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DROP IMPACT TESTING APPLICATIONS TO FRUIT QUALITY

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A b s t r a c t. Fruit growers and handlers need better methods to determine the firmness and storage potential of fresh fruit. Fruit quality can be predicted by measuring mechanical properties during various simulated loads. Drop impact testing of a single fruit is a good compromise between an ideal, highly controlled and a realistic, but less controlled load. The force vs time curve during impact provides numerous parameters which have been related to peach firmness and have been used for many practical applications. The impact variables contact time, peak force, peak force/contact time, and absorbed energy varied with fruit ripeness and between cultivars. Peaches were firmer when picked in the cool morning compared to the hot afternoon. Impact parameters and firmness were measured for various cooling and storage air treatments. All indicators show that peaches maintain firmness better when stored in cool, very high humidity air. High airflow is useful for good heat transfer during cooling but reduces the localized air humidity during storage.

K e y w o r d s: fruit quality, impact parameters, peaches

INTRODUCTION

Postharvest operations, packaging, and handling of fruit involve numerous mechanical operations and many opportunities for damage and impact-related flesh bruising. The cost of rejecting premium quality fruit after storage because of postharvest mishandling is the most expensive form of loss since production, storage and handling costs have already been incurred. These losses can often be reduced by careful handling practices, and through the use of proper equipment and packages which minimize the external impact forces applied to the fruit. Because the physical characteristics of the fruit change during storage [13], the impact response and corresponding bruise susceptibility of the fruit also vary with postharvest time.

The resistance of fruit to bruising and the potential for good storability are related to its firmness. Firmness can be quantified by mechanical loads simulating stresses expected during handling and storage. Loading can be either quasi-static or dynamic, either cyclic or single impact. To develop improved packaging for fruit, studies have been done of bruising produced by loads from impact, vibration, and compression [14]. An upper-bound analytical model was developed to quantify the bruise volume caused by impact of fruit with an elastic plate [10]. Threshold or critical drop heights for bruise production have recently been measured for apples, peaches, and pears [12]. This non-instrumented type of test requires larger numbers of fruit than individual fruit impact onto an instrumented plate test.

Various methods are available to measure fruit properties for specific purposes. The standard for comparison of any new texture measurement method is usually the Magness-Taylor puncture force [1]. Impact testing of a single fruit is a good compromise between applying a realistic load and having a method with sufficient control of the parameters. Instrumentation now allows experimental verification of theories related to the instantaneous force experienced during impact. The force versus time curve during impact can be acquired readily and accurately. Certain features of the force-time curve are related to fruit firmness and can be utilized for purposes of classification.

Fridley and Adrian's [9] attempted to relate impact energy to yield deformation but was limited because of variation in fruit maturity. During development of mechanical harvesters for peaches, Adrian *et al.* [2] dropped fruit onto various padded surfaces. Diener *et al.* [8] reported an increase in bruise resistance as the peach approaches full maturity. A bruise volume prediction model was developed by Chen and Yazdani [5] using acceleration history of apples impacting differently padded surfaces. Delwiche [6] quantitatively defined peach firmness by impact force analysis and, with that information, developed an impact fruit firmness sorter [6]. Hung and Prussia [11] determined the effect of fruit maturity and storage time on peach bruise volume and the absorbed energy during impact. The best indicators of bruise resistance during quasistatic loading were failure stress and puncture force. These studies used impact loading because of the short testing time, realistic nature of the type of loading and good correlation with long known qualitative texture methods i.e., flesh puncture force.

METHODS

An apparatus was constructed to hold a fruit by vacuum in a selected orientation prior to releasing it to drop onto the flat hard surface of the impact force transducer. The apparatus is described by Brusewitz and Bartsch [3]. The drop height was infinitely adjustable from zero to 500 mm to achieve the desired distance between the bottom of the fruit and the top of the PCB model 208M57 piezoelectric impact force transducer. The transducer signal was sampled very 20×10^{-6} s with a Nicolet model 2090-III oscilloscope where it was displayed and digitally stored. The 150 to 500 digitized voltage versus time pairs were transmitted to a microcomputer for data analysis. The drop of a sample produced numerous impact parameters of which the following were found most useful; impact peak force (*F*), contact time (*CT*), time-to-peak force (*T*), *F*/*T*, absorbed energy, and percentage of absorbed energy. Less firm fruit has lower peak force, longer contact time, longer time-to-peak force, lower F/T, more absorbed energy, and a greater percentage of absorbed energy.

RESULTS

The effects of cultivar, fruit mass, and ripeness stage on various impact forces, bruise incidence, and bruise volume were tested. Although fruit mass increased with advancing ripeness, peak force was not related to degree of ripeness (Table 1). Because peak force was strongly influenced by fruit mass and drop height, another parameter was computed by dividing the peak force by the time-to-peak force, *F*/*T*. This ratio *F*/*T* was affected by stage of ripeness and cultivar, but not fruit mass. *F*/*T* was strongly correlated to flesh puncture force. By comparing rankings for fruit firmness by cultivar and overall ripeness stages, the results for *F*/*T* indicate the range from; 'Topaz', 'Ranger', 'Glohaven', to 'Elberta' in order of most to least firm, respectively.

