Damage to intact fruit affects quality of slices from ripened tomatoes

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ARTICLE INFO

ABSTRACT

Breaker stage fruit (cvs 901 and Bobcat) were subjected to different types of physical damage: 3 impacts of a steel ball (67 g) from a height of 33, 66 or 99 cm, 8 impacts of the ball from 99 cm, or dropping the fruit once 1 m onto a hard surface. Fruit were then held at 20 °C until full red, sanitized, sliced and stored at 5 °C. Damaged fruit were less firm than undamaged fruit when ripe. Slice quality (appearance, translucency, lycopene content, juice loss) and shelf-life were affected by damage to the fruit. Lycopene concentrations were higher in undamaged (4.0 mg/kg) than damaged fruit (3.5 and 2.7 mg/kg with 3 impacts from 99 cm and drop damage) and decreased during storage at 5 °C. Translucency increased with time and onset was more rapid in moderate to high damage fruit. Juice loss was higher in slices from undamaged (6—8 g/100 g FW) than damaged fruit (1—4 g/100 g). Severe damage resulted in collapse of locular tissue and moderate damage may have induced mealiness. PG activities differed little between slices from severely damaged and undamaged fruit and no differences in PME activities were found.

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1. Introduction

Tomato fruit are often subjected to postharvest physical injuries, with bruising being a common type of mechanical damage. Bruise susceptibility is a measure of the response to external loading and depends on a number of elements such a variety, texture, maturity, water status, firmness, temperature, size, and shape (Mohsenin, 1970).

Many studies have focused on various aspects of mechanical damage in tomato. Sargent, Brecht, and Zoellner (1992) studied the development of internal bruising of tomato fruit damaged in early ripening stages. Other authors studied the effect of mechanical impact on bruise susceptibility (Van linden, De Ketelaere, Desmet, & De Baerdemaeker, 2006a, 2006b). Devaux et al. (2005) investigated how mechanical breakdown can influence the development of mealy tissue in tomato, while Moretti, Sargent, Huber, Calbo, and Puschmann (1998) analyzed the chemical composition of tomatoes with internal bruising. Internal bruising can alter the aroma of tomato fruit (Kader, Morris, Stevens, & Albright-Holton, 1978; Moretti, Baldwin, Sargent, & Huber, 2002) and affect enzyme activity in whole tomatoes (Van linden, Sila, Duvetter, De Baerdemaeker, & Hendrickx, 2008). In many fruit an altered balance of PG and PME could lead to incomplete cell wall pectin degradation (Crisosto & Labavitch, 2002) and the development of mealy tissue. In tomatoes, mealy texture could also be related to chilling injury (Jackman & Stanley, 1995; Rugkong et al., 2010).

The preparation and storage conditions to maintain the quality of fresh-cut tomato have been well studied (Aguayo, Escalona, & Artés, 2004; Artés, Conesa, Hernández, & Gil, 1999; Gil, Conesa, & Artés, 2002; Hong & Gross, 2001; Odriozola-Serrano, Soliva-Fortuny, & Martín-Belloso, 2008a, 2008b). However, limited information exists about how the initial quality of the intact fruit affects the quality and shelf-life of the fresh-cut product. Raw material quality is considered to be very important for quality of the fresh-cut product, and mechanical injuries before, during and after cutting are major contributors to more rapid deterioration in minimally processed fruit (Kader, 2002).

The aim of this work was to evaluate the effect of damage to tomatoes at early ripening stages on the subsequent quality, enzyme activity and shelf-life of slices from ripened fruit.

2. Materials and methods

Tomato fruit from two common fresh market field-grown cultivars were subjected to different damage treatments at the breaker

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(external red color no more than 10%) to turning (red color 30%) stages (USDA color classification; C.F.R., 1991). After ripening at 20 °C, fruit were sliced and the quality of the fresh-cut product was evaluated during storage at 5 °C. Three different experiments were carried out.

