



Science

EFFECT OF STORAGE DURATION ON MECHANICAL PROPERTIES OF BELLO EGGPLANT FRUIT UNDER QUASI COMPRESSION LOADING

Umurhurhu Benjamin¹, Uguru Hilary^{*2}

¹ Department of Mechanical Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria.

^{*2} Department of Agricultural and Bio-environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria

Abstract

The mechanical properties of eggplant fruit (cv. Bello) harvested at physiological maturity stage were evaluated in three storage periods (3d, 6d and 9d). These mechanical parameters (rupture force, rupture energy and deformation at rupture point) were measured under quasi compression loading, using the Universal Testing Machine (Testometric model). The fruit's toughness and rupture power were calculated from the data obtained from the rupture energy and deformation at rupture point. Results obtained showed that mechanical properties of the Bello eggplant fruit exhibited strong dependence on the storage period. The results showed that as the Bello fruit stored longer, its rupture force and rupture energy decreased from 812 N to 411 N, and 5.58 Nm to 3.11 Nm respectively. While the rupture power decreased from 1.095 W to 0.353 W. On the contrary, the toughness and deformation at rupture increased from 0.270 mJ/mm³ to 0.403 mJ/mm³, and 16.99 mm to 25.22mm respectively during the 9 days storage period. The knowledge of the mechanical properties of fruits is important for their harvest and post-harvest operations, therefore, information obtained from this study will be useful in the design and development of machines for the mechanization of eggplant production.

Keywords: Compression Loading; Bello Eggplant Fruit; Rupture Force; Toughness; Power.

Nomenclature

L	Length (mm)	T	Thickness (mm)
W=	Width (mm)	T _o	Toughness (mJ/mm ³)
E =	Rupture energy absorbed (Nm)	V	Volume (mm ³)
P =	Power (W)	S	loading rate (mm/min)
D	deformation at rupture point (mm)		

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1. Introduction

Eggplant (*Solanum aethiopicum* L.) is one of the indigenous crops planted in Africa countries. The consumption of eggplant is steadily increasing because of greater awareness of the health beneficial effects associated with increased consumption of fruits and vegetables (Singh *et al.*, 2009). Eggplant's fruits and leaves are highly valued constituents of the Nigerian foods and indigenous medicines; and are commonly consumed almost on daily basis by both rural and urban families (Tindal, 1965). The fruits are either eaten raw or fried as ingredient of soups and vegetable sauces. There are several varieties of African eggplant, displaying different traits like corolla diameter, petiole length, leaf blade width, plant branching, fruit shape and colour (Osei *et al.*, 2010). The consumption of eggplant is steadily increasing because of greater awareness of the health beneficial effects associated with increased consumption of fruits and vegetables (Singh *et al.*, 2009). The pharmacological properties of eggplant had been attributed to the presence of certain chemical substances, such as, fiber, ascorbic acid, phenols, anthocyanin, glycoalkaloids and α -chaconine in the plant (Alozie *et al.*, 1978; Sanchez-Mata *et al.*, 2010; Chinedu *et al.*, 2011). When compared to other fruits, eggplant fruit has relatively high carbohydrate (7.2 g/100g), crude fibres (2.0 g/100g), calcium (28 mg/100g), iron (1.5 mg/100), carotene (0.35 mg/100g) and ascorbic acid (8 mg/100g) content (Hornal *et al.*, 2007; Msogoya *et al.*, 2014).