Contact time increased, by as much as 50 %, with more ripe peaches. Contact time was well correlated with *F*/*T* values in ranking the different cultivars. The total absorbed energy at impact (*AE*) increased with stage of ripeness (Table 1). Standard deviations for *AE* increased with stage of ripeness, indicating that the energy absorbed at impact for riper fruit was more variable than that for less ripe fruit. Absorbed energy is expected to be dependent on fruit mass and this proved so. To eliminate the mass effect and reduce the variability between fruit, energy absorbed during impact was expressed as a percentage of the input energy (*%AE*; [4]). The *%AE* values did not

Table 1. Impact parameters for four peach cultivars and three ripeness stages[z]

Ripeness stage[y]	Peak force (N)	F/T (N/ms)	Contact time (ms)	Absorbed energy	
				(J x 10^3)	(%)
			Ranger		
1	108 (16)	67 (11)	3.5 (0.6)	31 (8)	55 (3)
2	96 (7)	49 (7)	4.4 (0.7)	35 (9)	57 (4)
3	98 (19)	40 (6)	5.5 (0.7)	50 13)	62 (3)
			Topaz		
1	119 (12)	78 (12)	3.3 (0.4)	31 (6)	53 (8)
2	138 (11)	66 (7)	4.6 (0.2)	49 (4)	54 (4)
3	150 (4)	60 (3)	5.4 (0.2)	76 (6)	63 (3)
			Glohaven		
1	121 (18)	61 (10)	4.3 (0.8)	42 (20)	53 (5)
2	116 (7)	57 (5)	4.5 (0.6)	44 (8)	58 (3)
3	119 (16)	52 (6)	5.0 (0.4)	52 (6)	68 (6)
			Elberta		
1	108 (10)	53 (8)	4.4 (0.4)	42 (6)	60 (4)
2	104 (15)	47 (7)	4.9 (0.4)	49 (8)	65 (3)
3	84 (12)	32 (4)	6.1 (0.3)	58 (9)	73 (3)

[z] All data are represented as means of seven measurements with standard deviations in parentheses.
[y] Ripeness stages were determined based on fixed L, a, and b values obtained from the greenest area of peaches: 1=thresahold-mature, 2=mature, 3=firm ripe.

increase in variability appreciably with increasing stage of ripeness. Between cultivars, there was a consistent ordering of *%AE* into two groups: 'Elberta' absorbed a higher percentage of energy than did the other three cultivars. Bruise volumes increased with drop height and stage of ripeness. Standard deviations were often larger than the mean values, partly because many drops produced no bruises at these drop heights of 5 to 15 cm.

During the first four days after being picked, the *F/T* values for uncooled peaches decreased 60-70 % (Table 2), contact time increased 40-60 %, and the absorbed energy increased 15-25 %. With cool storage, the change in impact parameters was small during the first four days in storage but between 4 and 13 days there was a noticeable change (Table 2). Contact time and *F/T* values had the largest changes with extended storage time; the other impact parameters were not significantly different.

Table 2. Mean (coefficient of variation, %) peach impact peak force/time-to-peak force (N/ms)

Ripeness stage	Cooling method	Before cooled	Storage time (days)			
			2	4	8	13
1	No cooling	109.3 (24)	63.8 (26)	41.3 (24)		
	Low RH air		76.3 (25)	49.5 (27)	29.1 (23)	
	Hi RH air			01.6 (25)	73.9 (20)	67.9 (14)
	Hydrocooled			99.8 (14)	73.5 (21)	55.9 (20)
2	No cooling	81.5 (28)	47.6 (19)	26.8 (20)		
	Low RH air			65.9 (21)	32.9 (27)	26.7 (26)
	Hi RH air			88.2 (17.1)	64.9 (25)	65.9 (31)
	Hydrocooled			53.6 (29.9)	55.0 (20)	44.7 (22)

The difference in impact parameters among the cooling methods was not significant after four days in storage, although, those fruit stored at 4 °C/93 % *RH* usually had impact values more attributable to firmer peaches than those stored at 6 °C/68 % *RH*. After 13 days in storage, differences were more detectable among the storage conditions. Fruit were less firm when cooled and stored at 6 °C/68 % *RH* than when stored at 4 °C/ 93% *RH*, with or without hydrocooling. Average values for contact time and *F/T* values showed the greatest difference, although these were not always significant.

The differences in impact parameters between peaches picked in the cool morning compared to the hot afternoon were not evident during early storage. Average values of the dependent impact parameters showed the greatest loss in firmness after 13 days in storage for peaches picked during the hot afternoon. Picking in the early morning vs. late afternoon was a distinguishing factor, however, when fruit were held to the end of their marketable storage life.

CONCLUSION

Parameters for impact of a fruit onto a flat hard surface were identified which were correlated with recognized measures of bruise resistance. Most of the impact parameters changed with ripeness. At constant drop height, ripeness was related to *F/T* and percent absorbed energy. Ripeness and drop height were highly correlated with the percentage of fruit bruised and bruise volume. Features of the impact force versus time curve are related to firmness and can be utilized in non-destructive grading and sorting of fresh fruit and in management decision-making.

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