2.1. Experiment one: low to moderate damage

Tomatoes (cv 901) were harvested in August 2010 at the mature-green stage at a commercial grower in northern California. Fruit (large size = 6.4 cm average diameter = 190 g average weight) were carefully handpicked to avoid injuries, transported to the laboratory and held overnight at 20 °C, and then treated with ethylene (50 ppm) at 20 °C for 48 h to promote ripening (Cantwell, 2010). After ethylene treatment, only breaker color stage fruit were selected based on color, size and absence of defects. Tests consisted in dropping a 2 cm stainless steel ball (67 g) 3 times on three equidistant points at the equator of the fruit. The ball was dropped through a cylinder from a height of 33 cm (treatment 1F) or 66 cm (treatment 2F). These treatments were compared with undamaged tomatoes (=NO damage, treatment NO). After inflicting the impact damage, the bruised areas were marked, and damaged and undamaged fruit were stored at 20 °C [80–85% relative humidity (RH)] until red ripe stage (stage 6 USDA) or hue 43. Nine fruit per treatment were evaluated at 0 day (=3 h after slicing) and at 3, 7 10, 13 days from slicing and storage at 5 °C.

2.2. Experiment two: moderate to high damage

Tomatoes (cv Bobcat, large size = 6.4 cm diameter = 180 g average weight) were harvested in September 2010 at the mature-green stage at a commercial grower in northern California. Fruit were handled as in the previous experiment. Breaker stage fruit were subjected to the following controlled damage tests: dropping a 2 cm stainless steel ball 3 times on the fruit from a height of 66 cm (treatment 2F) or 99 cm (treatment 3F) or dropping the whole fruit on the blossom end from a height of 100 cm onto a hard surface (treatment D). The control treatment was undamaged fruits (treatment NO). Fruit were stored at 20 °C (80–85% RH) until red ripe and at 5 °C after slicing. Twelve fruit per treatment were evaluated at −10 (=1day after damage), −5, −1, 0 (=3 h after slicing), 6, 10 days from slicing.

2.3. Experiment three: severe damage

Fruit (cv 901) at the breaker stage were obtained from the northern California grower's repack facility in July 2012. Fruit (small-medium size = 5.4 cm average diameter = 100 g average weight) were manipulated as in the previous experiments except that the fruit were handled commercially and the ethylene treatment was given at the repack facility. With the purpose of understanding the effect of the damage on enzyme activity, fruit at early ripening stage (between breaker and turning, average score of 2.7) were subjected to severe damage (SD), dropping a 2 cm stainless steel ball on the fruit from a height of 99 cm eight times per fruit at four different locations (two times per location). A control undamaged treatment was used for comparison (treatment NO). Fruit were stored at 20 °C (80–85% RH) until red ripe and at 5 °C after slicing. Twelve fruit per treatment were evaluated at −8 (=3 h after damage), −7, −4, −1, 0 (=3 h after slicing), 6, 11, and 14 days from slicing.

2.4. Slice preparation

When fruit reached red color with average peel hue 43 for cv 901 and hue 40 for cv Bobcat, they were held at 10 °C in a clean area for 16 h to ensure a pulp temperature of 10 °C, sanitized in 50 ppm sodium hypochlorite (pH 7) for 1 min, rinsed in potable tap water for 1 min and blotted dry with paper towels. A manual tomato slicer (Nemco model II, Phoenix AZ, USA) with razor sharp blades was used to slice the fruit perpendicularly to the stem axis, obtaining slices 4.5 mm thick. To minimize dehydration during storage and to simulate commercial preparation, all slices, included the ends, were regrouped to reconstruct the initial whole tomato. Each sliced tomato was placed in a small polypropylene tray and trays were covered by food-grade plastic film (not sealed) and placed on a large tray inside a polyethylene bag at 5 °C. Nine (expt. 1) or twelve (expt. 2 and 3) fruit were analyzed for each treatment and evaluation date.

2.5. Quality evaluation

Firmness of the whole fruit was analyzed on a texture analyzer (TA.XT PLUS Stable Micro Systems, Goldaming, UK) as the force to compress the fruit 5 mm at the equator using a flat cylinder (25 mm diameter) moving at 1 mm/s. External color of the whole fruit was measured with a Minolta CR200 colorimeter (Konica Minolta Sensing, Inc., Osaka, Japan). The L^* (Lightness), a^* (red-green) and b^* (yellow-blue) parameters (CIELAB Color Space, 1976) were recorded (3 equally spaced measurements at the equator) and hue was calculated as arctangent b^*/a^*. Slice color was determined on the parenchymatous tissue in three equidistant points on the top slice of 3 stacked slices.