During post-harvest operations, eggplant fruit experienced two major forces, namely; compression and puncture forces. Mechanical damage are unpleasant for both fresh fruits and vegetables, as it cause both immediate and subsequent physiological responses in wounded and adjacent tissues, leading to complex physiological, metabolic, and enzymatic changes (Pérez-López *et al.*, 2014). This increased the respiration at the injured sites, excessive tissue softening, browning of the tissue, wilting, discoloration, development of off-flavor, texture breakdown and, as a consequence, decreasing the visual appearance aspects, their commercial value, and the quality of final products (Allende *et al.*, 2004; Hu *et al.*, 2010; Li *et al.*, 2010). Therefore, the knowledge of the mechanical properties of agricultural materials can decrease the effects of unwanted mechanical loading, quantity of mass wastage and energy consumption during processing operation like peeling and milling operations (Emadi *et al.*, 2005). The mechanical behaviours of agricultural materials are dependent on the histological, anatomical, and biochemical specifications of their living cells (Varela *et al.*, 2007). In addition, since agricultural materials structure are heterogeneous structure and are frequently anisotropic, mechanical stresses are distributed inhomogeneous within their tissue (Dan and Kohyama, 2007; Li *et al.*, 2013).

There were several researches focusing on the mechanical properties of fruits as a function of loading orientation, maturity stage and storage period. Eboibi and Uguru, (2017) studied the effects of storage conditions and fruit region on the physic-mechanical properties of *Nandini* cucumber fruit. They reported that the failure strength, compressive strength, compressive energy and Young modulus of cucumber fruits stored at ambient condition declined by 53.86, 54.01, 65.35 and 47.92 % respectively within nine storage days. Some physico-mechanical properties of *Santa Maria* pear cultivar were studied by Ozturk *et al.*, (2009), and their result gives the bulk density, rupture force and fruit hardness as 365.84kgm^{-3} ; 23.04 N and 9.87 N/mm. Tabatabaekolour, (2014) reported that

kiwifruit firmness declined by 59 % when stored at ambient condition and 51 % at cold conditions for 16 days. According to (Singh and Reddy, 2006) increasing storage duration of orange fruit, the force and energy needed to cut the orange fruit decreases; while Arendse *et al.*, (2014) reported 53.56 % decreased in the toughness of pomegranate fruits stored for 5 months in cold storage. Masoudi *et al.*, (2007) recorded 66.57 % drop in the toughness of *Golden Delicious* apple cultivar stored for six months at ambient condition. According to Ashtiani *et al.*, (2016) the rupture force and Young's modulus of eggplant cv. Siah-e-Mashhad fruit decreased monotonically with the increasing of storage time. Salvador *et al.*, (2007) studied the changes in color and texture of banana during storage at 10 °C and 20 °C, and reported that during storage, the peel colour change (from green to yellow) was gradual in the *M. Cavendish* samples, whereas the *M. Paradisiacal* variety remained green for the first 8 days and then changing rapidly to a yellow from day 12 onwards.

From literature review so far, information related to the effect of storage period on mechanical properties of locally cultivated eggplant fruit is lacking. Therefore, the specific objectives of this study were to: (1) measure the mechanical properties (rupture force, rupture energy, deformation at rupture point, toughness and rupture power) of *Bello* eggplant fruit under compression test; and (2) evaluate the effect of storage time on the mechanical properties of *Bello* eggplant fruit.

2. Materials and Methods

2.1. Collection and Sampling

The *Bello* eggplant fruits used for this research were harvested from the research farm of Delta State Polytechnic, Ozoro, Nigeria, at full maturity stage (Figure 1). The harvested eggplant fruits were selected on the basis of uniformity of size and shape, washed with chlorine solution (concentration of 100 parts per million) to eliminate microbial growth and other infections during storage (Eboibi and Uguru, 2017). The washed and dried *Bello* fruits were packed in woven basket and stored at ambient temperature of $24^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and 65 -75 % humidity for 9 days. The mechanical properties of the *Bello* fruits were determined at intervals of three days (0, 3, 6 and 9 d).



Figure 1: *Bello* eggplant fruit

2.2. Mechanical Properties Determination

The mechanical test of the *Bello* eggplant fruit was done using a Universal Testing Machine (Testometric model), equipped with a 500 N loading cell and integrator. During the test, each fruit

sample was placed under the compression tool of the machine, ensuring that it was in alignment with the tool, and compressed at a loading rate of 20 mm/min (Eboibi and Uguru, 2017). The compression (loading) continued until the fruit ruptured, when the compression stopped automatically. During the compression, a load-deformation curve was plotted by the micro-processor of the machine in relation to the response of the *Bello* fruit to the compression (Eboibi and Uguru, 2017). The following mechanical parameters were calculated by the machine read from the screen.

