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Impact Damage to Selected Agricultural Produce from South Eastern Nigeria.

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ABSTRACT

An Impact Test Apparatus was developed to determine the impact damage and bruise parameters of five fresh agricultural produce, namely: banana (*Musa spp*), tomato (*Lycopersicon esculentum*), sweet potato (*Ipomea batatas*), cassava tuber (*Manihot esculenta*) and lemon (*Citrus limon*) using Impact – Drop Height method. A constant impact energy of 0.9J – 4.5J was maintained as drop heights ranged from 0.20m – 1.00m. The bruise diameter, bruise depth, bruise width, bruise volume, bruise resistance and bruise susceptibility of banana ranged from 10mm – 18mm, 6mm – 8mm, 2mm – 4mm, 62.68mm^3 – 300.87mm^3, 0.014J/mm^3 – 0.015J/mm^3, 69.64mm^3/J – 73.12mm^3/J. That of tomato ranged from 10 – 26mm, 6 – 6.5mm, 2.1 – 5mm, 65.81 – 441.39mm^3, 0.015 – 0.010J/mm^3, 73.12 – 98.08mm^3/J. That of sweet potato ranged from 8mm – 16mm, 4mm – 6mm, 2mm – 6mm, 33.43mm^3 – 300.87mm^3, 0.02J/mm^3 – 0.014J/mm^3, 37.14mm^3/J – 66.86mm^3/J. That of cassava tuber ranged from 10mm – 16mm, 3mm – 8mm, 2mm – 4mm, 31.34mm^3 – 267.44mm^3, 0.03J/mm^3 – 0.02J/mm^3, 38.82mm^3/J – 59.43mm^3/J. While that of lemon ranged from 0mm – 7.5mm, 0mm – 4.5mm, 0mm – 5mm, 0mm^3 – 88.14mm^3, 0J/mm^3 – 0.05J/mm^3 and 0mm^3/J – 19.58mm^3/J respectively. Results indicated that bruise parameters increased with impact energy. Tomato has the highest bruise susceptibility, followed by cassava tuber, banana, sweet potato, and lemon, but lemon has the highest bruise resistance. The results would be useful to food processors and engineers in designing packages to reduce impact damage to agricultural produce.

Keywords: Impact energy, Impact damage, Bruise volume, Bruise Resistance, Bruise susceptibility.

INTRODUCTION

Fresh agricultural produce are perishable and extremely sensitive to impact damage, cracks, abrasions and bruises during harvesting, handling and transportation. All horticultural products should be handled gently to minimize bruising and breaking of the skin (Atanda et al. 2011). Fruits are susceptible to bruising when they impact each other or a hard surface during picking, packing, transportation, and retailing at stores and during other handling steps (Saracoglu et al. 2011). Impacts are short-time mechanical forces that occur during drops, knocks, and collisions and are responsible for many of the physical injuries that lower quality of fresh horticultural produce (Thomson and Lopresti, 2008). Fruit bruise cause tissue softening and make them more susceptible to undesired agents such as diseases-inducing agents (Ahmadi, 2012). Avoiding physical damage such as bruising is one the most important goals of postharvest handling (Mbuk et al. 2011), because fruit quality is adversely affected by bruise damage (Abedi and Ahmadi, 2013). Monitoring the damage during handling is key to understanding the causes of the losses and developing the means of overcoming them (Tomlins et al. 2000). According to Ortiz and Torregrosa (2014), mechanical damage to fruit is mainly caused by impacts during harvest, transport, and handling because these forces are higher in incidence and magnitude than static forces. Impact damage occurs when fruit drops onto a surface with adequate force, and when an item hits a surface with sufficient force to rupture or even separate cells. Common impact damage usually happens in free drops of fruits from trees to ground during harvesting and in dynamic impacts between single fruits and between them and packaging or containers, the external sign is a bruise or a crack (Niels et al. 1992; Li and Thomas, 2014). The factors affecting damage severity caused by impact are fruit fall height, contact energy, the number of contact, the kind of contact surface and the size and ripeness stage of the fruit (Saeed and bruises lead to physical changes in colour, flavor, taste, texture, and weight of agricultural produce with consequent loss of aesthetic appeal and nutritive values. Harvesting fruits at half ripe stage when the fruit stiffness is higher than that of ripe fruits has been suggested as a means of alleviating impact damage (Li and Thomas, 2014). Therefore, agricultural produce must be harvested at the right time because over ripen produce such as tomatoes are more susceptible to physical injury than nearly ripe ones. Reducing the amount of bruising can increase food safety by decreasing the potential for microbial infestation (Idah et al. 2007). The detrimental effect of impact damage is not restricted to visual aspects, but higher risk of bacterial and fungal contamination leading to a lower shelf-life (Van Zeebroeck et al. 2007).