Juice loss is one of the major problems with sliced tomato quality. For this reason, after slicing and during storage at 5 °C, total juice loss was evaluated. Immediately after slicing (day = 0) the measure of juice loss was based on the weight difference (nearest 0.01 g) between the whole fruit and the reconstructed sliced fruit. During storage at 5 °C, the amount of juice released from the sliced fruit was weighed when slices were evaluated. For this, the reconstructed fruit were kept at room temperature until their internal temperature (measured by a needle probe thermometer) reached 16 °C (1–2 h). The total juice loss was calculated as: [(Juice loss after slicing (g) + Juice loss during storage (g))*100 (g)]/initial fruit weight (g). We considered a juice loss of <3 g/100 g fresh weight (FW) as low, 4–6 g/100 g FW as moderate, and >6 g/100 g as high.

Visual quality of the slices was scored by the same experienced operator under the same light conditions. A 9–1 scale was used, where 9 = excellent, fresh appearance, 7 = good, 5 = fair, limit of marketability, 3 = poor, limit of usability, 1 = unusable. Typical aroma, translucency and dehydration of the slices were scored on 1–5 scales, where 1 = none, 2 = slight, 3 = moderate, 4 = almost typical aroma or moderately severe, and 5 = maximum or severe.

Tomato fruit can differ in the number of locules and in the quantity of locular tissue (composed of gel and tissue that can liquefy) in the locular cavity. To assess fruit uniformity, the surface filled by locular tissue (LT) was evaluated visually once, just after slicing, on the central slice of each tomato using a 1–4 scale where: 1 = low (LT was less than *1/10* of the slice surface), 2 = medium-low (*1/10* < LT < *3/10* of the slice surface), 3 = medium (*3/10* < LT < *5/10* of the slice surface), 4 = high (LT > *5/10* of the slice surface).

Two central slices per tomato were homogenized and centrifuged for determination of soluble solids content (SSC) by a digital refractometer (model PR 100 Atago U.S.A. Inc, Bellevue, USA), pH and titratable acidity (TA) using NaOH (0.1 mol equiv/L) to titrate to 8.1 pH endpoint and calculating TA as mg citric acid/100 g FW.

2.6. Lycopene

Lycopene extraction and determination were based on the spectrophotometric method of Davis, Fish, and Perkins-Veazie (2003). A pooled sample from two central slices of each of three

tomatoes (three replicates per treatment per evaluation) was pureed in a commercial blender and 4 g of this tomato pulp and 4 mL water were further blended in an Ultra Turrax homogenizer. Then 0.6 g of homogenate was added to a solution containing 5 mL BHT (0.5 mg/mL), 5 mL ethanol 95% and 10 mL hexane 99.9% in amber glass tubes, shaken on ice at 180 rpm for 15 min, and held at room temperature for 15—20 min. Absorbance of an aliquot of the upper solvent was measured at 503 nm (Spectrophotometer UV—Vis 1700, Shimadzu, Columbia MD, USA) and lycopene concentration was calculated as mg/kg fresh weight.

2.7. Respiration and ethylene production

In experiment two, respiration and ethylene production rates were determined during ripening at 20 °C. Six fruit per treatment were placed in individual containers through which humidified air (RH ≈ 90—95%) flowed at rates to maintain CO_2 concentrations below 0.5 %. Rates were monitored daily by taking samples from the outlet streams of the containers, and CO_2 was determined by infrared analysis (model PIR-2000, Horiba, Japan) and ethylene by FID-gas chromatography (model 8A, Shimadzu, Columbia MD, USA). Standards of 0.5 % CO_2 and 1 ppm ethylene were used for calibration and calculations were based on difference between inlet and outlet concentrations.

2.8. Electrolyte leakage

A method modified from Saltveit (2002) was used for ion leakage evaluation. Two rectangular pericarp portions 1 cm long and 4.5 mm thick were excised with a razor blade from two opposite sides of the central slice of each of four tomatoes (when whole fruit were analyzed, they were sliced just before taking samples). For the damage treatments, samples were always taken from the bruised areas, previously circled externally with a felt tip pen at the moment of bruising. Three replications were made for each treatment and evaluation. Pericarp portions were immediately washed three times in deionized water for 1 min then blotted dry with paper towels, put into 50 mL tubes with 25 mL of mannitol solution (0.2 mol/L) and gently shaken for 1 h. After shaking, initial conductivity of the solution (μS/cm) was measured with a digital conductivity meter (Accumet AR20, Fisher Scientific, Waltham, MA, USA) and the tubes were frozen at −20 °C. For total conductivity, the frozen samples were held at room temperature for 24 h, shaken for 1 h, and conductivity measured. Electrolyte leakage of the samples was calculated as the ratio between initial conductivity and total conductivity.

