Proc. Fla. State Hort. Soc. 117:373-377. 2004.

IMPACT THRESHOLDS TO MAXIMIZE POSTHARVEST QUALITY OF ROMA-TYPE TOMATO

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Additional index words. Lycopersicon esculentum, Roma tomato, impact injury, postharvest quality

Abstract. **Tomato (*Lycopersicon esculentum Mill.*) is one of the highest volume vegetables sold for fresh consumption. In recent years, the consumption of specialty tomatoes, e.g., roma, cluster, grape, and mini-pear types, has increased. However, there is little reliable postharvest information available for growers and shippers to maintain the quality of specialty tomatoes. Damage from bruising due to improper handling and shipping is one of the major causes of poor quality of fresh tomatoes. Experiments were conducted to determine the effect of impact force on roma tomato quality. Fruits were harvested at mature-green stage and treated with ethylene (100 ppm; 20 °C, 90% relative humidity (RH)) for 60 hours to initiate ripening. Breaker-stage fruits were individually suspended and impacted by a pendulum (230 g) with angles equivalent to vertical drops of 20 cm, 40 cm or 60 cm, and then stored at 20 °C with 90% RH. Fruits impacted with force equivalent to 40 or 60 cm drop ripened to full red color stage (Hue angle = 36-38) 1 to 2 days faster, and had 25-40% more peak ethylene and 15% more peak CO_2 production than control. Roma tomatoes impacted with the force equivalent to 20 cm height drop were not significantly different from the control fruits. However, impact force caused no significant differences in electrolyte leakage, total titratable acidity, pH, or total soluble solids content. Severe internal bruising was not observed in any treatment. Therefore, it can be concluded that a drop of 40 cm or more caused significant loss of postharvest life, but did not affect the quality of fresh, roma-type tomato.**

Tomato (*Lycopersicon esculentum* Mill.) is one of the highest volume vegetables sold for fresh consumption. In 2002, about 1.8 million tons of tomatoes were produced in the US. Florida, the No. 1 tomato producer in the US, produced about 40% of the US total production, 0.7 million ton (National Agricultural Statistics Service, U.S. Dept. of Agriculture). Since the mid-1990s, demand for fresh flavor tomatoes has grown, which has promoted introductions of several specialty tomatoes—such as roma, cherry, cluster, grape, and mini-pear types in the food market.

However, tomatoes are packed after at least 15 handling steps. Damage from bruising during improper handling and shipping is one of the major causes of poor quality of fresh tomatoes. Wright and Billeter (1975) reported that mechanical injury was the leading cause of quality loss at wholesale and retail levels for apples, peaches, potatoes, and strawberries. Peleg (1984), noted that bruising losses in some fruit and vegetable crops might reach about 30% of the yield. The U.S. $1.2 billion apple and the $280 million pear industries also suffer substantial losses each year due to bruising (USDA, 1999). Annually, billions of dollars are spent to reduce bruising in fruits and vegetables.

Static pressure, impacts, strong shocks, or vibrations could induce bruise on tomatoes. Halsey (1955) reported that impacts caused more bruising on tomato rather than static pressure. Impact bruising resulted from dumping, sorting, tossing or dropping onto hard surfaces. McColloch (1962) reported much of the bruising injury is internal, and is not visible on the outside of the tomato. Externally bruised fruits can be eliminated during processing, but internal bruising easily can be overlooked. Although internal bruising is hidden damage, its symptom is severe. Internal bruising of tomato was described by Halsey (1955) as "water-soaked cellular breakdown of crosswall and locular areas" and by Hatton and Reeder (1963) as "breakdown of the locular gel from the normal, clear pink to a cloudy, yellowish, stringy, collapsed, disorganized and gelatinous tissue".