Damage is the failure of the product under either excessive deformation when it is forced through fixed clearances or excessive force when it is subjected to impact (Mohsenin, 1986). Permanent damage occurs in agricultural produce as the pressures during impact exceed the dynamic yield pressure of the tissue of the produce (Mohsenin, 1986). Damage to agricultural produce can occur during the following stages: picking, placing into collection bags, baskets, boxes or bins; transport to and unloading at packinghouses or cold stores, cleaning, grading, sorting, ripening and packing, handling at wholesale market, off-loading at retail outlets, handling of packages by retailers and customers, etc. In the course of loading and offloading, fruit loads or packages are at times thrown from certain heights on to other surfaces and this result in impact damage (Idah et al. 2007). The desire to reduce impact damage to seeds, fruits and vegetables during harvesting and handling led to investigations of their impact behaviour. Therefore, the response of some agricultural produce to impact damage has been studied, such as bananas and plantains (Kajuna et al. 1997), apples (Van Zeebroeck et al. 2007; Unuigbe and Onuoha, 2013; Abedi and Ahmadi, 2013), tomatoes (Idah et al. 2007; Salamolah et al. 2010) strawberry (Saeed et al. 2013); kiwifruit (Ahmadi, 2012), peach cultivars (Niels et al. 1992), potato (Tomlins et al. 2000; Danila and Gaceu, 2011), citrus fruits (Montero et al. 2009; Ortiz and Torregrosa, 2014), table olive fruit (Saracoglu et al. 2011).

Krzysztof and Pawel (2011) reported that low impact height (a few centimeters) can cause bruises of a dynamic nature; hence there is a necessity to determine the susceptibility of fruit and vegetables to bruising. It is usual to develop a relationship between the impact energy and size of damage in the form of area or volume of damage (Salamolah et al. 2010).

The objective of this study is to measure the effects of different impact energies and drop heights on bruise parameters of agricultural produce. The aim of the study is to generate data or information which can be useful in the design and management of handling and transport devices that will reduce impact and mechanical damage to agricultural produce.

MATERIALS AND METHODS

Edible samples of banana, tomato, sweet potato, cassava tuber, and lemon were bought at Ogbete main market in Enugu, Enugu state. An Impact-Test Apparatus with a metal base was developed and used to determine bruise parameters of the samples according to the method of Unigbe and Onuoha (2013). A stainless, spherical impactor of mass 0.45kg was dropped from heights 0.20m, 0.40m, 0.60m, 0.80m and 1.00m onto the test samples on a metal surface. A hollow, cylindrical plastic pipe of diameter 0.11m was used to guide the fall of the object so that the impact was always perpendicular to the test sample. Vernier caliper was used to measure bruise width (w) and bruise diameter (d). The sample was then cut into two through the centre of the bruise with a sharp stainless steel knife to measure the bruise depth (p). The experiment was replicated four times for each produce, the mean values and standard deviations were then obtained and recorded.
Impact energy (E) was calculated as follows:

$$E = mgh \quad - \quad - \quad - \qquad (1)$$

Where: E = Impact energy (Joules)
m = mass of spherical impactor (kg)
g = acceleration due to gravity ($9.81 m/s^2$)
h = drop height (m).

The bruise volume (V) was calculated using the formula (Chonhenchob and Singh, 2004):

$$V = 1.33\ \pi \frac{dpw}{8} \quad - \quad - \quad - \quad (2)$$

Where: V = Bruise volume (mm^3); d = bruise diameter (mm), $\frac{E}{V}$ p = bruise depth (mm), w = bruise width (mm).

$$Br = \frac{V}{E} \quad - \quad - \quad - \quad (3)$$

Where: B_r = Bruise resistance (J/mm^3), E = Impact energy (J), V = bruise volume (mm^3).