2.9. Enzyme activity

Locular (LT) and parenchymatous (PT) tissue from three central slices of each tomato were separated using the scraper end of a stainless steel spatula and placed immediately in a 50 mL tube, frozen in liquid nitrogen, and stored at −80 °C until analysis. PT samples were ground in a mortar with liquid nitrogen and again stored at −80 °C until analysis (few days) while LT samples were simply thawed, filtered through 1 layer of cheesecloth, and immediately utilized to prepare extracts. Three repetitions per time and treatment were made for PT and for LT, each of them pooling the tissue from 4 tomatoes.

2.9.1. Pectinmethylestrase activity

The PT or LT samples were added (1:1) to a cold NaCl solution (3 mol/L) shaken in ice for 1 h and centrifuged at $20,000 \times g$ and 4 °C for 30 min. The supernatant was filtered (Whatman filter paper 4), adjusted to pH 7.5 with concentrated NaOH, and stored a few days at −80 °C. PME activity was assayed using the method of Hagerman and Austin (1986). An aliquot of 50 μL was mixed with

Table 1
Firmness and peel color of whole tomatoes subjected to damage and ripened at 20 °C to full red. NO = No damage; 1F = 3 drops of a 67 g stainless steel ball from a height of 33 cm; 2F = 3 drops of a ball from 66 cm; 3F = 3 drops of a ball from 99 cm; D = dropping fruit 99 cm onto the blossom end; SD = severe damage caused by dropping the ball 8 times from 99 cm. Different letters within a column for a given experiment indicate significant differences at $p < 0.05$ (DMR test).

Experiment	Treatment	Firmness (N)	Color (Hue)
Expt. 1 cv 901 (N = 45)	NO	23.6 b	43.6 a
	1F	22.9 ab	42.9 a
	2F	21.9 a	43.6 a
Expt. 2 cv Bobcat (N = 36)	NO	19.5 b	41.2 a
	2F	19.1 b	40.9 a
	3F	17.8 a	41.3 a
	D	17.4 a	41.5 a
Expt. 3 cv 901 (N = 48)	NO	21.5 a	45.4 a
	SD	21.2 a	43.3 a

2 mL of citrus pectin (5 mg/mL), 850 μL H_2O and 150 μl of bromothymol blue (0.1 mg/mL) and the rate of decrease in absorbance at 620 nm was recorded after 3 min. A calibration curve was based on various amounts of Galacturonic acid (GalA).

2.9.2. Polygalacturonase activity

PT samples were extracted according to Van linden et al. (2008). Five grams of frozen PT or LT tissue were added to cold demineralized water (1.5:1 w/v), adjusted to pH 3, shaken for 15 min, centrifuged ($8000 \times g$, 20 min at 4 °C) and filtered (Whatman filter paper 4). This step was repeated twice, always recovering the pellet. The pellet was then suspended in 5 mL of NaCl (1.2 mol/L), adjusted to pH 6, and extracted by stirring for 3 h, keeping the pH constant. After extraction, the suspension was centrifuged ($20,000 \times g$, 20 min, 4 °C) filtered and stored at −80 °C until analysis (few days). PG activity was based on formation of reducing groups (Gross, 1982) where 350 μL of a buffered polygalacturonic acid solution (2 mg/mL, containing 0.04 mol/L of Na acetate at pH 4.4), and 50 μL of sample extract were mixed in 10 mL glass tubes. Reaction mixtures were incubated (35 °C) for 1.5 h then, 2 mL cold borate buffer (0.1 mol/L, pH 9) and 0.4 mL of a 2-cyano-acetamide solution (10 mg/mL) were added. Tubes were incubated for 10 min at 100 °C, immediately cooled in ice water and left at room temperature to equilibrate. The absorbance was measured at 276 nm. The final result was converted into concentration of reducing sugars using a standard curve of GalA in Na acetate buffer (0.04 mol/L), pH 4.4. Enzyme activity was calculated as the release of reducing groups per unit of time and per fresh weight (μmol/g FW-min).