Incidence of bruising injury was influenced by the kind of tissue damaged, by the stage of maturity, and by the severity of the treatment. Moretti (1998) reported locules are the most visibly affected and vulnerable tissue to bruising. Also, it was reported by McColloch (1962) that the damage increased with the drop height and maturity, and fruits at turning ripeness stage were four times more sensitive to bruising as at mature green (Halsey and Showalter, 1953). Sargent et al. (1992) showed 73% of breaker stage tomatoes dropped once from 10 cm onto a hard surface later showed internal bruising, whereas only 5% of tomatoes dropped at green stage developed the disorder. Also, there are cultivar differences in impact damage susceptibility (Halsey, 1963; MacLeod, 1976).

Mechanical injury has been correlated with metabolic disorder and quality change. C_2H_4 production increased within 1hr after tomatoes were dropped (MacLeod et al., 1976). In winter squash, this was related to increases in 1-aminocyclopropane-1-carboxylic acid (ACC) syntheses and ACC oxidase (Hyodo et al., 1993). Increased respiration rate was reported in impacted peas and beans (Tewfik and Scott, 1954), apples (Dewey et al., 1981), cherries (Mitchell et al., 1980), and sweet potatoes (Saltveit et al., 1982). Also, soluble solid content decreased in grapes (Morris et al., 1979), firmness decreased in cucumbers (Miller et al., 1987), and aroma volatiles changed in tomatoes (Moretti et al., 2002).

This study was designed to determine the potential effect of impact force on roma tomato quality.

Materials and Methods

Plant material. Roma tomatoes ('BHN 467') were hand-harvested at mature-green color stage near Immokalee, Fla, on 9 Feb. 2004. Harvested fruits were transported to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville. Green tomatoes were stored in sealed containers with flow through air containing 100 ppm ethylene for 60 h at 20 °C, 90% R.H. At breaker stage, tomatoes were sorted, washed with chlorine solution (pH 6.8-6.9), rinsed and dried

This research was supported by the Florida Agricultural Experiment Station, and approved for publication as Journal Series No. N-02559.

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by air. After impact treatment, two roma tomatoes were placed in each clamshell (8 replications) and ripened at 20 °C with 90% R.H. Respiration rate and ethylene production were measured daily for 13 d and the other data were collected when individual tomatoes reached full-red ripeness stage (3 d after light-red stage).

Pendulum impactor. To impact on the surface of tomatoes, a pendulum (230 g) was used. Two steel stands were connected by a steel cross-bar; a pocket to suspend the tomato was hung from the cross-bar. A sliding bar stand in the middle of the board was marked to indicate desired angles (equivalent to vertical drops of 20 cm, 40 cm or 60 cm). Drop force was converted into pendulum impact force by solving the following set of equations;

1) $Mrg = mhg$

   Where, M = mass of pendulum, r = drop height of pendulum,

   g = gravitational acceleration (9.8 m/s^2), m = mass of tomato, h = drop height of tomato

   Solving for r, $r = (m/M)h$.

2) $\cos\theta = (L - r)/L$

   Where, L = length of string of pendulum, θ = angle of pendulum

   Substituting for r, $\cos\theta = (L - (m/M)h)/L$

Tomatoes were marked with white marker pencil on the locule surface suspended in the pocket, and impacted by the pendulum from desired angles. Tomatoes were caught after just one impact.

Ripening rate. Ripening of each roma tomato fruit was determined subjectively using the percent of red color on the surface of fruits according to U.S. Dept. of Agric. Grade Standards. Fruits were considered to reach full-red ripeness stage 3 d after all surface of fruit reached orange-red color. At that time, the hue angle was from 36 to 38°.

Electrolyte leakage. Electrolyte leakage was measured using a conductivity bridge (YSI 3100 conductivity instrument) equipped with a conductivity electrode at full-red ripeness stage (3 d after light red) and at 18 d after impact treatments. Pericarp discs (n = 7) of 1.5 cm diameter, trimmed of locular gel tissue, were excised using No. 4 Cork borer from each fruit. Discs were rinsed with distilled water, briefly dried on Whatman #4 filter paper, and transferred into 10 mL of 300 mM mannitol solution in a 50 mL capped centrifuge tube. After each sample was shaken for 4 h, electrical conductivity was read. Samples then were frozen at -20 °C for 24 h. The next day sample was thawed at room temperature, boiled in water for 15 min, and the final conductivity was taken to determine total electrolyte conductivity. All leakage data were expressed as a percentage of the total electrolyte conductivity, where initial conductivity was divided by total conductivity, and multiplied by 100.