Bruise susceptibility (B_s) was quantified as the ratio of bruise volume (V) to impact energy (E), that is:

$$Vs = \frac{V}{E} \quad - \quad - \quad - \quad (4)$$

Where: B_s = Bruise susceptibility (mm^3/J), V = bruise volume (mm^3), E = impact energy (J).

Data collected from the experiments were subjected to analysis of variance (ANOVA) and Duncan's Multiple Range Test mean comparison technique using SPSS version 16.0 (SPSS Inc., USA) software. Microsoft Excel 2007 (Microsoft Corp., USA) was used to plot graphs, and to perform second-order polynomial regression and correlation analysis. Results are presented in tables and figures.

RESULTS AND DISCUSSIONS

Table 1 shows the results obtained from experiments performed on the test samples using the Impact-Drop Height method. Similar method has been used to measure impact damage of citrus fruits (Ortiz and Torregrosa, 2014), fresh tomato fruits (Idah et al. 2007) and table olive fruit (Saracoglu et al. 2011).

It was observed that as drop heights increased from 0.20 -1.00m, impact energy increased from 0.90-4.50J. The bruise diameter, bruise depth, bruise width, bruise volume, bruise resistance and bruise susceptibility of banana also increased from 10mm – 18mm, 6mm – 8mm, 2mm – 4mm, 62.68mm^3 – 300.87mm^3, 0.014J/mm^3 – 0.015J/mm^3, 69.64mm^3/J – 73.12mm^3/J. That of tomato ranged from 10 – 26mm, 6 – 6.5mm, 2.1 – 5mm, 65.81 – 441.39mm^3, 0.015 – 0.010J/mm^3, 73.12 – 98.08mm^3/J within the same range of drop height and impact energy. The bruise diameter, bruise depth, bruise width, bruise volume, bruise resistance and bruise susceptibility of sweet potato ranged from 8mm – 16mm, 4mm – 6mm, 2mm – 6mm, 33.43mm^3 – 300.87mm^3, 0.02J/mm^3 – 0.014J/mm^3, 37.14mm^3/J – 66.86mm^3/J. Within the same range of drop height and impact energy, The bruise diameter, bruise depth, bruise width, bruise volume, bruise resistance and bruise susceptibility of cassava tuber ranged from 10mm – 16mm, 3mm – 8mm, 2mm – 4mm, 31.34mm^3 – 267.44mm^3, 0.03J/mm^3 – 0.02J/mm^3, 38.82mm^3/J – 59.43mm^3/J; while that of lemon ranged from 0mm – 7.5mm, 0mm – 4.5mm, 0mm – 5mm, 0mm^3 – 88.14mm^3, 0J/mm^3 – 0.05J/mm^3 and 0mm^3/J – 19.58mm^3/J respectively. Since the range of drop heights and the weight of the impacting object were the same for the test samples, the impact energy was also the same from a particular drop height for all the test samples. The bruise parameters varied because of the difference in textural strength of the test samples.

Tomato has the highest bruise susceptibility followed by cassava tuber, banana, sweet potato, and lemon, but lemon has the highest bruise resistance due to its thick exocarp and capacity to withstand impact forces. Nil bruise parameters were recorded for lemon at impact energy of 0.90 – 1.80J. Table 2 shows mean comparison of bruise parameters of the selected agricultural produce using Duncan's Multiple Range Test mean comparison technique.

The results of the experiments revealed that high impact energies produced high impact damage in the test samples. This trend is in agreement with results obtained by Ahmadi, (2012) for kiwifruits, who reported that the difference in absorbed energy between two extremes of kiwifruit curvature radius (21.8 and 34.3 mm) was 41% at the low impact energy (0.013 J) but only 27% at the high impact (0.19