2.10. Statistical analysis

Data are means of values from 3 central slices from each of 9 or 12 fruit per treatment per evaluation. Data were subjected to analysis of variance using the multifactor ANOVA procedure (Statgraphics 5.1) evaluating the main effects of the factors "treatment" and "days from slicing" as well as their interaction. Differences among treatments were determined by Fisher's Least Significant Difference (LSD) or Duncan's multiple range test (DMR) at $P < 0.05$ where appropriate.

3. Results

3.1. Experiment one: low to moderate damage

Fruit of the cv 901 were undamaged (NO) or subjected to 3 drops of a stainless steel ball (67 g) from 33 cm (1F) or 66 cm (2F). When

fruit had ripened nine days after bruising, tomatoes from 2F damage treatment had slightly lower firmness than undamaged fruit but similar hue color (Table 1).

Total juice loss over 13 days at 5 °C was higher in the slices from undamaged than damaged fruit (Fig. 1) with no difference between treatments 1F and 2F. No significant differences were found in the locular tissue score (evaluated at the moment of slicing), with an average score of 3 (medium) in all treatments.

Visual quality of the slices (Table 2) decreased over time but, after 10 and 13 days, slices from the undamaged tomatoes and the two damage treatments had similar visual quality scores, all above the limit of marketable quality. Bruising tomato at the breaker stage had an important effect on translucency of the fresh-cut slices (Table 2). Slices from undamaged fruit had no translucency 3 days after slicing while translucency was already observed on slices from damage treatments. After 7 days there were also differences, but by 10 days translucency scores were similar among treatments (Table 2).

After slicing, titratable acidity decreased slightly (from 0.39 to 0.37 g citric acid/100 g FW) with no differences among treatments. Soluble solids content and pH did not vary significantly (data not shown) due to damage treatment or storage time.

Tomato aroma is very characteristic and relatively easy to distinguish by smelling and an aroma score was given to slices from each treatment (Table 2). The 2F (66 cm) bruised tomatoes always had a lower aroma score than slices from undamaged fruit, while slices from the 1F (33 cm) treatment had intermediate values. In all treatments, typical aroma of the slices was lost after 7 days at 5 °C (Table 2).

Hue values of slices from all treatments increased during storage at 5 °C indicating a decrease in red color. No differences were found in other color parameters (data not shown). Lycopene content of slices from red fruit at slicing (day = 0) was significantly higher in undamaged tomatoes than in slices from bruised fruit (Fig. 2). The decrease in lycopene concentrations with time at 5 °C corresponded to the increase in hue values.

3.2. Experiment two: moderate to high damage

Fruit of the cv Bobcat were subjected to 3 drops of a stainless steel ball (67 g) from 66 (2F) or 99 cm (3F) or fruit were dropped 100 cm one time (treatment D). Respiration rates during fruit ripening varied from an average of 12.4 (breaker stage) to 9.8 (table
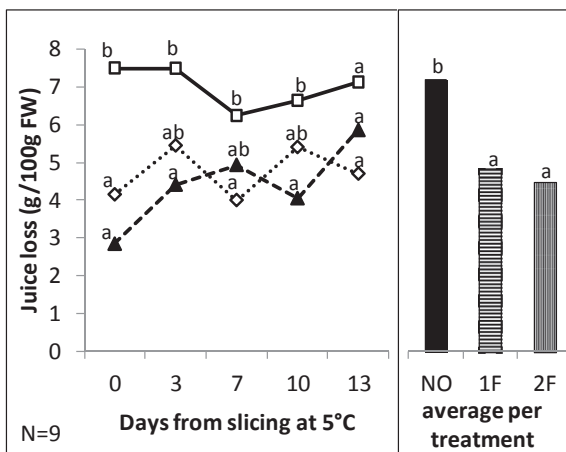
Table 2
Quality attributes of fresh-cut tomato (cv 901) slices during 13 days at 5 °C. Slices were prepared from ripe fruit that had been damaged at the breaker stage. NO No damage, 1F = 3 drops of a ball from 33 cm, 2F = 3 drops of a ball from 66 cm. Data are means from slices of 9 tomatoes. N.S., not significant. LSD values are in brackets (*=$P > 0.05$; **=$P > 0.01$).