Respiration and Ethylene measurements. Two tomatoes were weighed and placed in a 1025 mL plastic container, loosely capped with plastic lids fitted with a rubber septum and stored at 20 °C. Every 24 h, the containers were sealed for 1 h, followed by removal of a 0.5 mL sample (for CO_2) and 1.0 mL sample (for ethylene) of the head space from each container. Right after impact treatment, measurements were conducted every 2 hr for 24 h. Carbon dioxide concentration and ethylene production rate were measured using a gas chromatograph fitted with a thermal conductivity detector and a ¼-inch Carbopack column (series 580; GOW MAC, Bridgewater, N.J.) and fitted with a flame ionization detector and alumina packed column (HP 5890; Hewlett Packard, Avondale, Pa.).

Supernatant preparation. Upon reaching the evaluation stage, individual fruits were homogenized, followed by centrifugation at 15K RPM, 5 °C for 20 min. The resulting supernatant was filtered using cheesecloth and then frozen for later analysis of the following parameters.

Soluble solids content. One to two drops of the supernatant as prepared above was placed on the prism of the digital refractometer (Model 10480, Reichert-Jung, Mark Abbe II Refractometer, Depew, N.Y.) and the soluble solids content (SSC) was reported as °Brix.

pH. The pH was determined from the same supernatant with a pH meter (pH meter 140, Corning Scientific Instruments, Medfield, Mass.) standardized with pH 4.0 and 7.0 buffers.

Total titratable acidity. Each sample supernatant (6 g) was weigh out and diluted in 50 mL of distilled water. The samples were analyzed by an automatic titrimeter (No. 9-313-10, Fisher Titrimeter II, Pittsburgh, Pa.), titrated with 0.1 N NaOH to endpoint of pH 8.2. TTA was expressed as percentage of citric acid.

Statistical analysis. All data was subjected to analysis of variance and treatment means were compared using Duncan's Multiple Range Test ($P < 0.05\%$).

Results and Discussion

Day to full-red ripe. Days to ripe were inversely related to impact force. Tomatoes impacted with the force equivalent to 60 cm height drop reached at full red-ripeness stage about 1 day earlier than non-impacted ones (Table 1). Those impacted with 40 cm or 20 cm drop height ripened between these days.

Incidence of internal bruising. There was no significant difference in internal bruising. Even though some bruising symptoms, such as detached gel, color change, were observed, impact treatments didn't induce more internal bruising.

Electrolyte leakage. The electrolyte conductivities of all treatments were similar (about 16%), and also there was no significant difference in conductivity 18 d after treatment (about 20 ~ 23%). As reported in other fruits, electrolyte leakage in roma tomato gradually increased during ripening. This means the deterioration of cell membranes in pericarp tissue, since electrolyte leakage is the indicator of cellular membrane integrity (Wilson and McMurdo, 1981). In addition, the deviation within each treatment was higher at late ripen-

Table 1. Days to full-red ripeness stage after impact treatments.

Treatment	Days
Control	10.13 ± 2.17 a[y]
I-20[z]	9.58 ± 1.79 ab
I-40	9.33 ± 1.52 ab
I-60	9.08 ± 1.56 b

[z]I-20, I-40, or I-60 means impact treatment with the force equivalent to 20, 40, or 60 cm height drop, respectively.
[y]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