J). Increase in drop height produced a corresponding increase in impact energy, this is in tandem with results obtained for tomato fruits (Idah et al. 2007), who reported that the impact energy on the fruit is greatly influenced by the drop height and the mass of fruits. Fruits dropped from a height of 140 cm absorbed the greatest energy indicating that they suffered the most impact damage. Unuigbe and Onuoha (2013) also reported that the impact damage of apples measured in terms of bruise diameter is highly influenced by the drop height. Fruits dropped from a height of 1400mm absorbed the greatest impact energies of 2.647KJ for wood, metal, plastic, foam and cardboard respectively which indicate that they suffered the most impact damage while the damaged area increased from 834.80-1,018.01mm^2, 498.82-951.27mm^2, 494.87-660.61mm^2, 326.89-460.02mm^2 and 100.30-227.00mm^2 for wooden, metallic , plastic, cardboard and foam surfaces respectively as drop heights increased from 500-1400mm. Similarly, Danila and Gaceu (2011) stated that the height of drop of potato affects bruising with greater damage when occurring at greater heights. Wood or metal surfaces do not absorb impact energy, while cushioned or padded surfaces can absorb some of the energy and reduce bruising severity. Niels et al. (1992) reported that as drop heights ranged from 5-15cm, the bruise volume of Ranger, Topaz, Glohaven and Elberta peach cultivars ranged from 0.00 – 0.040.10cm^3, 0.00 – 0.540.09cm^3, 0.00 – 0.600.65cm^3 and 0.00 – 0.740.67cm^3 respectively. The results of the experiment are also in tandem with the findings of Thomson and Lopresti (2008) who reported that severity of internal bruising of Tempest tomatoes generally increased from a bruise rating of 1 (bruise free) to 4 (heavy internal bruising, commercially important) as drop-heights increased from 10-80cm. Drops above 60 cm onto steel caused injury that was considered commercially important. Therefore, reducing impact energies will reduce impact damage to fresh agricultural produce especially during handling and transportation.

Graphical representations of results are shown from figure 1 to figure 6. Figure 1 is a graphical representation of the relationship between bruise diameter and impact energy of the selected agricultural produce, while figure 2 is a graphical representation of the relationship between bruise depth and impact energy of the selected agricultural produce. Figure 3 is a graphical representation of the relationship between bruise width and impact energy of the selected agricultural produce, while figure 4 represents of the relationship between bruise volume and impact energy of the selected agricultural produce. Figure 5 is a graphical representation of the relationship between bruise resistance and impact energy of the selected agricultural produce, while figure 6 is a graphical representation of the relationship between bruise susceptibility and impact energy of the selected agricultural produce. The results obtained from the experiments can be useful to food process engineers in designing packages using cushioning materials and designs in order to reduce impact damage to agricultural products. The results would also be of great benefit to designers of processing plants and handlers of fresh agricultural produce to reduce mechanical damage, especially those due to impact, and to ensure good quality agricultural products in Nigeria and for export purposes.

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Table 1: Bruise parameters of selected agricultural produce at various drop heights and impact energies.

Agricultural Produce	Drop height of Impactor, h (m)	Impact Energy, E (J)	Bruise diameter, d (mm)	Bruise depth, p (mm)	Bruise width, w (mm)	Bruise volume, V (mm^3)	Bruise resistance, B_s (J/mm^3)	Bruise susceptibility, B_s (mm^3/J)
Banana	0.20	0.90	10.00±0.10	6.00±0.25	2.00±0.05	62.68±1.51	0.014±0.010	69.64±0.63
	0.40	1.80	12.00±0.50	6.00±0.10	2.40±0.04	90.26±1.70	0.019±0.020	50.14±0.54
	0.60	2.70	15.00±0.35	6.80±0.14	2.80±0.01	149.18±1.56	0.018±0.011	55.25±0.30
	0.80	3.60	15.00±0.24	7.20±0.25	3.00±0.10	169.24±1.84	0.020±0.04	47.01±0.60
	1.00	4.50	18.00±0.15	8.00±0.40	4.00±0.50	300.87±1.90	0.015±0.005	66.86±0.65
Tomato	0.20	0.90	10.00±0.25	6.00±0.15	2.10±0.10	65.81±0.99	0.015±0.015	73.12±0.18
	0.40	1.80	15.00±0.20	6.00±0.12	2.50±0.08	117.53±1.25	0.015±0.145	65.29±0.15
	0.60	2.70	20.00±0.30	4.20±0.16	3.50±0.05	153.57±1.25	0.017±0.020	56.87±0.14
	0.80	3.60	24.00±0.33	6.00±0.14	4.50±0.06	338.48±1.42	0.010±0.009	94.02±0.12
	1.00	4.50	26.00±0.50	6.50±0.18	5.00±0.09	441.39±0.99	0.010±0.084	98.08±0.18
Sweet potato	0.20	0.90	8.00±0.15	4.00±0.04	2.00±0.03	33.43±0.11	0.02±0.009	37.14±0.13
	0.40	1.80	10.00±0.14	4.00±0.06	4.00±0.08	83.57±1.10	0.02±0.010	46.42±0.15
	0.60	2.70	11.50±0.12	4.50±0.10	5.00±0.10	135.16±1.51	0.019±0.008	50.05±0.12
	0.80	3.60	13.00±0.11	5.00±0.13	5.50±0.11	186.74±1.05	0.019±0.006	51.87±0.36
	1.00	4.50	16.00±0.09	6.00±0.12	6.00±0.12	300.87±1.09	0.014±0.003	66.86±0.42
Cassava tuber	0.20	0.90	10.00±0.10	3.00±0.13	2.00±0.02	31.34±0.50	0.03±0.008	38.82±0.76
	0.40	1.80	11.00±0.09	4.50±0.20	3.00±0.01	77.57±0.18	0.02±0.001	43.09±0.55
	0.60	2.70	13.00±0.03	4.00±0.08	3.50±0.09	95.06±0.37	0.03±0.012	35.20±0.44
	0.80	3.60	14.00±0.05	5.0±0.06	3.50±0.12	127.97±0.11	0.03±0.018	35.54±0.29
	1.00	4.50	16.00±0.07	8.00±0.09	4.00±0.06	267.44±0.19	0.02±0.006	59.43±0.13
Lemon	0.20	0.90	-	-	-	-	-	-
	0.40	1.80	-	-	-	-	-	-
	0.60	2.70	4.00±0.05	2.00±0.01	2.50±0.02	10.44±1.69	0.07±0.003	3.86±0.10
	0.80	3.60	6.0±0.38	3.5±0.05	4.0±0.07	43.87±1.34	0.08±0.001	12.18±1.03
	1.00	4.50	7.5±0.12	4.5±0.10	5.0±0.14	88.14±1.56	0.05±0.001	19.58±1.30