Treatment	Days after slicing	Visual quality	Translucency	Color of the slices (Hue)	Aroma
NO					
	0	8.8	1.0	41.8	3
	3	7.6	1.0	43.1	3
	7	7.4	1.8	46.8	1
	10	6.3	2.4	45.7	1
	13	5.8	2.5	48.0	1
1F					
	0	8.6	1.0	42.1	3
	3	7.5	2.0	40.7	2
	7	7.3	2.4	44.6	1
	10	6.0	2.5	45.8	1
	13	5.4	3.4	48.0	1
2F					
	0	8.4	1.0	40.6	2
	3	7.5	2.0	41.7	2
	7	7.3	2.3	44.1	2
	10	6.5	2.6	45.6	1
	13	5.8	3.0	47.0	1
Treatment		N.S.	**(0.09)	*(1.2)	
Days		**(0.12)	**(0.11)	**(0.54)	
Treatment × days		**(1.07)	**(0.96)	**(4.71)	
N = 9					

ripe) μL CO_2/g-h without significant differences among damage treatments. Neither were there significant differences in ethylene production rates among damaged and undamaged fruit, except in initially higher rates for treatment D fruit (5.9 nL/g-h versus 4.7 nL/g-h for undamaged fruit). Average ethylene production rates declined during ripening from 5.0 to 3.6 nL/g-h without significant differences among treatments. Visible bruise damage disappeared after a few days of storage in fruit from all treatments as also reported by others (Van linden et al., 2008). Perhaps red color development masked the bruises.

Ripened fruit firmness values were lower in fruit from 3F and D treatments (Table 1) than undamaged and 2F fruit. There were no differences in hue values of the ripened fruit (Table 1).
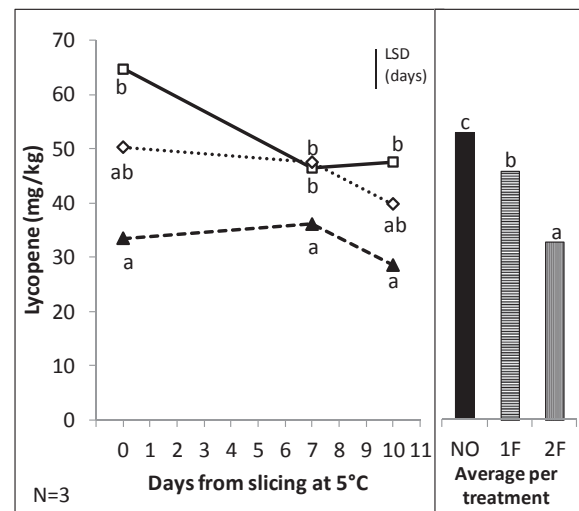

Fig. 1. Total juice loss of tomato (cv 901) slices during 13 days at 5 °C. Slices were prepared from ripe fruit that had been damaged at the breaker stage. NO(□) = No damage, 1F(◇) = 3 drops of a ball from 33 cm, 2F(▲) = 3 drops of a ball from 66 cm. Different letters on a given day indicate significant differences at *p* < 0.05 (DMR test).

Fig. 2. Lycopene content of slices during 10 days at 5 °C from ripe tomato fruit (cv 901) that had been damaged at the breaker stage. NO(□) = No damage, 1F(◇) = 3 drops of a 67 g ball from 33 cm, 2F(▲) = 3 drops of a ball from 66 cm. Different letters on a given day indicate significant differences at *p* < 0.05 (DMR test). The bar on the top right indicates the LSD for days (LSD.05 = 5.4).
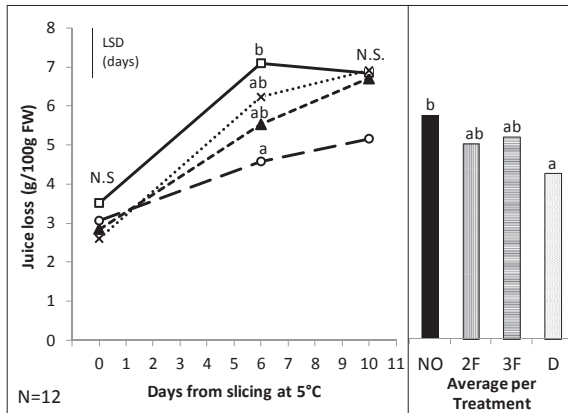
Fig. 3. Total juice loss of tomato (cv Bobcat) slices during 10 days at 5 °C. Slices were prepared from ripe fruit that had been damaged at the breaker stage. NO(□) = No damage, 2F(▲) = 3 drops of a 67 g stainless steel ball from a height of 66 cm, 3F (x) = 3 drops of a ball from 99 cm, D (○) = dropping fruit from 99 cm onto the blossom end. Different letters on a given day indicate significant differences at $p < 0.05$ (DMR Test); NS = not significant. The bar on the top left indicates LSD for days (LSD.05 = 1.2).

