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Strength Parameters of Packaged Roma Tomatoes at Bioyield under Compressive Loading

F.A. Babarinsa[1]* and M. T. Ige[2]
1. Nigerian Stored Products Research Institute, P.M.B. 1489, Ilorin. Nigeria.
2. Department of Agricultural and Environmental Engineering, Obafemi Awolowo University. Ile-Ife, Nigeria.
**E-mail of corresponding author*: fababarinsa@yahoo.com

Abstract

Compression test was conducted on packaged Roma tomatoes to study the effects of stage of ripeness, level of vibration and container type on load, deformation and stress at bioyield point of the fruit. Tomatoes harvested at three stages of ripeness: unripe (5.6 Brix %), half-ripe (3.9 Brix %), and full-ripe (3.2 Brix %), were packed in plastic crate and raffia basket and were subjected to three levels of vibration: non-vibrated, low vibration (frequency 3.7 hz) and high-vibration (frequency 6.7 hz). The tomatoes were then compressed at a loading rate of 2.50 mm/min^{-1} in a Testometric Universal Testing Machine. Data obtained directly from computer printout were statistical analyzed using the SPSS 110 software package. Load and stress at bioyield decreased significantly (P=0.05) with advances in ripeness stage of the fruit. of increasing vibration significantly (P=0.05) increased deformation at yield and also reduced load and stress at bioyield.

Keywords: Roma tomato, Packaging, Mechanical damage, Strength parameter, Bioyield, Ripeness, Vibration, Universal Testing Machine

1. Introduction

Tomato (*Lycopersicon esculentum Mill.*) is a major vegetable crop grown in Nigeria and the Roma variety is highly favoured in commercial production and transportation in the country. The variety is widely grown in the northern part of Nigeria and is usually bulk packaged in raffia woven baskets for transportation, by road, to the southern parts using commercial trucks. Considerable mechanical damage is inflicted, due to compression, to the packaged fruits in the distribution system (Babarinsa & Nwangwa, 1987, Okhuoya, 1995 and Daramola, 1998). This contributes substantially to the huge postharvest losses suffered by the tomatoes in the country. The strategic reduction of this aspect of losses requires improvement to the packaging method with a clear understanding of the behavior of the delicate tissues under externally applied forces. As noted by Rorbertson (2006), modern packaging of fresh horticultural produce is expected to meet a wide range of requirements, including the prevention of mechanical damage resulting from compression.

Mohsenin (1986) reported that, in intact fruits and vegetables, mechanical damage is usually initiated through a rupture in the internal or external cellular structure of the material. He recalled that at bioyield point, cells start to rupture or move with respect to their neighbors. Hence, relating externally applied forces to the initial disruption of the cellular structure of a packaged fruit calls for a clear understanding of the strength parameters at bioyield point. Bioyield behavior of the fruit under compressive loading characterizes the microstructural (cellular) disintegration of its vegetable tissues in packaging during transportation. Deformation at bioyield, which weakens the cell walls and the forces binding cells together, has been attributed to weak ruptured cells by (Okhuoya 1995 and Daramola 1998). Typically, bioyield does not show an immediate external symptom for mechanical damage in tomatoes (McColloch, 1962) but causes permanent (irreversible) deformation at the cellular level. It particularly encourages breakdown of cell structure, with loss of firmness, by allowing breakdown of polymeric carbohydrates, especially pectic substances. The resulting internal damage often degenerates into tissue disintegration, external fracture and other forms of mechanical damage which eventually leads to physiological disorder and greatly reduce fruits shelf life. Determination of bioyield deformation and measurements of strength parameters in fruits often involves a study of force-deformation behavior under compression (Burkner & Kinch. 1967). This approach has been justified for fresh tomato fruits on the ground that the fresh tomato is usually subjected to mechanical forces in packaging.

Mechanical behavior of a compressed material at bioyield can be expressed in terms of strength parameters such as of maximum sustainable load, resultant deformation and maximum sustainable stress (Vursavus & Ozguven 2004, Mencarelli et al., 2005). This provides a basis for predicting the occurrence of mechanical damage under an applied force.

This study investigated the effects of stage of fruit ripeness, level of vibration and packaging container on strength parameters (load, deformation and stress) at bioyield of packaged Roma tomatoes under compressive loading.