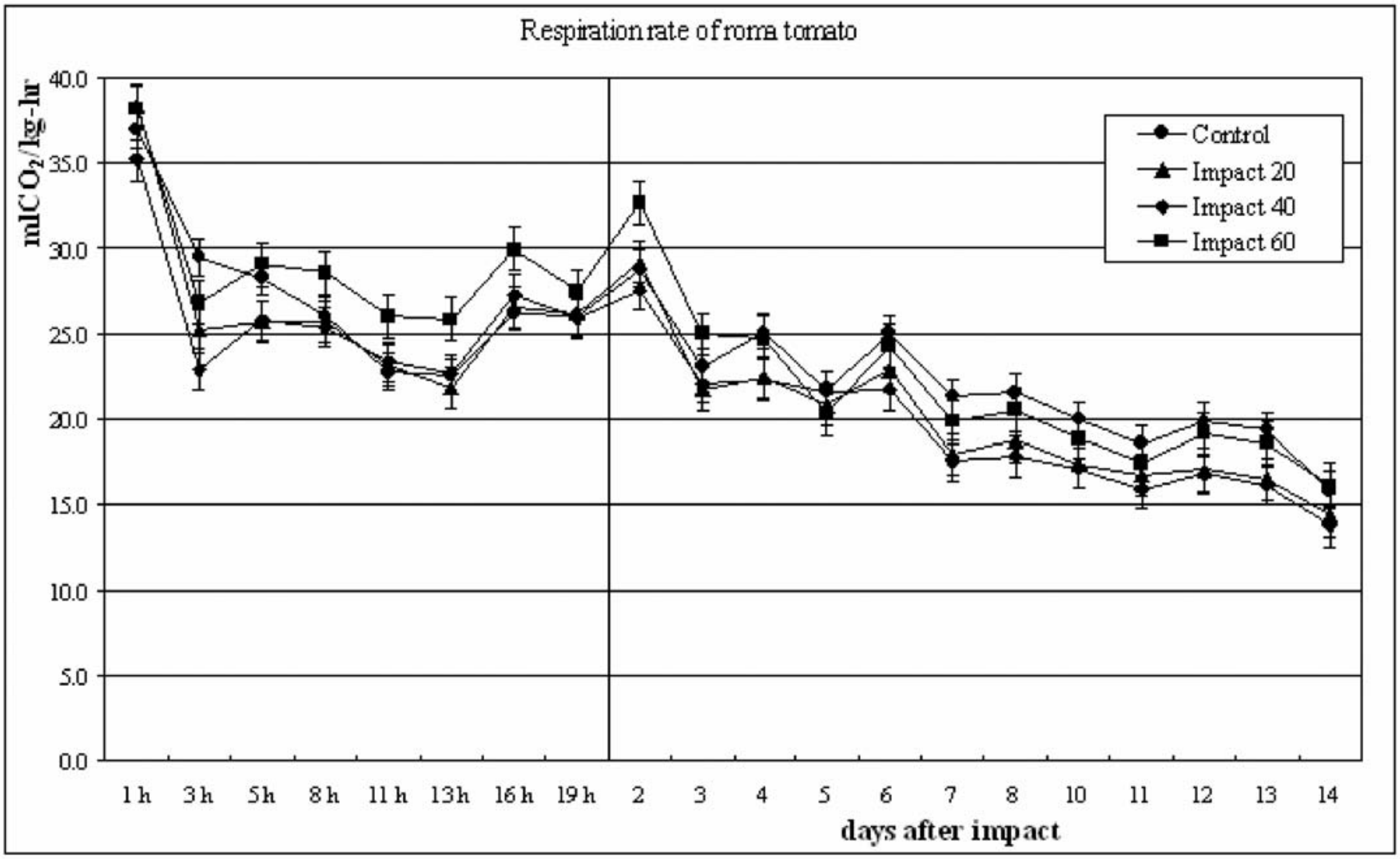

Fig. 1. Respiration rate of roma tomato during ripening at 20 °C.

ing stage, which indicates individual fruit has different resistance against disruption of cell wall tissue.

