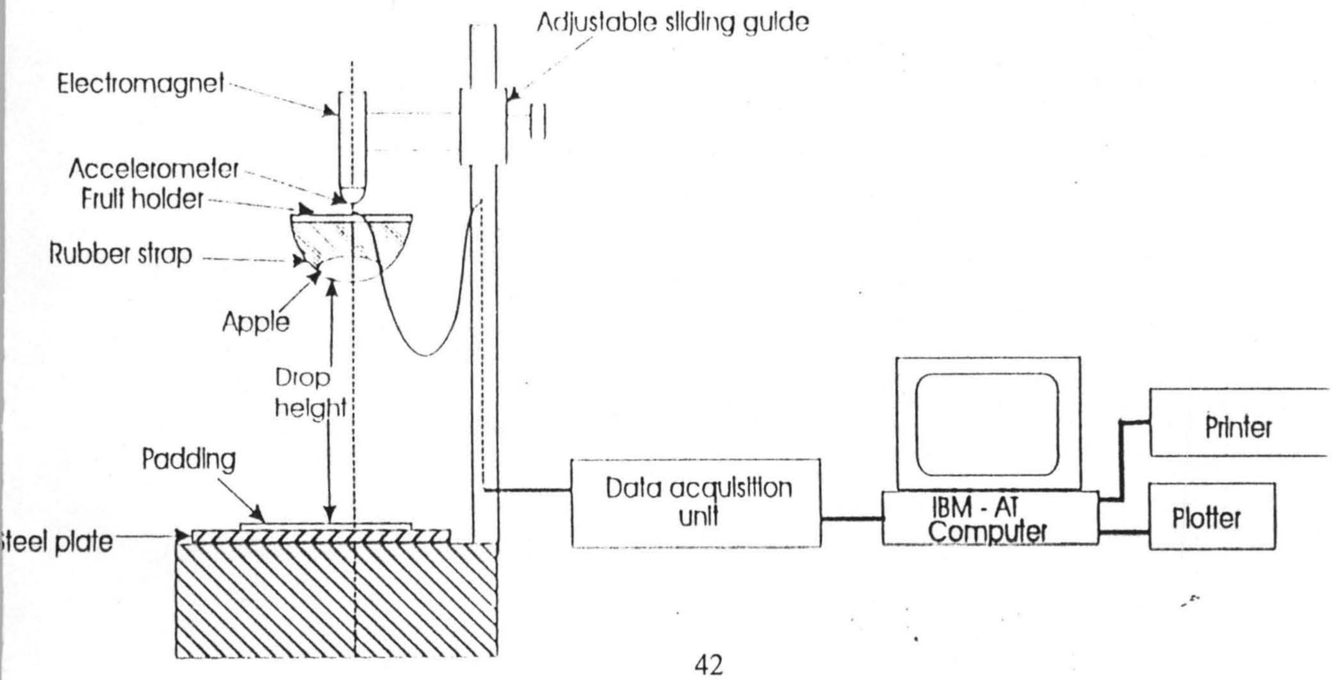
# APPENDIX I

## IMPACT TESTING DEVICES AND ASSOCIATED INSTRUMENTATION

(CHEN et al., 1985; Chen and Yazdani, 1989)