- 1) Rupture force
- 2) Rupture energy
- 3) Deformation at rupture point

Bello eggplant fruit like other agricultural materials has complex biomechanical systems and cannot be characterized by simple constants (Mohsenin, 1986), therefore, it is necessary to introduce some new concepts such as failure and rupture points (Nyorere and Uguru, 2018; Uguru and Iweka, 2019). According to Steffe, (1996) bioyield point (also expressed as the failure point) is related to a failure in the microstructure of the material associated with an initial disruption of cellular structure; and the rupture point of the material, correlates to the macroscopic failure (breaking point) in the sample, the failure strength was taken as the stress at which the sample failed in its internal cellular structure (Steffe, 1996; Eboibi and Uguru, 2017). The test was replicated ten times and the mean value of each parameter was recorded.

Toughness of the *Bello* eggplant fruit was calculated as the energy absorbed by fruit up to the rupture point as shown in Equation 1 (Olaniyan and Oje, 2002). The rupture power required to rupture the *Bello* fruit was calculated by using equation 2; while the volume (V) of the fruit was calculated using equation 3 (Khazaei *et al.*, 2002).

$$T_o = \frac{E}{V} \quad (1)$$

$$P = \left(\frac{E \times S}{6000D} \right) \quad (2)$$

$$V = \frac{\pi \times L \times W \times T}{6} \quad (3)$$

2.3. Statistical Analysis

All data obtained from this study were subjected to statistical analysis using the using the Statistical Package for Social Statistics (SPSS version 20.0) and Duncan's Multiple Range Test (DMRT) was used to compare the mean at 95 % confidence level.

3. Results and Discussions

Analysis of variance (ANOVA) result of the data obtained from this study showed that for the storage duration had significant effect ($P \leq 0.05$) of all the mechanical parameters investigated (Table 1). The plots (charts) of the results of the mechanical test of the *Bello* fruit are presented in Figures 2 to 6. From the plots, it can be clearly seen that the all parameters investigated, except

deformation at rupture point and toughness, decreased monotonically with the increasing of storage time.

Table 1: ANOVA result of the effect of storage period on the mechanical properties of *Bello* fruit

Parameter	df	Sig
Rupture force	3	5.11E-06*
Rupture energy	3	1.09E-08*
Deformation at rupture	3	3.95E-07*
Toughness	3	0.000341*
Power	3	4.52E-10*

* =Significant at $P \leq 0.05$

3.1. Rupture Force

As shown in Figure 2, the storage period had significant effect on the fruit rupture force. The rupture force decreased significantly ($P \leq 0.05$) with increasing storage duration from 0 d to 6 d, but further increase in storage duration (from 6 d to 9 d) had no significantly effect on the rupture force. The maximum and minimum values of the *Bello* fruit rupture force were 812 N and 411 N, obtained at the harvest day and 9 days of storage respectively. In similar trend, Singh and Reddy, (2006) reported that increasing storage duration of orange fruit, the force and energy needed to cut fruit decreased. Rupture force of fruits is an essential parameter in the design and development of their crushing and other processing machines.