Respiration measurements. Both impacted and non-impacted tomato produced decreasing amounts of CO_2 and showed no peak during storage (Fig. 1). The initial CO_2 production of roma tomato was from 35 to 38 mL CO_2/kg h^{-1}, and a little peak of CO_2 production was seen 2 d after impact treatment. During first 2 d, fruits at breaker stage ripened to turning ripeness stage. And tomatoes impacted with the largest force (32.65 mL CO_2/kg h^{-1}) produced 15% more CO_2 than control tomato (28.79 mL CO_2/kg h^{-1}). After 2 d storage at 20 °C, there was no significant difference in the amount of peak among the treatments. An interesting observation was the fact that all impacted fruits produced less CO_2 than non-impacted ones 3hr after impact treatments, which may indicate that the impact stress induced some self-defense reactions in roma tomatoes. Tomatoes impacted with the force of 60 cm height drop consistently produced more CO_2 consistently during 5-24 h after the impact treatment than tomatoes from the other treatments.

Ethylene production. Tomatoes from all treatments exhibited a climacteric peak in ethylene production. Tomatoes impacted with the force of 40 or 60 cm height drop produced ethylene in a similar trend, while fruits impacted with the force of 20 cm height drop or not impacted had similar pattern of ethylene production (Fig. 2). Impact of 60 cm height drop force caused the highest increase in ethylene production of tomato. Also, tomatoes impacted by the force of 40 or 60 cm height drop showed the peak of ethylene production 4 ~ 6 d earlier and produced 25% or 40% more than control fruit, respectively.

Chemical analysis. The values for total titratable acidity (TTA), soluble solids content (SSC), and pH was similar for control and impacted fruits (Table 3). TTA ranged from 0.45 to 0.52%, and SSC of tomato impacted with the force of 40 or 60 cm height drop (2.55 and 2.5 °Brix, respectively) was slightly higher than tomatoes not impacted or impacted with the force of 20 cm height drop (2.18 or 2.20 °Brix, respectively). Roma tomato was acidic (about pH 4.4). In tomato flavor, sugar/acid ratio is more important than increasing sugar content or acidity. Although there was no significant difference among treatments, impacted tomato showed slightly higher ratio than non-impacted one. The sugar/acid ratio of tomatoes impacted with the force of 60 cm height drop (5.41) was about 23.5% higher than non-impacted fruit (4.38).

Table 2. Electrolyte leakage measurement 3 d after light red ripeness stage and at 18 d after treatments.

	Electrolyte Conductivity (%)	
Treatment	3 d after light red	18 d after treatments
Control	15.86 ± 1.38 a[z]	20.45 ± 3.55 a
I-20	15.99 ± 1.44 a	20.64 ± 3.84 a
I-40	16.29 ± 1.91 a	23.60 ± 4.86 a
I-60	16.19 ± 1.55 a	20.22 ± 3.82 a