2. Materials and Method

2.1 Experimental Plant Material

Tomatoes of the Roma variety were hand-harvested from a local market farm in Ilorin suburb at three stages of maturity. These were transported to the Engineering Material Testing Laboratory at the National Center for Agricultural Mechanization (NCAM), Ilorin. Wholesome fruits were sorted for reasonable uniformity into shape and size range of 2.5 to 3.0cm.

Stages of tomato ripeness were first determined subjectively by skin colour as (i) unripe (mature green/breaker or green pink, consisting of the first point of skin colour change from complete green to about 30% pink), (ii) half-ripe, consisting of 30-70% pink to red skin and (iii) the ripe, consisting of 70-100% red skin but still firm, These are identical to skin colour levels depicted as 1, 5 and 9 on the recommended tomato colour chart of the Organisation de Cooperation et de Development Economiques, Paris (Thompson, 2003). The ripening stages are also equivalent to colour levels 2, 4 and 6 on another chart presented by McGlasson et al. (1985).

The ripeness stages were further evaluated objectively by measuring the total soluble solids (as Brix %) in the undiluted juice of samples of the tomato fruit. The digital hand-held refractometer (ATAGO® PAL-1 No.3810) used had an automatic internal temperature compensation feature, a measurement resolution of Brix 0.1% and accuracy of Brix ±0.2%. Approximately 0.3ml of the tomato samples, blended to a uniform juice, were placed on the prism of the digital refractometer. The total soluble solids content (in Brix %), measured in triplicates, were 5.6, 3.9 and 3.2 for the unripe, half- ripe and full ripe stages respectively.

2.2 Packaging containers

The two packaging containers used are plastic crate and raffia basket. The plastic crate (manufactured by Shongai Packaging Industries Ltd) has been recommended by the Nigerian Stored Products Research Institute for packaging tomatoes for road transportation in Nigeria (NSPRI, 1990). It is similar to the nest/stack type described by Thompson (2003). The crate has total external dimensions of 60cm x 40cm x 25cm high and is capable of holding 25kg of tomato fruit. The basket is the traditional hand-woven raffia type extensively used in road transportation of tomatoes in Nigeria. It is 30cm deep and 43cm in diameter, capable of holding 20kg of tomato fruit. Both containers are adequately ventilated and are strong to resist failure by buckling.

2.3 Experimental design

A 2×3^2 factorial experiment was conducted to study the effect of three ripening stages, three vibration levels and two containers on load, deformation and stress at bioyield point of Roma tomatoes under compressive loading.

2.4 Vibration treatment

A laboratory mechanical vibrator, a Gallenhamn Orbital Shaker (App. No 9B 3742 E), was used to vibrate the packaged tomatoes in their respective containers (plastic crate and raffia basket) while being carried on the vibrator's platform. The carriage platform is fitted internally with oscillating cams that vibrate the platform, thereby imparting oscillation at the variable speed of 0-400 rev/min. Vibration, designated either as low-level or high level, was applied at fixed frequencies of oscillation, 3.5 and 6.7 Hz respectively, by setting the operating speed at 200 or 400 rev/min for duration of 60 minutes.

2.5 Compression test

Compression tests were conducted with the Testometric Universal Testing Machine (UTM), (manufactured by Testometric Co. Ltd. UK), with a force exerting capacity of 50kN. The functional components of the testing machine include the load frame, load cell, crosshead, control console and a printer. It was installed in the Engineering Material Testing Laboratory of the National Center for Agricultural Mechanization (NCAM), Ilorin.

The compression test was conducted in triplicates by mounting and compressing the tomatoes in the loading space of the UTM. A pair of rigid plates of 1.27cm thick plywood was used as the force-transmitting devices, one as bottom support and the other as top loading device for the fruit. Loading rate (crosshead speed) of 2.50 mm/ min was applied as recommended by Mohsenin (1986). The electronic computing unit of the UTM was set to measure selected strength parameters (load, deformation and stress) at bioyield of the compressed tomatoes. Data sheets of measured values and load-deformation plots were obtained directly as produced with the aid of a PC.

2.6 Statistical Analysis

Data collected from compression test runs were subjected to statistical analysis using randomized complete block design based on a 3^2x2 factorial experiment. Statistical analysis was carried out using Statistical Package for Social Sciences (SPSS 110 software package). Treatment means were compared using Duncan's Multiple Range Test ($P< 0.05$).