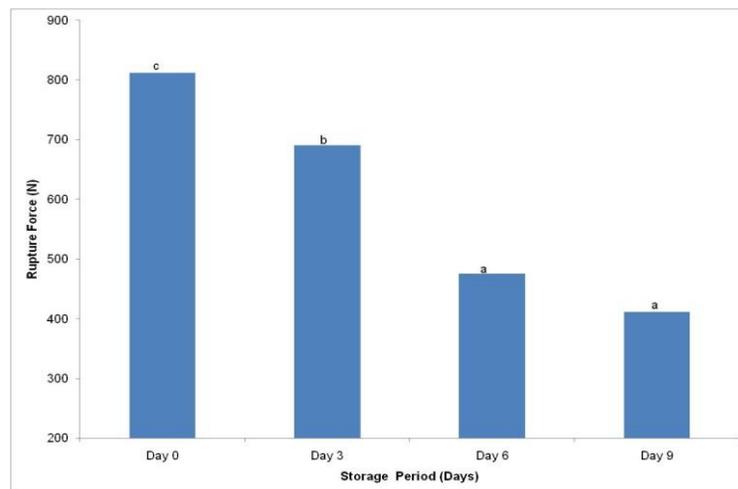


Figure 2: Effects of storage duration on the rupture force of *Bello* eggplant fruit. Columns with the same common letters means that they are not significant different at ($P \leq 0.05$).

3.2. Rupture Energy and Power

The plot in Figures 3 and 4 showed the rupture energy and power of *Bello* eggplant. The charts showed that rupture energy and power of the *Bello* eggplant fruit, decreased with increase in storage duration for 0d to 9d. The declined in the rupture energy of the *Bello* fruit during storage could be attributed to increase of evaporation, transpiration and metabolic activity of fruits during storage at ambient temperature, which will be made the fruit texture softer due to the cellular water

loss and disintegration the cell wall structure composition (Brusewitz *et al.*, 1989). It is clear from Figures 3 and 4 that with increasing storage duration from 0 d to 9 d, the rupture energy and power decreased significantly ($P \leq 0.05$) from 5.58 Nm to 3.11 Nm (46.75 decrease); while the power decreased significantly ($P \leq 0.05$) from 1.095 W to 0.353 W (76.6% decrease).. These results indicated that the rigidity of the cellular structures of the *Bello* fruit diminished over 9 days of storage due to loss of moisture through transpiration and enzymatic changes and thus the fruit structure became softer as storage duration progresses (Cen *et al.*, 2013). Similar results were recorded by Jahangiri *et al.*, (2016) for *Viola cucumber*fruit, where the failure stress value decreased significantly ($P < 0.01$) from 0.85 MPa to 0.53 MPa during nine storage days. Yurtlu and Erdogan, (2005) reported that the apple and pear tissue strength decreased during storage duration due to decrease in the thickness of cell wall. Masoudi *et al.* (2007) in their study recorded decreased in the modulus of elasticity, failure stress and failure energy of apples with increasing storage duration

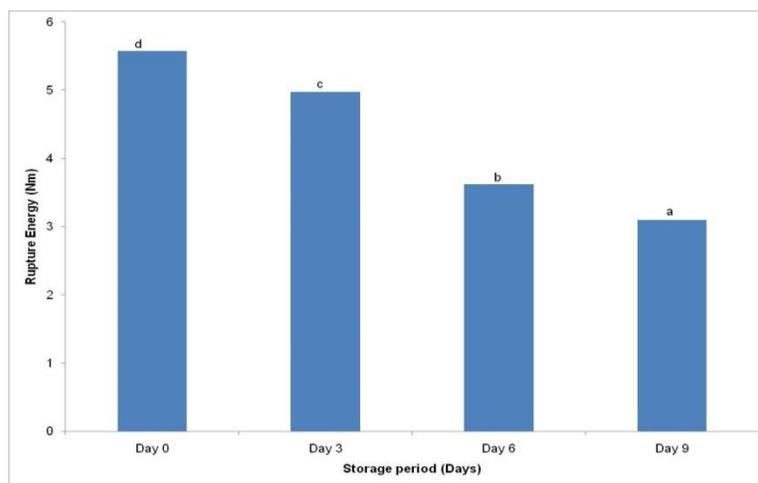


Figure 3: Effects of storage duration on the rupture energy of *Bello* eggplant fruit
Columns with the same common letters means that they are not significant different at ($P \leq 0.05$).

