J Food Sci Technol 2009, 46(2), 153–155

Resonance frequency of Nigerian tomato fruit as related to prevention of damage during transportation

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Effect of natural frequency (NF) of vibration of fresh tomato *(Lycopersicon esculentum)* fruits of Nigerian cultivars ('Chico', 'Roma' and 'Cherry') for preventing damage during transportation and handling was studied. The quality was determined at turning and fully ripe stages using compression test from which the modulus of elasticity of the fresh tomatoes was computed. The NF was then determined using an established relationship. The results show that the average NF of vibration for fresh tomato fruit at turning stage of maturity were 17.6, 14.9 and 9.1 Hz for 'Chico', 'Roma' and 'Cherry' varieties, respectively and were significantly different ($p \leq 0.05$). At ripe maturity stage, the average values were 14.7, 14.2 and 13.2 Hz for 'Chico', 'Roma' and 'Cherry' varieties, respectively. The NF of the 'Cherry' variety is significantly ($p \leq 0.05$) lower than those of 'Roma' and 'Chico', while that of 'Roma' was significantly ($p \leq 0.05$) lower than 'Chico' at turning stage of maturity. The practical utility of these data is in selecting proper traveling speed for vehicles used in hauling this fresh fruit to minimize mechanical damage.

Keywords: Tomato, Natural frequency, Transportation, Vibration, Mechanical damage

Tomato (*Lycopersicon esculentum)* is a major fruit widely grown and utilized in Nigeria. During harvest, there is glut in the production areas and in order to have good prices for the produce, traders and farmers send truck loads of the produce to long distance markets, when mechanical damage due to impact and vibration occurs. One important property of this fresh produce, which directly influences such damage, is the natural frequency of vibration of the fruit itself.

Fresh fruits and vegetables with high moisture content ranging from 75 to 95 % in some cases are susceptible to mechanical damage especially during transportation and handling (Singh and Singh 1992). Impact, friction and compression occur during harvest, handling and transportation resulting in mechanical injury (Berardinelli et al 2005). The problem of damage during transportation can be studied from the context of vibration theory, based upon which, it is possible to reduce the damage. Several factors are responsible for fresh produce damage during transportation such as bad roads, the dynamic characteristics of the vehicles, poor handling containers and the physical properties of the produce.

Several research works have been carried out regarding the physical and mechanical properties of fresh fruits and vegetables (O'Brien et al 1965, Mohsenin 1978, Roudot et al 1991, Peters 1996, Jan et al 1997, Batu 1998, Dewulf et al 1999, Nwanekezi and Ukagu 1999, Idah et al 1999, 2006, Owolarafe et al 2006, Kundan et al 2006). One property that is very crucial for the damage of fresh fruits during transportation is the natural frequency of vibration of the fruit.

It has been observed that when the natural frequency (NF) of vibration of the fruit being transported coincides with the excitation frequency of the haulage vehicle then it leads to increase in acceleration that eventually culminates in produce damage (O'Brien et al 1965, Ogut et al 1999). It is therefore noted that the damage can be reduced if this condition is avoided by letting the NF of the containers of fruits to be away from the range of frequencies of excitation force while in transit (Ogut et al 1999). But there is little data on the NF of the varieties of tomato fruits grown in Nigeria. The knowledge of this property of the fruit can greatly assist in reducing losses that are currently being incurred during handling. This can be achieved by selecting appropriate traveling speed which will eliminate the conditions that will lead to resonance and subsequent damage of the fruits. The processors of these fresh fruits are just as much concerned about mechanical injury to the fruits they receive as the fresh fruits retailers (Altisent 1991).