3. Results and Discussion

3.1 Load-deformation curves

Typical compression load-deformation curve generated for the compressed tomatoes is shown in Figure 1. The curves generally showed sharp peaks after the elastic deformation at the end of each compression. Bourne (2002) made similar observation with Instron generated curves which show sharp peaks at the end of each compression, rather than rounded peaks like those yielded by the General Foods Texturometer. Fellows (2009), while considering idealized and typical load-deformation curves for various foods, attributed the observed behavior in compression to soft, weak brittle materials. He particularly noted that the point of maximum force or rupture could also occur at bioyield point. This, thus, explains why in curves such as that in Figures 1, bioyield point may not be distinguishable from rupture point.

3.2 Statistical Analysis

Results of analysis of variance of the compression tests for determination of load, deformation and stress at bioyield, are as presented in Tables 1 to 3 respectively, showing the effects of ripeness, vibration and container. The Tables revealed vibration level had significant effects on load at bioyield and deformation at bioyield (at P = 0 005) while stage of ripeness shows significant effects on load at bioyield and deformation at bioyield (at P = 0.05). The effects of container were not significant on any of the treatments. The two-factor interactions were not significant (P=0.05) on the strength parameters. The analysis also indicated that Vibration*Container interaction, with F-value 1962, was also the most important two-factor interaction on stress at bioyield (with F-value 1962), load at bioyield and stress at bioyield (with F-value 0.785). Effects between the subject three factors (Ripeness*Container*Vibration) were not significant for all strength parameters at bioyield.

3.3 Effects of stage of ripeness

Stage of ripeness had highly significant (p = 0.001) effects on stress at bioyield (Table 3) while having significant (p=0.005 level) effects on load at bioyield. The effects of ripeness were, however, not significant for deformation at yield (Table 2). The statistical analysis of variance means and differences among the three stages of ripeness tested during the compression testing are presented in Table 4. Load at bioyield as well as stress at bioyield of Roma tomato reduced with advancing stages of ripeness. This can be attributed to the reduction of turgor in tomatoes during ripening as noted by Shackel et al., (1991) Tong et al., (1999) and De Belie et al., (2000). Shackel et al., (1991) observed that this reduced stressing of the cell wall in intact tomato (variety "Castelmart") fruit., When such tissues are subjected to compressive loads, higher turgor tends to make the cell more brittle, and fail at a lower force (Lin & Pitt, 1986; Tu, et al., 2000).. This, perhaps, is why Schouten et al. (2007) stated that mechanical damage results in immediate loss in cell wall only in the riper fruit of tomato. This is also supported by findings of Garcia et al. (1995) who noted that mechanical stresses in the tissues were higher in turgid fruit. The two modes of structural feature, which initiate the failure of the cellular conglomerate - the tension failure of the cell walls and the failure of the intercellular bonds- both vary among different commodities and may change as the tissue ripens.

The observed reduction in load and stress at bioyield and increase in deformation at bioyield with advancing stage of ripeness of tomato fruits (Table 1) indicate a decrease in the resistance of the fruit to compression loading. Compression force will, thus inflict greater bioyield damage on tomatoes at advancing stages of ripeness. The results obtained therefore support the findings of Olorunda & Tung (1985) that the susceptibility to mechanical injury depended on fruit maturity. The authors noted that ripe tomatoes were more subject to mechanical injury.

The results obtained in the present work may be explained by the hypothesis that changes such as solublization and degradation of pectin, that occur in the cell wall during ripening of fruit, are critical to the mechanical properties of the fruit (Seymour & Gross, 1996; Harker et al., 1997). The practical significance of these results is that fresh tomatoes to be packaged for road transportation should be harvested at earlier stages of ripeness to minimize internally mediated mechanical damage (caused by bioyield).

3.4 Effects of Vibration Level

The analysis of variance (Tables 1 to 3) revealed that vibration level had significant effects only on load at bioyield and deformation at bioyield (at P = 0 005). The effect of vibration shows significant (P=0.05 level) differences on load at bioyield.

Table 5 shows the statistical analysis of variance means and differences among the three levels of vibration tested during the compression testing. Load at bioyield, deformation at bioyield as well as stress at bioyield of Roma tomato all reduced with advancing levels of vibration.