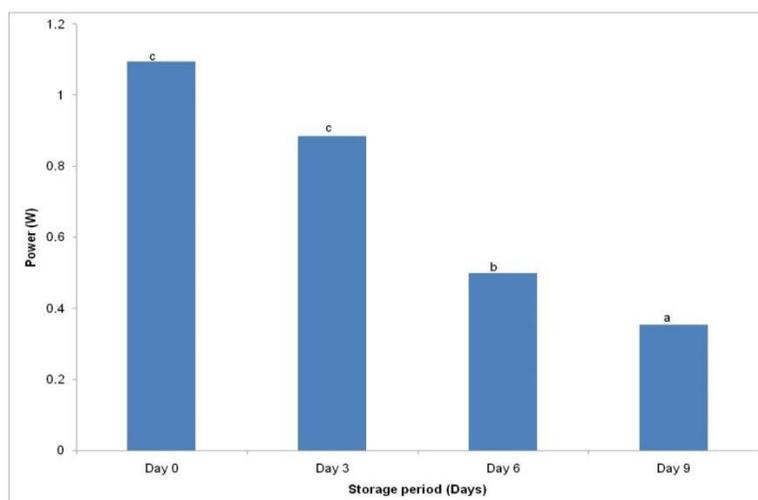


Figure 4: Effects of storage duration on the rupture power of *Bello* eggplant fruit
Columns with the same common letters means that they are not significant different at ($P \leq 0.05$).

3.3. Deformation at Rupture Point

Figure 5 showed the variation in the deformation of *Bello* fruit at rupture point during storage period. As seen in the chart in Figure 5, the deformation of the *Bello* fruit increased with increased in storage period. The deformation increased from 16.99 mm to 25.22mm within the 9 days storage period. This may be attributed to the declined in the rigidity of the cellular structure of the *Bello* fruit. Similar results were recorded by Ashtiani *et al.*, (2016) for *Siah-e-Mashhad* eggplant fruit, where the deformation increased from 11.42 to 14.82 mm within 9 storage days. According to Zdunek *et al.*, (2010) during storage the maximum force needed to rupture fruits decreased, but its position on the force–displacement curve increased, therefore the stress decreased and the strain increased by time passing. The decrease in stiffness of the tissue by the effect of the storage time depends largely on the extent to which the structural changes occur in the cell wall constituents (Pérez-López *et al.*, 2014). The maturity stage of the fruit at harvest time, due to its influence on the speed at which occurs the loss in the form of parenchyma cells that give overall rigidity to the tissue (Kays and Paull, 2004; Redgwell and Fischer, 2002).

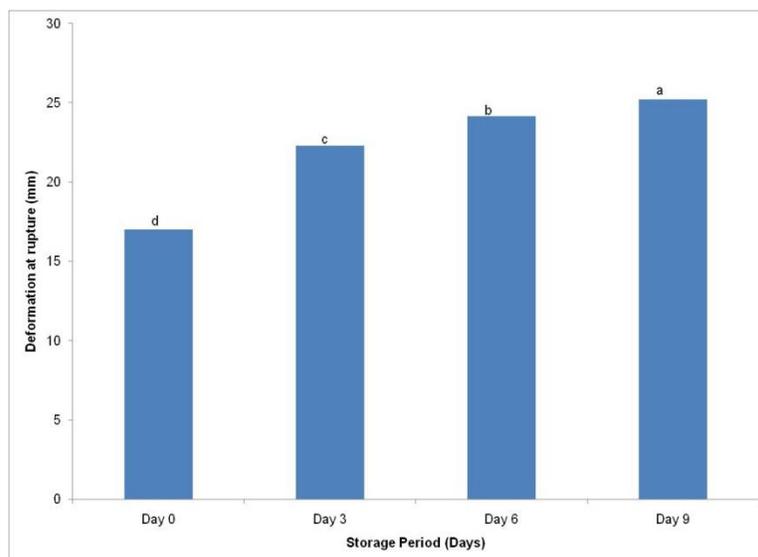


Figure 5: Effects of storage duration on the deformation at rupture of *Bello* eggplant fruit. Columns with the same common letters means that they are not significant different at ($P \leq 0.05$).