Materials and methods

Fresh tomato (*Lycopersicon esculentum)* fruits of 3 varieties ('Chico', 'Roma' and 'Cherry') at 2 maturity stages (turning to maturity and ripe) were harvested from local farms; 200 fruits were collected for each maturity stage. The samples were sorted, weighed and classified into 4 mass groups M_1 (< 30 g), M_2 (31 to 41 g), M_3 (42 to 52 g) and M_4 (> 52 g). The dimensions, major, minor and intermediate diameters were measured using the principal axes method described by Mohsenin (1978). The volumes and densities were also determined using the water displacement method described by Mosheim (1978). The oven drying method was used to determine the moisture content. For each of the varieties and from each maturity stage under each of the mass groups, 5 samples of fruits were subjected to compression test using a Triaxial testing equipment (ELE International Limited, Hemel Hempstead Hendfordshire, HP2 7HP, England) which was adopted for the test following the procedure specified in ASAE (1998). The equipment is motor driven and has constant head travel. A speed (loading rate) of 2 mm/min was used for the test. Force-deformation curves were plotted from the compression tests. Using these curves and other measured parameters such as force at bioyield, radius of curvature and deformation, the modulus of elasticity was computed from the relationship (ASAE 1998);

$$E = \frac{0.388(1-\mu^2)F}{D^{3/2}}\left[K_u\left[\frac{1}{R_u}+\frac{1}{R'_u}\right]^{\frac{1}{3}} + K_l\left[\frac{1}{R_l}+\frac{1}{R'_l}\right]^{\frac{1}{3}}\right]^{\frac{3}{2}} \quad ... (1)$$

where, E = modulus of elasticity (Pa), D = deformation (m), F = force (N), μ = Poisson's ratio, R_u R'_u = minimum and maximum radii of curvature respectively at the point of contact for the upper convex surface (m), R_l, R'_l = minimum and maximum, radii of curvature, respectively at the point of contact for the lower convex surface (m). K_u, K_l are dimensionless constants obtained from ASAE (1998).

The natural frequency (NF) of vibration F_n of the fruits were determined as discribed by Ogut et al (1999).

$$F_n = \frac{1}{4\lambda}\sqrt{\frac{Eg}{\rho}} \quad ... (2)$$

where, F_n = natural frequency (Hz), E = modulus of elasticity (Pa), ρ = density of fruit (kg/m^3), λ = depth of column of fruit (m), g = acceleration due to gravity (m/s^2).

The data obtained were subjected to statistical analysis (ANOVA) and Duncan's multiple range test to ascertain the effects of variety, maturity and size on the values of the NF.

Results and discussion

Fig.1 shows typical force-deformation curves obtained from the compression tests. The curves follow the usual pattern or shapes (sigmoid) obtained for visco - elastic substances such as biomaterials (Mohsenin 1978).

The results presented in Table 1 show that the average NF of the fruits at turning stage of maturity and various sizes ranged from 12.4 to 17.2, 14.1 to 19.4 and 7.3 to 10.6 Hz for 'Roma' 'Chico' and 'Cherry' varieties, respectively. At fully ripe stage the corresponding values were 12.8 to 16.9, 12.9 to 16.8 and 11.1 to 15.5 Hz. The values obtained compared well with the results (9 to 20 Hz) obtained by O'Brien et al (1965) for fresh tomatoes. The study assessed vibrating characteristics of fruits as related to in-transit injury.

Statistical analyses of results show that there were no significant differences between the NF of different cultivars of the fresh tomato fruits assessed at fully ripe stage of maturity. However, at turning stage, the NF differed significantly between the varieties. It is worthy to note that it is at the turning stage that the fresh produce meant for long distance markets are harvested. These results are therefore important and can serve as a guide when selecting produce to be distributed to long distance markets. In other words, the 'Chico' and 'Roma' varieties, which are naturally stronger than 'Cherry' should normally be selected for long distance markets since they can withstand more stresses resulting from vibration and hence less susceptible to mechanical injury.

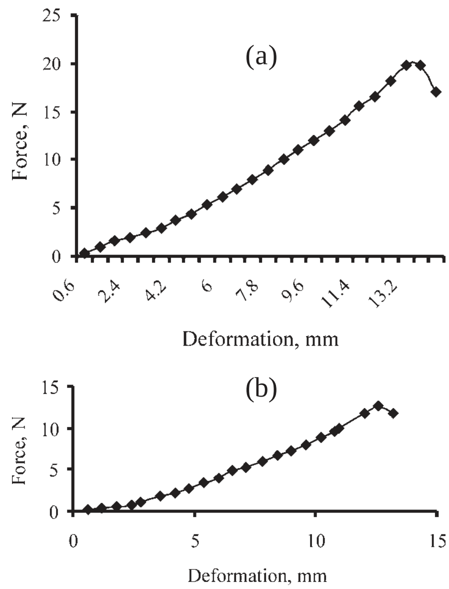

Fig 1. Force-deformation curve of (a) fresh turning to maturity and (b) fully ripe tomato