The experimental application of varying levels of vibration to packaged Roma-type tomato before compressive loading aimed at simulating vibration of fruit during road transportation. Packaged tomatoes subjected to increasing vibration generally become weaker and softer. The packaged fruit was rendered susceptible to mechanical damage by the imparted vibration received in the packaging containers. Vibration is inter-related with ripeness and together determine the intensity of compression damage inflicted on the packaged fruits. Tomatoes subjected to excessive vibration will easily be inflicted with mechanical damage, judged by the low maximum load and stress at bioyield recorded for the treated fruit.

These results agree with other studies carried out by Idah et al. (2007)**,** which revealed that severity of compression damage to fruits is primarily related to the level of vibration (and the stage of ripeness). Since the non-vibrated fruits suffered the least compression damage, it can be inferred from the study that in considering tomato fruits for transportation by road in packaging containers, the well maintained vehicles and roads should be preferred. Therefore, subjection of packaged tomatoes to excessive vibration, before or during road transportation is discouraged. Berardinelli et al. (2003) noted that the vibrations due to transportation are influenced by road roughness, distance, travelling speed, load, and some characteristics of the truck such as the suspension and the number of axles

3.5 Effects of container types

Table 1 to 3 shows that the effects of container on all strength parameters at bioyield were not significant (P=0.05) during the compression testing of Roma tomato fruits. For example, deformation at bioyield was not affected by container type (Table 6). Regardless of the stage of ripeness, the stress at bioyield was consistently higher in basket packaged tomatoes than in crate. The stress reduction of $0.0008 N/mm^2$ and $0.001 N/mm^2$ observed in half- ripe and full-ripe fruits respectively in crate were maintained in the basket. In crate, load at yield drops from 340N in unripe fruits to 220N and 130N in half-ripe and full-ripe fruits respectively. The same trend was observed in basket packaged fruits but all values were slightly elevated by 20N above those in crate.

4. Conclusions

This research investigated the effects of ripeness stage, imparted vibration and packaging containers (raffia basket and plastic crates) on three important strength parameters – load, deformation and stress – all at bioyield point of the packaged fruit when compressed.

Measurements of the strength parameters at bioyield point of Roma tomatoes revealed that stage of fruit ripeness is the major factor contributing to the internal mechanical damage encountered in the compressed fruit. Advancing stage of fruit ripeness or increased level of vibration rendered the fruit more susceptible to compression stress and reduced fruit resistance to bioyield. This, thus, increases the susceptibility of the packaged fruit to mechanical damage under compressive loading. The factors (ripeness and vibration) are inter-related and together determine the intensity of compression damage inflicted on the packaged fruits. Therefore, packaging of tomatoes at advanced stage of ripeness or subjection to excessive vibration is discouraged.

Hence, unripe tomatoes fruits should be preferred in considering tomatoes for road transportation in packaging containers. Considering the correlation between ripening and vibration, careful choice of well maintained vehicles for road transportation is also crucial to avoid imparting vibration to the packaged fruit. The findings of this study will facilitate an understanding of the mode of mechanical damage caused by compressive loading induced within the packages during road transportation.

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Table 1: Statistical Analysis of Variance (ANOVA) of data on load at bioyield of tomato fruit under compression

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	512206.500[a]	11	46564.227	3.848	.001
Intercept	3102283.684	1	3102283.684	256.384	.000
VIBRATION	150098.437	2	75049.219	6.202	.004
CONTAINER	2403.556	1	2403.556	.199	.658
RIPENESS	131036.190	2	65518.095	5.415	.008
VIBRATION*CONTAINER	18989.001	2	9494.501	.785	.463
VIBRATION*RIPENESS	37354.895	4	9338.724	.772	.550
CONTAINER*RIPENESS	.000	0			
VIBRATION*CONTAINER*RIPENESS	.000	0			
Error	508206.888	42	12100.164		
Total	4210955.070	54			
Corrected Total	1020413.388	53			

Table 2: Statistical Analysis of Variance (ANOVA) of data on deformation at bioyield of tomato fruit under compression

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	512206.500[a]	11	46564.227	3.848	.001
Intercept	3102283.684	1	3102283.684	256.384	.000
VIBRATION	150098.437	2	75049.219	6.202	.004
CONTAINER	2403.556	1	2403.556	.199	.658
RIPENESS	131036.190	2	65518.095	5.415	.008
VIBRATION*CONTAINER	18989.001	2	9494.501	.785	.463
VIBRATION*RIPENESS	37354.895	4	9338.724	.772	.550
CONTAINER*RIPENESS	.000	0			
VIBRATION*CONTAINER*RIPENESS	.000	0			
Error	508206.888	42	12100.164		
Total	4210955.070	54			
Corrected Total	1020413.388	53			