3.4. Fruit Toughness

The chart presented in Figure 6 showed that storage period had significant effect ($P \leq 0.05$) on *Bello* fruit toughness. *Bello* fruit toughness increased significantly between 3 and 6 days of storage, however, there was no significant difference between storage 0 d and 9 d. The maximum and minimum values of *Bello* fruit toughness were 0.270 and 0.403 mJ/mm³ for 0d and 9d storage period. From the plot in Figure 6, it can be seen that toughness decreases after 6d of storage period. This could be attributed to the deterioration of the *Bello* fruits, leading to the breakdown of the fruit epicarp strength. Therefore, the inconsistency in the fruit toughness during may be attributed to weaken of the fruit epicarp after storage day 6, caused by enzymatic reactions. Apart from the increased in the firmness of the fruit epicarp during the initial storage period, another factor that could be responsible for the increased in the fruit toughness is the shrinkage in the fruit size and

mass during the storage at the high temperature. According to Fricke and Wright, (2016) small seeds usually had the highest tissue densities across all crops species; therefore, seed toughness strongly decreases as its mass increases. In a research they reported that smaller seeds had higher specific toughness (2340 times greater) than larger seeds. Similar results were recorded by Ashtiani *et al.*, (2016) for *Siah-e-Mashhad* eggplant fruit, where the fruit's pulp toughness increased from 0.113 Nm to 0.146 Nm during 9 storage days. But on the contrary Arendse *et al.*, 2014 reported 53.56 % decreased in the toughness of pomegranate fruits stored for 5 months in cold storage condition.

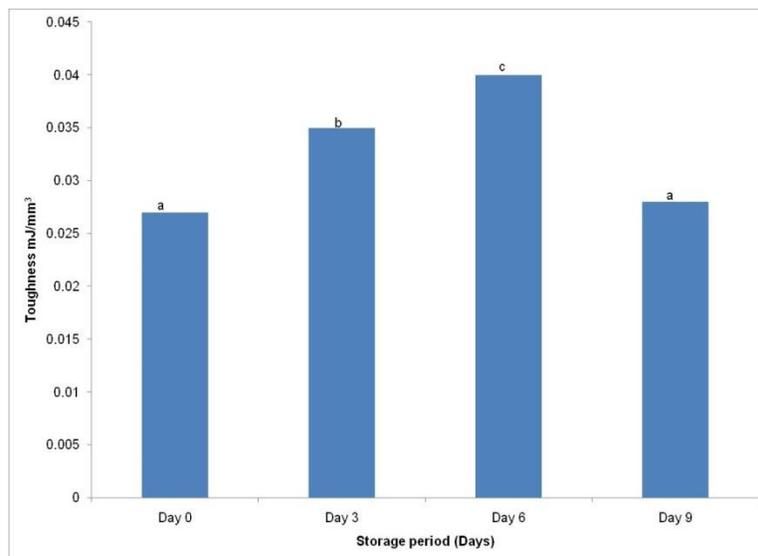


Figure 6: Effects of storage duration on the toughness of *Bello* eggplant fruit. Columns with the same common letters means that they are not significant different at ($P \leq 0.05$).

4. Conclusion

In this study, some mechanical properties of *Bello* eggplant fruit were assessed over the course of a 9-day storage period. The results obtained from the mechanical tests demonstrated that mechanical parameters of *Bello* fruit are highly dependent on storage duration. Apart from the fruit toughness and deformation at rupture, the three remaining mechanical parameters (rupture force, rupture energy and power) decreased monotonically with the increasing of storage time. The rupture force decreased from 812 N and 411 N; rupture energy declined from 5.58 Nm to 3.11 Nm (46.75 decrease); while the fruit toughness increased from 0.270 mJ/mm³ and 0.403 mJ/mm³. The findings of this study are useful in designing of eggplants' processing and packaging systems.

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*Corresponding author.

E-mail address: erobo2011@ gmail.com