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# Strength Parameters of Packaged Roma Tomatoes at Peak Point 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] Obafemi Awolowo University, Ile-Ife, Nigeria

**Abstract.** Compression test was conducted to investigate the peak stress and deformation induced in packaged Roma tomatoes under compressive loading and the effects of ripeness stage, vibration level and type of container on the two strength parameters. Tomatoes of three ripeness stages: unripe (5.6 Brix%), half-ripe (3.9 Brix%) and full-ripe (3.2 Brix%), were packed in plastic crate and raffia basket. Using a laboratory vibrator, the fruit bulks were subjected to three levels of vibration: non-vibrated, low vibration (frequency 3.7 Hz) and high vibration (frequency 6.7 Hz). These were then compressed in a Universal Testing Machine at a loading rate of 2.50mm/min and deformation and stress at peak point in the fruit bulk were measured. Level of vibration significantly (P=0.001) reduced maximum deformation and the corresponding stress at peak point. Stage of ripeness, however, showed no significant effects on both deformation and stress at peak. Rather, it induced minimal overall differences in stress, ranging from 8.123 E-03 N/mm$^2$ to 9.956E-03 N/mm$^2$. Effects of container types on stress were significant (P=0.001) but were not significant on deformation. Average peak deformation of the fruit ranged from 43.688 N to 50183N while peak stress ranged from 5.917E-03 N/mm$^2$ to 6.936E-02 N/mm$^2$. The three levels of vibration exhibited stress values ranging from 1.274E-02 N/mm$^2$ to 8.988E-03 N/mm$^2$.

**Keywords:** strength parameter, packaged Roma tomatoes, peak point, compressive loading,

## 1. Introduction

The tomato (*Lycopersicon esculentum* Mill.) is a tender and compression-sensitive fruit. The fruit contains a considerable amount of water and other liquid-soluble materials surrounded by semi-solid cell wall and pectic middle lamella materials. It is thus susceptible to mechanical damage, especially compression injury, during handling and road transportation, in Nigeria, as the handlers sometimes subject the packaged produce to various forms of compressive loading in lorry truck.

In Nigeria raffia baskets are the most used packaging containers in commercial transportation of fresh tomato fruit but other packaging materials such as fiberboard cartons are used. The handlers usually stack these containers one over the other whereby greater part of the compression load is transmitted directly into the fruit via packaging. Much compression damage is therein encountered due to cracking and squeezing of the fruit in multi-layers. This contributes much to the mechanical damage inflicted on the fresh fruit in transit.

Mechanical properties such as compressive strength are important engineering data needed to study fruit resistance to cracking and breaking. The key measurements of mechanical behavior under compression force can be made in terms of three strength parameters: maximum load, deformation and stress. These are measured at three points of deformation - bioyield, break and peak points. These basic strength parameters have been measured and studied in Roma tomatoes at the bioyield point and break point [1], [2]. Other important strength parameters studied include energy absorption capacity and Young's modulus [3], [4] of the fruit. The strength parameters at the peak point denote the properties leading to the point of maximum load sustained by the vegetative tissues. The evaluation of strength parameters of tomatoes at this point is

[+] Corresponding author: F.A. Babarinsa. Tel.: +2348033769653
*E-mail address*: fababarinsa@yahoo.com

essential for a clear understanding of the maximum stress which the tissues can withstand. It is useful therefore to study these properties from compression testing.

This work investigated the peak (maximum) stress and corresponding deformation induced in packaged Roma tomatoes under compressive loading. Compression test was conducted to study the effects of ripeness stage, vibration level and type of container on the two strength parameters.

## 2. Materials and Method

### 2.1. Experimental material

Fresh tomatoes of the Roma variety used were hand-harvested at three stages of maturity/ripeness from a local market farm in the suburb of Ilorin, Nigeria. The three stages The unripe stage is the mature green/breaker (or green pink) stage, consisting of the first point of skin colour change from complete green to about 30% pink. The half-ripe stage will consist of 30-70% pink to red skin while the ripe (or table ripe) stage with of 70-100% red skin but still firm. Stages of tomato ripeness were determined subjectively by skin colour rating [5]-[7] and objectively (using digital hand-held refractometer), as described in our previous work [2],