[z]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

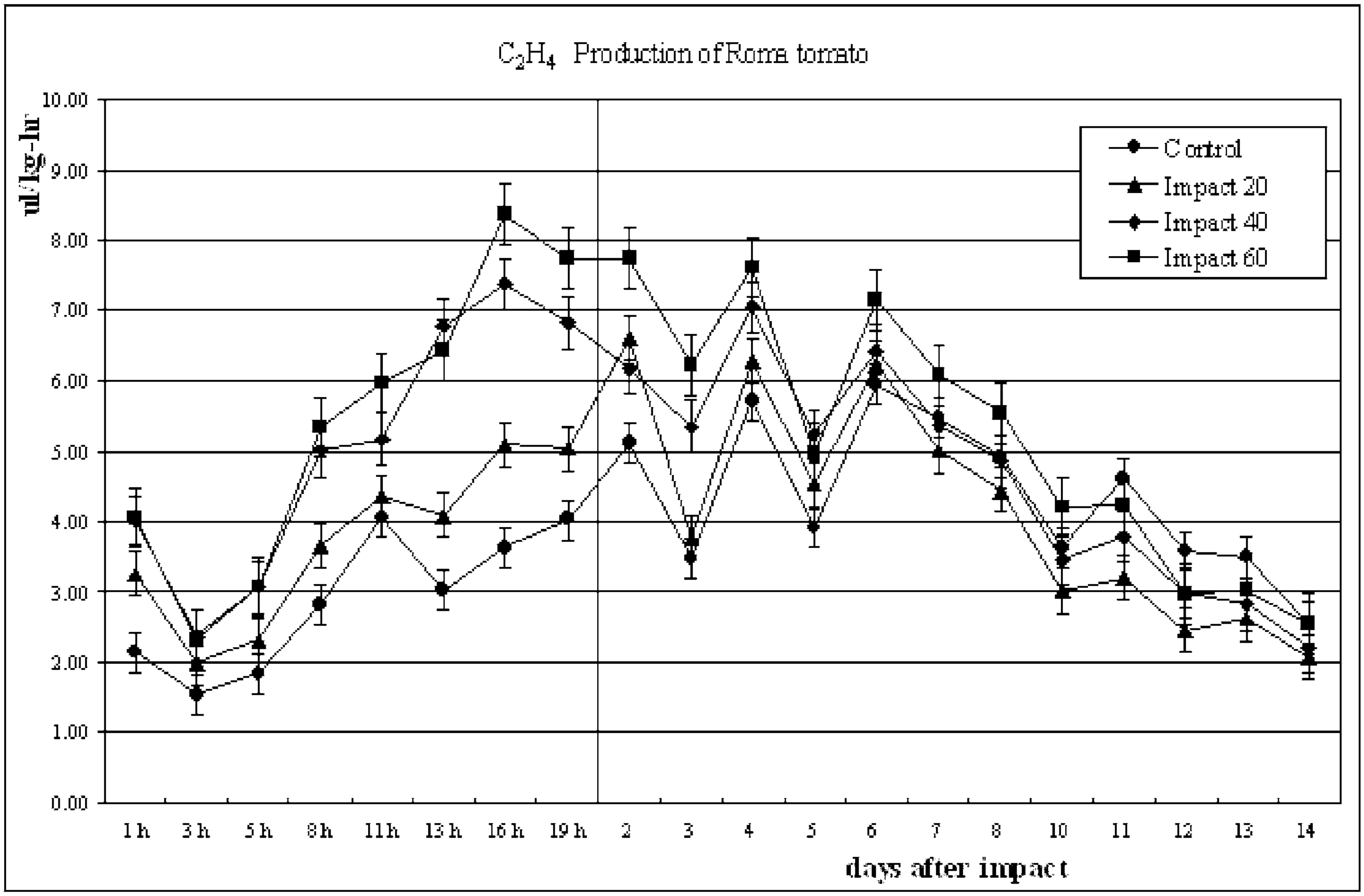

Fig. 2. Ethylene production of roma tomato during ripening at 20 °C.

Table 3. Chemical analysis at full red-ripeness stage.

Treatment	pH	SSC[z] (°Brix)	TTA (%)	Sugar/acid ratio
Control	4.42 ± 0.09 a[y]	2.18 ± 0.69 a	0.515 ± 0.156 a	4.38 ± 2.86 a
I-20	4.39 ± 0.08 a	2.20 ± 1.07 a	0.500 ± 0.098 a	5.06 ± 2.88 a
I-40	4.41 ± 0.04 a	2.55 ± 0.65 a	0.451 ± 0.213 a	5.06 ± 2.05 a
I-60	4.40 ± 0.05 a	2.50 ± 0.35 a	0.488 ± 0.110 a	5.41 ± 1.59 a

[z]SSC = Soluble Solids Content; TTA = Total Titratable Acidity (citric acid equivalent).
[y]Columns with different letters are significantly different at $P < 0.05$, according to Duncan's Multiple Range Test.

The force of a 20 cm drop did not cause loss of quality or physiological change, which means Roma tomato is less susceptible to impact injury than round tomatoes. In 1992, Sargent et al. reported round tomato developed internal bruising after a 10-cm drop. In the present study, ripening rate and ethylene production were accelerated with an impact equivalent to 40- or 60-cm height drop. Roma-type tomatoes are subjected to several impact opportunities during commercial harvesting, packing and transportation, so the effect of impact on the tomato is cumulative. To maximize the quality of roma-type tomatoes, careful handling is necessary to protect against frequent and high drop heights.

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