The NF of 'Cherry' (9.1 Hz) was significantly lower in comparison to 'Roma' (14.9 Hz) and 'Chico' (17.1 Hz). With regards to the sizes (masses) of the fruits, the average NF for turning to maturity were, M_1(15.0 Hz), M_2(14.7 Hz), M_3 (12.5 Hz) and M_4 (13.3 Hz) and these were not significantly different (p≤0.05). The corresponding values for the fruits at fully ripe maturity stage were 14.8, 13.9, 14.9 and 12.5 Hz and these were also not significantly different (p≤0.05). In other words, the sizes of the fruits do not influence the values of the NF determined. This result differs from other findings because it has been revealed that the NF of apples decreased with increase in apple size (Renfu and Abbott 1996).

It has been established (O'Brien et al 1965, Ogut et al 1999) that when the NF of the fruits coincides with that of the excitation frequency of the haulage vehicle, then resonance results and the fruits move with very high acceleration which results in their damage. Table 2 shows the average values of excitation frequencies of haulage vehicle at different speeds on a Nigerian trunk A road with average pot hole depth of 0.23 meter.

It is thus suggested that the speed of the vehicle should be selected such that excitation frequency of the vehicle is away from the NF of vibration of the fruits to avoid resonance (Ogut et al1999). From these data (Table 2), the incidence of resonance can be avoided if the haulage vehicle speeds are selected outside the range that will produce frequencies close to those of the fruits. It can be seen from the data that the excitation frequencies of the vehicle plying in these roads at speeds of 80 km/h and above are clearly within the range of the average frequencies of the fruits, hence that the vehicle conveying these fruits on the roads under study should not exceed 60 km/h, if resonance is to be avoided.

The results of the study can also be

Table 1. Natural frequency (Hz) of fresh tomatoes at turning and ripe stages of maturity and different fruit sizes

Variety	M_1	M_2	M_3	M_4
		Turning stage		
'Chico'	19.3	19.4	17.7	14.1
'Roma'	15.1	14.9	12.4	17.2
'Cherry'	10.6	9.9	7.3	8.7
		Ripe stage		
'Chico'	15.7	13.4	16.8	12.8
'Roma'	16.8	12.9	13.5	13.6
'Cherry'	11.9	15.5	14.4	11.1

M_1-M_4: As in text

Table 2. Excitation frequencies (Hz) of 'Mercedes 911' lorry (truck) at different

Vehicle speed, km/h	W_l=2.84	W_l=2.00	W_l=1.33
20	2.0	2.8	4.2
40	4.0	5.6	8.4
60	6.0	8.3	12.5
80	8.1	11.1	16.7
100	9.8	13.9	20.9
120	11.7	16.7	25.1

W_l = wavelength (m) = (a + b)/n, where, a=distance from the front wheel of the vehicle to centre of gravity, b = distance from the rear wheel to the centre of gravity, n =constant used to select the varieties of fresh tomatoes that are more suitable for long distance transportation and distribution with minimal losses. It can be seen from the results that the 'Chico' variety is likely to be more resilient than the other two varieties. This result correlates with earlier studies on other engineering properties of these tomato varieties (Idah et al 2006).

Conclusion

The values of NF differed significantly between the cultivars. The NF of the 'Cherry' variety is significantly lower than those of 'Roma' and 'Chico', while that of 'Roma' is significantly lower than 'Chico' at turning stage of maturity. The results of the study can be used to reduce losses resulting from mechanical damage during transport by selecting appropriate speed of the haulage vehicle at which the excitation frequency will be different and far from that of the fresh fruits mean NF being transported to avoid resonance condition. In order to achieve this, fresh tomatoes should not be transported by 'Mercedes 911' Lorries (trucks) at speeds greater than 60 km/h on the Nigerian roads considered here based on the results of this study.

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Received 26 September 2007; revised 02 July 2008; accepted 03 July 2008