Table.1: Statistical Analysis of Variance (ANOVA) of data on deformation at peak of Roma tomato fruit under compression

| Source | Type III Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 884,971[a] | 11 | 80,452 | .956 | .499 |
| Intercept | 115044,065 | 1 | 115044,065 | 1367,043 | .000 |
| Vibration | 446,809 | 2 | 223,404 | 2,655 | .082 |
| Container | 35,676 | 1 | 35,676 | .424 | .519 |
| Ripeness | 24,089 | 2 | 12,045 | .143 | .867 |
| Vibration*Container | 172,913 | 2 | 86,457 | 1,027 | .367 |
| Vibration*Ripeness | 155,322 | 4 | 38,830 | .461 | .764 |
| Container*Ripeness | .000 | 0 | , | , | , |
| Vibration*Container*Ripeness | .000 | 0 | , | , | , |
| Error | 3534,528 | 42 | 84,155 | | |
| Total | 121967,518 | 54 | | | |
| Corrected Total | 4419 499 | 53 | | | |

### 2.2. Compression testing

Compression tests were conducted, in a 2 x $3^2$ factorial experiment, with a Testometric Universal Testing Machine installed in the Engineering Material Testing Laboratory at the National Center for Agricultural Mechanization (NCAM), Ilorin, Nigeria. This was applied in studying the effects of three ripening stages, three vibration levels and two containers on load, deformation and stress at peak point of Roma tomatoes under compressive loading. Roma tomatoes of three ripeness stages of 1) unripe (5.6 Brix%), 2) half-ripe (3.9 Brix%) and 3) full-ripe (3.2 Brix%), were packed in plastic crate [6]-[8], and raffia basket. A laboratory vibrator was used to apply vibration onto the fruits. The three levels of applied vibration are 1) non-vibrated 2) low vibration (frequency 3.7 Hz) and 3) high vibration (frequency 6.7 Hz).

The basic methodology for compression testing of the packaged tomatoes (at a speed of 2.50mm/min) to obtain measurements of deformation (mm) and stress was described by Babarinsa and Ige [1], The measured values, at the peak point, were recorded on a computerized PC data acquisition system in a personal computer. Load-deformation plots were obtained directly as produced with the aid of the PC during compression.

### 2.3. Statistical Analysis

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

Table 2: Statistical Analysis of Variance (ANOVA) of data on Stress at peak of Roma tomato fruit under compression.

| Source | Type III Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 9,562E-04[a] | 11 | 8,693E-05 | 8,448 | .000 |
| Intercept | 4,351E-03 | 1 | 4,351E-03 | 422,818 | .000 |
| Vibration | 3,619E-04 | 2 | 1,809E-04 | 17,582 | .000 |
| Container | 4,322E-04 | 1 | 4,322E-04 | 41,999 | .000 |
| Ripeness | 3,565E-04 | 2 | 1,782E-04 | 17,320 | .000 |
| Vibration*Container | 1,174E-04 | 2 | 5,870E-05 | 5,705 | .006 |
| Vibration*Ripeness | 1,142E-04 | 4 | 2,856E-05 | 2,776 | .039 |
| Container*Ripeness | .000 | 0 | , | , | , |
| Vibration*Container*Ripeness | .000 | 0 | , | , | , |
| Error | 4,322E-04 | 42 | 1,029E-05 | | |
| Total | 5,730E-03 | 54 | | | |
| Corrected Total | 1,388E-03 | 53 | | | |

## 3. Results and Discussion

### 3.1. Load-deformation curve

Force-deformation curves yielded by the compression test for all stages of ripeness, levels of vibration and containers indicated that deformation for the bulk is non-linear viscoelastic. The generated curves show sharp peaks at the end of each compression, rather than rounded peaks. This observed behavior in compression has been attributed to soft, weak brittle materials [9]. It is particularly noted that the point of maximum force or rupture could also occur at bioyield point.

### 3.2. Effects of stage of ripeness

Fruit ripeness is an important factor that affects tomato compression tolerance. Stress was highest in the unripe stage regardless of containers and levels of vibration. Pereira & Calbo [10] reported that the riper the fruit the bigger is the effects of fruit compression, because ripe fruits have lager plasticity and elasticity. However the compressive measurements in this study demonstrated that ripeness stage did not have significant effect on deformation at peak (Table 1) of fruit at the three ripeness stages tested. Average deformation of the fruit at peak point showed minimal or no overall differences within comparative treatments. This was quite at variance with reported response of deformation in tomato when measured at both bioyield point [1] and break point [2], whereby deformation (at both bioyield and break points) reduced significantly with stage of ripeness. An apparent little or no variation in measured deformation with stage of ripeness may be explained by the fact that application of force (hence stress) beyond the peak point leads to rupture rather than further deformation.