Each value is the mean of four replicates standard deviation.

Table 2: Mean comparison of bruise parameters of selected agricultural produce.

Agricultural produce	Bruise diameter, d (mm)	Bruise depth, p (mm)	Bruise width, w (mm)	Bruise volume, V (mm^3)	Bruise resistance, B_s (J/mm^3)	Bruise susceptibility, B_s (mm^3/J)
Banana	14.00 ± 3.08^{bc}	6.80 ± 0.85^{c}	2.84 ± 0.75^{a}	154.45 ± 92.50^{ab}	0.0172 ± 0.003^{ab}	57.780 ± 10.05^{b}
Tomato	19.00 ± 6.56^{c}	5.74 ± 0.89^{bc}	3.52 ± 1.24^{a}	223.36 ± 159.44^{b}	0.0134 ± 0.003^{a}	77.476 ± 17.96^{c}
Sweet potato	11.70 ± 3.03^{b}	4.70 ± 0.84^{ab}	4.50 ± 1.58^{a}	147.95 ± 102.85^{ab}	0.0184 ± 0.003^{ab}	50.468 ± 10.78^{b}
Cassava tuber	12.80 ± 2.34^{b}	4.90 ± 1.88^{ab}	3.20 ± 0.76^{a}	119.88 ± 89.56^{b}	0.0260 ± 0.006^{b}	42.416 ± 10.03^{b}
Lemon	5.83 ± 1.76^{a}	3.33 ± 1.26^{a}	3.83 ± 1.26^{a}	47.48 ± 39.98^{a}	0.0667 ± 0.015^{c}	11.873 ± 7.86^{a}

Means and standard deviations in columns with the same superscript are not significantly different at $P<0.05$.

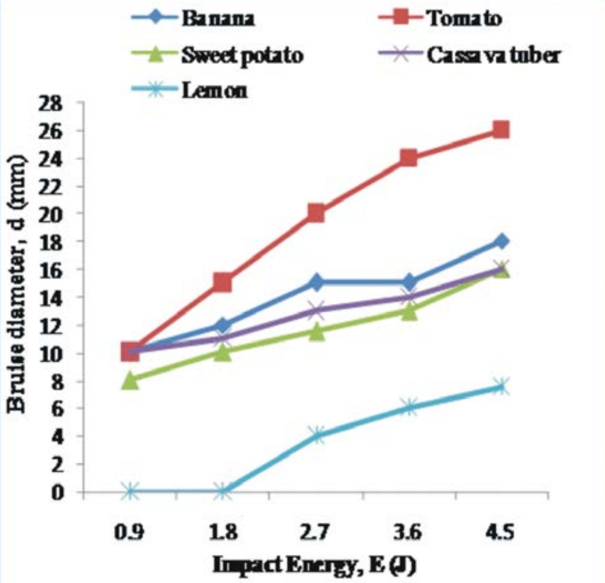

Fig.1: Graphical represenation of bruise diameter and impact energy of selected agricultural produce.