Table 3: Statistical Analysis of Variance (ANOVA) of data on stress at bioyield of tomato fruit under ompression

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.614E-05[a]	11	1.467E-06	9.869	.000
Intercept	1.898E-04	1	1.898E-04	1276.675	.000
VIBRATION	5.312E-06	2	2.656E-06	17.869	.000
CONTAINER	9.245E-06	1	9.245E-06	62.193	.000
RIPENESS	6.957E-06	2	3.479E-06	23.402	.000
VIBRATION*CONTAINER	5.833E-07	2	2.917E-07	1.962	.153
VIBRATION*RIPENESS	3.993E-07	4	9.981E-08	.671	.615
CONTAINER*RIPENESS	.000	0			
VIBRATION*CONTAINER*RIPENESS	.000	0			
Error	6.243.E-06	42	1.487E-07		
Total	2.147E-04	54			
Corrected Total	2.238E-05	53			

Table 4: Statistical analysis of variance means and ripeness stages

Strength parameter	**Stage of ripeness**		
	Unripe	**Half-ripe**	**Full-ripe**
Load at yield (N)	339.933a	233.069b	156.217c
Deformation at yield (mm)	18.888a	16.179a	17.483a
Stress at yield (N/mm^2)	1.8944E-03a	1.950E-03a	1.817E-03a

In each row, means with the same letter were not significantly (p = 0.05) different.

Table 5: Statistical analysis of variance means and vibration levels

Strength parameter	**Level of vibration**		
	Non-vibrated	**Low-vibration**	**High-vibration**
Load at yield (N)	309.379a	221.350b	190.983b
Deformation at yield (mm)	21.091a	16.511b	13.945b
Stress at yield (N/mm^2)	2.287E-03a	1.875E-03ab	1.546E-03b

In each row, means with the same letter were not significantly (p = 0.05) different.

Table 6: Statistical Analysis for variable means and container type

Strength parameter	**Type of container**	
	Crate	**Basket**
Load at yield (N)	280.722a	200.419b
Deformation at yield (mm)	16.799a	17.565a
Stress at yield (N/mm^2)	1.564E-03a	2.242E-03a

In each row, means with the same letter were not significantly ($p = 0.05$) different.

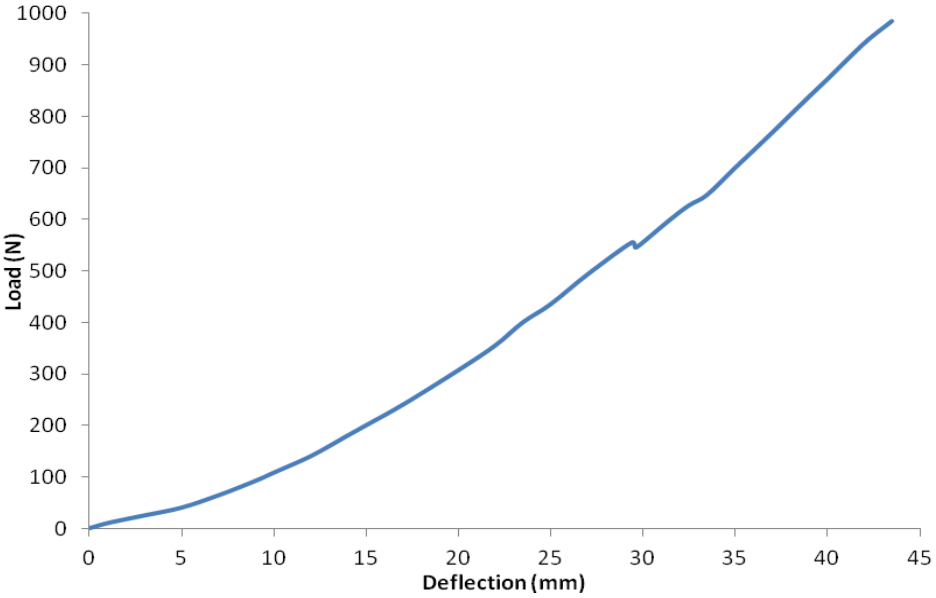

Figure 1: Load-deformation curve for vibrated ripe tomatoes packaged in basket

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