A study of ripening-related changes of the mechanical properties of the tomatoes by Andrews et al. [11]) shows that the epidermal cell walls contribute to a large extent to the mechanical properties of the tomato fruit exocarp. The epidermis also presumably plays a major role in resistance to turgor-driven tomato fruit growth ([6]-[11]). The observed ripening-related changes of the mechanical properties of the skin seem to be determined mainly by modifications of the chemical composition of the cuticular membrane. Several studies have been carried out ([6]-[11]) noting that the mechanical properties of tomato fruit exocarp strips resulted from increasing fruit age, especially during ripening. A macromolecular explanation for the biomechanical behavior of fruit CM describes (i) greater stiffness associated with a glass state below the transition ripeness and (ii) plastic characteristics, being associated with a more viscous state, above the transition ripeness [12].

The strength properties at peak point of whole tomato fruit can be recognized as a limiting point to effect of imparted force in increasing deformation in the fruit. This point marks the beginning of energy dissipation towards structural failure in the form of fracture leading to bruising, cracking or cutting ([6]-[11]). The amount of deformation of 43.688 to 47.323 mm, stress at peak point ranged from 8.123 E-03 $N/mm^2$ to 9.956E-03 $N/mm^2$ at the three levels of ripeness. In most cases, the packaged tomatoes became cosmetically unacceptable, at the point of peak and this determined failure. The lowering of mechanical strength is an important part of the ripening process in tomatoes, as changes in cell walls accompany fruit softening [13]. For example, tomato fruit ripening is accompanied by significant degradation of cell wall pectin [14]. At both bioyield and break points ([1], [2]), deformation and stress reduced significantly with stage of ripeness, but the strength parameters at the peak point were unaltered by stage of ripening.

### 3.3. Effects of Vibration

The increasing level of vibration caused an apparently little variation in measured deformation ranging from 43.688 mm to 50.183 mm with minimal differences among treatments. Increase in deformation recorded following the application of low-vibration to fruits was higher than increase in deformation caused by subsequent application of high-vibration. This is probably because the initially measured deformation seemed to be driven, in part, by the existence of interspaces' (void) volumes within the bulk, the larger amount of which has been removed during the initial application of low-vibration.

The analysis of results presented in Table 2 indicates that the level of vibration had highly significant ($p = 0.001$) effects on peak strength (or stress at peak). Stress at peak point decreased with increasing level of vibration level, with values ranging from 5.917E-03 to 1.274E-02 $N/mm^2$. Level of vibration, thus, displayed a tendency to decrease for both peak stress and deformation in unripe to fully ripe fruits. The decrease in stress at peak and increase in deformation at peak at high level vibration might be influenced by the breaking (or cracking) of fruit skin resulting from weakening of the cuticle at high level of vibration. The tissues of vibrated tomatoes had earlier undergone yielding, in which its ability to resist applied load was drastically reduced [1]. In particular, the observed relationship here between vibration and strength would indicate the effect of vibration on the structural relation of skin components. It has been reported that strength in a composite biomaterial, like tomato fruit cuticular membrane (CM), depends on the biomaterial components [12], [13], Bargel and Neinhuis [15] and Mattas et al. [14] particularly reported that CM contributes to the resistance of Cherry tomato fruit to tension mechanically.

Application of vibration to bulk tomatoes, caused settlement to set in as the immediate effect of the rotational and relocational movement of the respective fruit in multilayer in vibration. Vibration force then relocates the individual fruits relative to other fruits in the bulk, leading to an initial compaction of the fruit bulk. Thus, application of external load (or force) first and foremost causes contact compression. The resulting self compaction increases the number of contact points, and eventually changes the distribution of energy dissipated into the fruit layers during subsequent inter-layer compression.

## 4. Conclusion

Compression testing was used to characterize peak strength of the packaged tomatoes. This work has demonstrated that strength parameters at peak of the Roma tomato fruit depend more on level of imparted vibration and less on stage of ripeness, which both affected the structural component. Maximum deformation at peak was found to be constant at the range of ripeness and vibration tested. The peak strength parameters lead to a point where further compressive loading does not increase deformation.

Our result demonstrates that the combined effect of ripeness and vibration seems critical in explaining the biomechanics of the fruit, and provides the basis for explaining mechanical failure such as fruit bruising and skin cracking. These findings can provide useful information about the influence of fruit properties (for example ripeness) on mechanical damage susceptibility, whereby bruise prediction, for example, can be made for cultivar 'Roma". Recorded test results could provide expected control limits for tomato fruit strength and provide a good baseline for material or design modifications. They would provide an accurate way of assessing the overall strength of a fruit bulk in filled container.

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