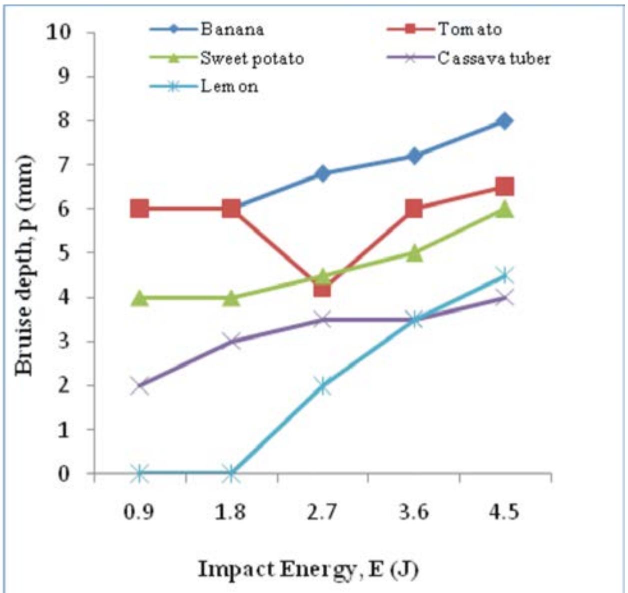

Fig.2: Graphical representation of bruise depth and impact energy of selected agricultural produce.

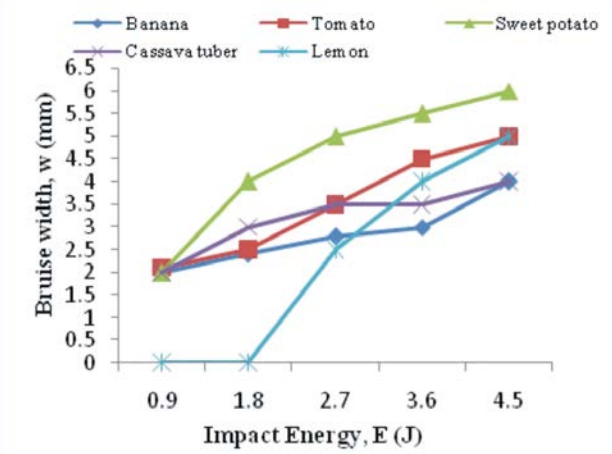

Fig.3: Graphical representation of bruise width and impact energy of selected agricultural produce.

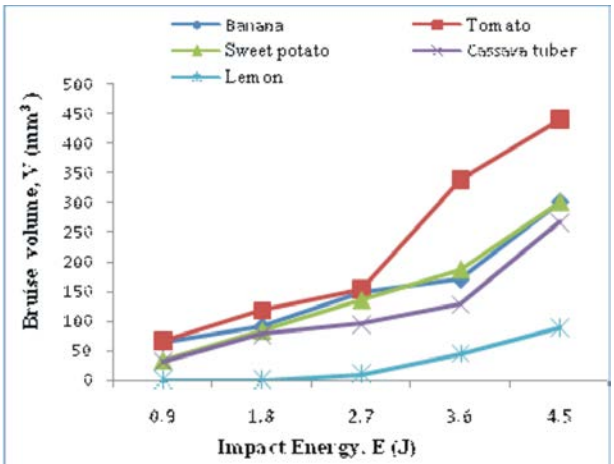

Fig.4: Graphical representation of bruise volume and impact energy of selected agricultural produce.

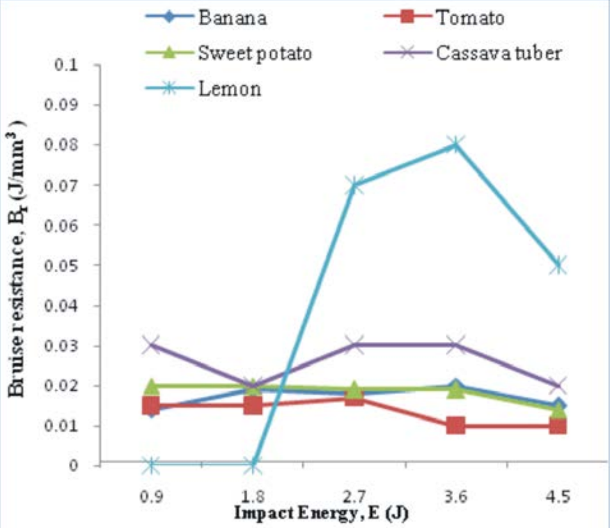

Fig.5: Graphical representation of bruise resistance and impact energy of selected agricultural produce.