"A" Dropping Steel sphere on fruits



"B" Dropping fruit on steel plate and padding materials

# APPENDIX II

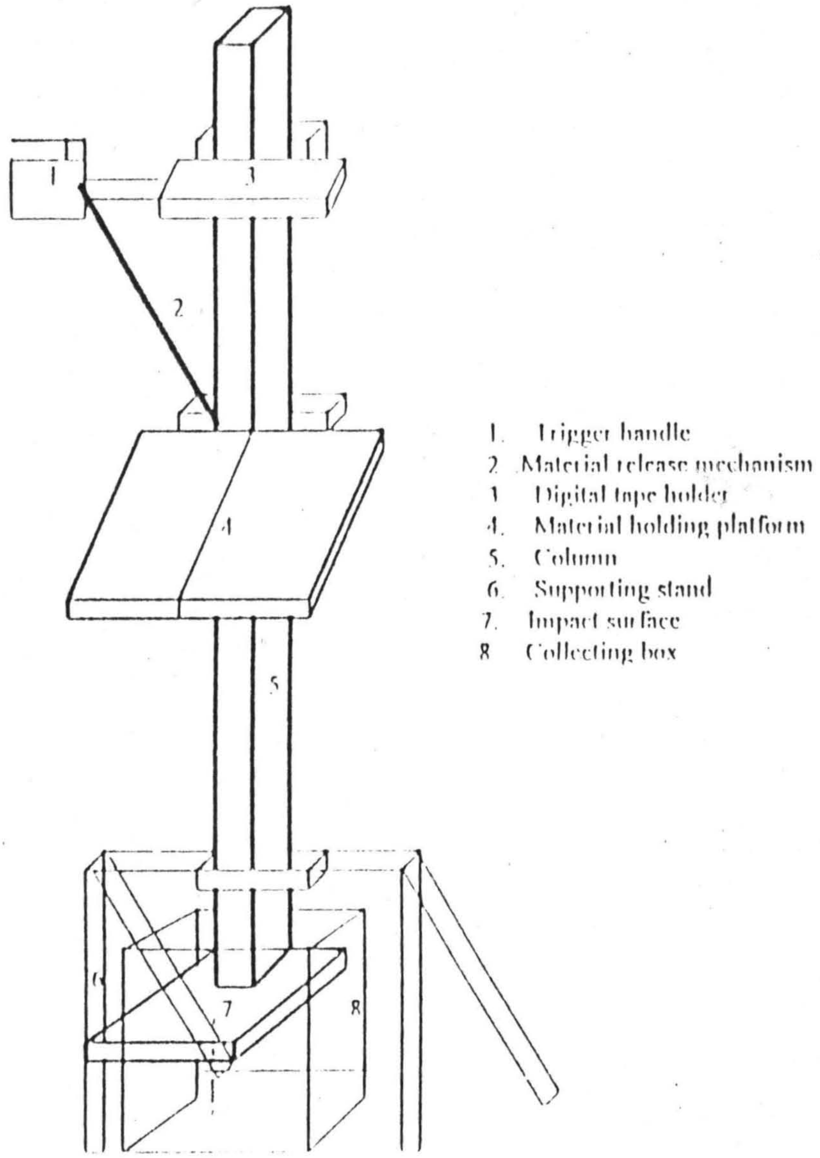


**Figure 1. Assembly Drawing of the Impact Machine**

# APPENDIX III

Plate 1: Above is a picture of red fresh tomato fruits

# APPENDIX IV

Plate 2: the picture of some cracked tomatoes after the droppings

# APPENDIX V

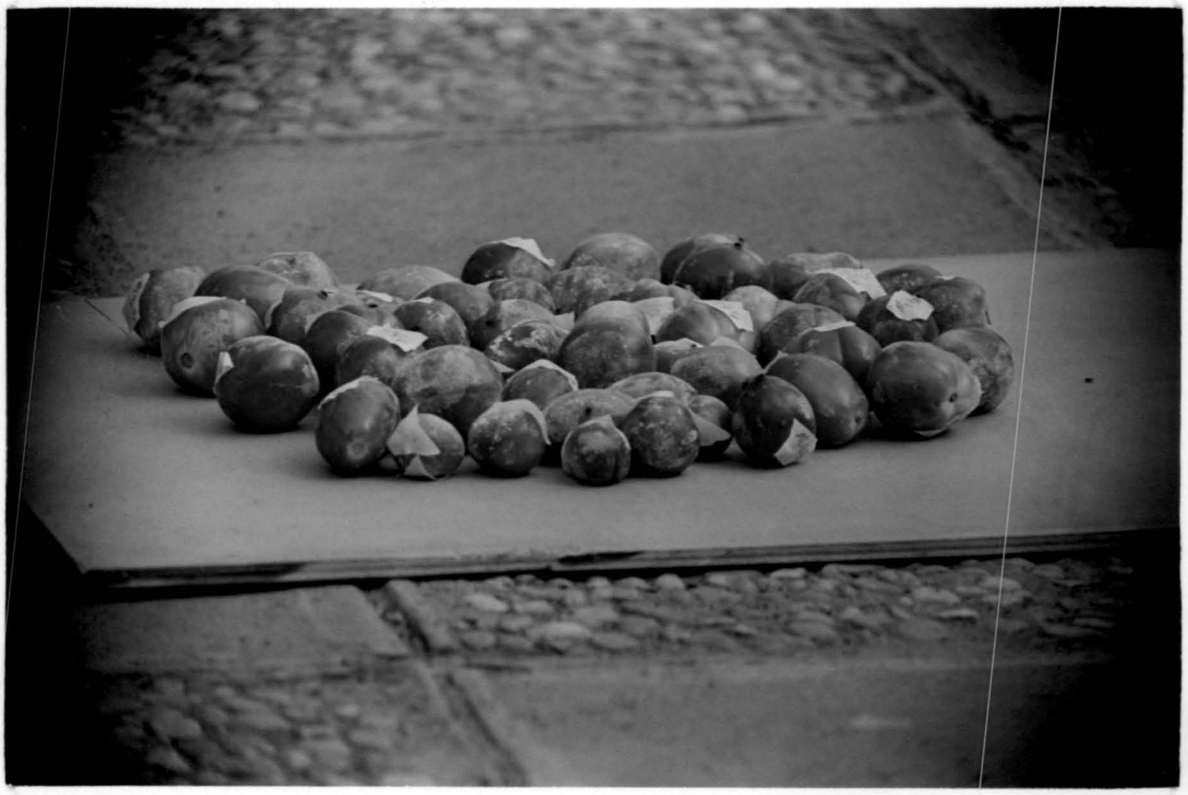


PLATE 3: The picture of some bruised tomatoes after the drops

# APPENDIX VI

PLATE 4: The picture of some student in the act of sample release during the experiment