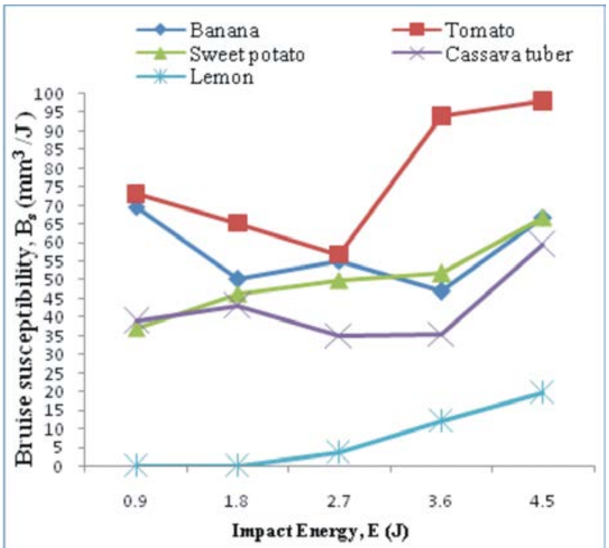

Fig. 6: Graphical representation of bruise susceptibility and impact energy of selected agricultural produce.

The relationships between impact energy and bruise parameters of the selected agricultural produce are shown in Table 3 through to Table 8 using second-order polynomial regression analysis.

As shown in Table 3, lemon has the least coefficient of determination (R^2) while cassava tuber has the highest value. This shows that there is a stronger relationship between impact energy and bruise diameter of cassava tubers more than other test samples. High correlation exists between impact energy and bruise diameter of all the test samples at 5% level of significance ($P < 0.05$). As shown in Table 4, tomato has the least coefficient of determination (R^2) while sweet potato has the highest value. Table 4 also indicates that a stronger relationship exists between impact energy and bruise depth of sweet potato than the other test samples. No correlation was recorded for impact energy and bruise depth of tomato and cassava tuber, high correlation however exists between impact energy and the bruise depth of the other test samples at 5% level of significance ($P < 0.05$).

Table 3: Relationship between impact energy (E) and bruise diameter (d) of selected agricultural produce.

Agricultural produce	Regression model	R^2	Remark
Tomato	$d = -0.5E^2 + 7.1E + 3.2$	0.997	High correlation
Banana	$d = -0.071E^2 + 2.328E + 7.8$	0.951	High correlation
Sweet potato	$d = 0.142E^2 + 1.042E + 7.0$	0.988	High correlation
Cassava tuber	$d = 0.071E^2 + 1.071E + 8.8$	0.990	High correlation
Lemon	$0.071E^2 + 1.671E + 2.3$	0.939	High correlation

Table 4: Relationship between impact energy (E) and bruise depth (p) of selected agricultural produce.

Agricultural produce	Regression model	R^2	Remark
Tomato	$p = 0.328E^2 - 1.871E + 7.74$	0.511	No correlation
Banana	$p = 0.085E^2 + 0.005E + 5.84$	0.974	High correlation
Sweet potato	$p = 0.142E^2 - 0.357E + 4.2$	0.994	High correlation
Cassava tuber	$p = 0.321E^2 - 0.878E + 4.0$	0.878	No correlation
Lemon	$p = 0.107E^2 + 0.607E - 1.0$	0.956	High correlation

As shown in Table 5, lemon has the lowest coefficient of determination (R^2) while sweet potato has the highest value. This shows that there is a stronger relationship between impact energy and bruise width of sweet potatoes than the other test samples. There is a high correlation between impact energy and bruise width of all the test samples. Table 6 indicates that cassava tuber has the lowest coefficient of determination (R^2) while lemon has the highest value. A stronger relationship therefore exists between impact energy and bruise volume of lemon than the other test samples. There is high correlation between impact energy and bruise volume of all the test samples at 5% level of significance ($P < 0.05$). Table 7 shows that cassava tuber has the lowest coefficient of determination (R^2) while sweet potato has the highest value. This shows that there is a stronger relationship between impact energy and bruise resistance of sweet potatoes than the other test samples. No correlation was observed between impact energy and bruise resistance of tomato, banana, cassava tuber and lemon; high correlation however exists between impact energy and bruise resistance of sweet potato at 5% level of significance ($P < 0.05$). Table 8 reveals that cassava tuber has the lowest coefficient of determination (R^2) while lemon has the highest value. This shows that there is a stronger relationship between impact energy and bruise susceptibility of lemon than the other test samples. No correlation was recorded between impact energy and bruise susceptibility of tomato, banana and cassava tuber, while high correlation exists between impact energy and bruise susceptibility of sweet potato and lemon at 5% level of significance (P < 0.05) respectively.

Table 5: Relationship between impact energy (E) and bruise width (w) of selected agricultural produce.

Agricultural produce	Regression model	R^2	Remark
Tomato	$w = 0.014E^2 + 0.694E + 1.28$	0.980	High correlation
Banana	$w = 0.071E^2 + 0.031E + 1.96$	0.962	High correlation
Sweet potato	$w = -0.25E^2 +2.45e - 0.1$	0.990	High correlation
Cassava tuber	$w = -0.107E^2 + 1.092E + 1.1$	0.950	High correlation
Lemon	$w = 0.071E^2 + 0.971E - 1.4$	0.945	High correlation

Table 6: Relationship between impact energy (E) and bruise volume (V) of selected agricultural produce.

Agricultural produce	Regression model	R^2	Remark
Tomato	$V = 17.94E^2 - 10.46E + 57.34$	0.973	High correlation
Banana	$V = 12.08E^2 - 16.99E + 72.45$	0.960	High correlation
Sweet potato	$V = 9.140E^2 + 8.960E + 20.52$	0.989	High correlation
Cassava tuber	$V = 14.42E^2 - 34.26E + 64.04$	0.942	High correlation
Lemon	$V = 7.966E^2 - 25.78E + 18.21$	0.998	High correlation

Table 7: Relationship between impact energy (E) and bruise resistance (B_r) of selected agricultural produce.

Agricultural produce	Regression model	R^2	Remark
Tomato	$Br = -0.000E^2 + 0.002E + 0.013$	0.686	No correlation
Banana	$Br = -0.001E^2 + 0.007E + 0.007$	0.803	No correlation
Sweet potato	$Br = -0.000E^2 + 0.002E + 0.017$	0.900	High correlation
Cassava tuber	$Br = -0.000E^2 + 0.003E + 0.024$	0.142	No correlation
Lemon	$Br = -0.008E^2 + 0.069E - 0.074$	0.736	No correlation

Table 8: Relationship between impact energy (E) and bruise susceptibility (B_s) of selected agricultural produce.

Agricultural produce	Regression model	R2	Remark
Tomato	B s = 4.953E2 - 21.85 + 88.55	0.745	No correlation
Banana	Bs = 4.667E2 - 28.87E + 93.06	0.774	No correlation
Sweet potato	Bs = 0.686E2 + 2.370E + 35.80	0.920	High correlation
Cassava tuber	Bs = 3.390E2 - 16.97E + 56.05	0.682	No correlation
Lemon	Bs = 1.375E2 - 3.120E + 1.352	0.990	High correlation

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CONCLUSION

In conclusion, this study reveals that increase in drop heights and impact energies of agricultural produce increases their bruise parameters. Agricultural produce with thick exocarp like lemon (*Citrus limon*) are less susceptible to impact damage than others like tomatoes ((*Lycopersicon esculentum*) with thin and filmy exocarp. Farmers and other handlers of agricultural produce are expected to consider the bruise susceptibility and bruise resistance of agricultural produce during handling, transportation and processing.

RECOMMENDATION

It is recommended that other methods should be used to determine, measure and compare the impact damage to different agricultural produce under different conditions. It is also recommended that Impact Test Apparatus be constructed with replaceable bases such as wood, metal, foam, cardboard, plastic, etc to conduct further experiments and to obtain wider results for the produce. The results would be useful in designing machines to eliminate impact damage to agricultural produce especially during handling, transportation, storage and processing.

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