For this cultivar, initial juice loss was similar in all treatments (Fig. 3). Total juice loss increased considerably in all treatments during storage at 5 °C (Fig. 3). Among treatments, only slices from D fruit had significantly lower juice loss values than undamaged slices (NO).

Damage to breaker fruit had a negative effect on visual quality and the shelf-life of the slices (Table 3). By 6 days, slices from treatments 2F and 3F were at the limit of marketable quality (visual quality score 5). Based on the visual quality and translucency scores (Table 3), the shelf-life of the most damaging treatment (D) was less than 6 days. Regardless of treatment, typical aroma was undetectable after 6 days of storage.

Lycopene content of the fruit increased during ripening at 20 °C (Fig. 4). There was also a continued increase in lycopene 3 h after slicing, without significant differences among treatments. During further storage at 5 °C, lycopene generally decreased, and at the end of storage it was higher in the control (NO) and 2F treatments than in the treatments 3F and D. Correspondingly, hue values did not change in slices from undamaged and 2F fruit, while values increased in slices from 3F and D damage treatments (Table 3).

3.3. Experiment three: severe damage

Fruit were undamaged or subjected to severe damage (SD) by dropping a stainless steel ball on the fruit from 99 cm eight times per fruit. Fruit firmness at the ripe stage was not different between undamaged and SD fruit (Table 1). Peel color (Hue) of the ripened damaged tomatoes indicated that they were slightly redder than control fruit (Table 1).

The internal structure of the fruit was notably affected by the severe bruising treatment (Fig. 5). By 3 h after damage, much of the locular tissue of SD fruit had disappeared or been absorbed, although external damage was barely visible. By 10 days after bruising, many SD fruit showed signals of internal bruising with lessdevelopment of locular tissue.

Based on juice loss there were clear differences between the severely damaged and undamaged tomatoes (Fig. 6). The SD slices had very low juice loss which did not change during storage, while juice loss was much higher and increased slightly in slices from undamaged fruit. Visual quality of the slices of SD tomatoes was always lower than that of the control slices (data not shown). The shelf-life (visual quality score of 5) of SD slices was 5 days, while

undamaged slices reached the limit of marketability after 14 days. No clear differences between treatments were found in translucency scores, increasing from 1 (day 0) to 2.5 (day 10) in both treatments. No differences were found in the color values of the slices from the two treatments (data not shown).

Within one day, ion leakage increased in SD tomatoes and remained higher than that of undamaged fruit until slicing (Fig. 7). With slicing, electrolyte leakage increased substantially from about 1.5 to 4, but there were no significant differences between treatments until 10 days. At that time, ion leakage was higher in slices from undamaged than SD fruit.

PG and PME activities (Fig. 8) in parenchymatous tissue increased in both treatments during ripening, especially in the last days of ripening. After slicing and during storage at 5 °C, PME activity remained relatively constant without any difference between treatments, while PG activity of the control (NO) slices was always slightly higher than that of slices from SD treatment. In locular tissue, no PME activity was observed while only traces of PG activity were detected and there were no differences between treatments (data not shown).

4. Discussion

Mechanical damage from inappropriate harvest, manipulation and transport techniques is a common defect of fresh tomatoes (Moretti et al., 1998; Van linden et al., 2008). In the U.S., fresh-cut slices are generally prepared from field-grown tomatoes harvested at the mature-green stage and partially ripened with ethylene treatment, a system that involves considerable product handling. The quality of the intact fresh produce is considered a key determinant of the quality of the fresh-cut fruit (Colelli & Elia, 2009; Francis et al., 2012; Kader, 2002).

In the present work, many characteristics of fresh and fresh-cut tomatoes were affected by damage inflicted at an early stage of ripeness. Firmness and color, very important quality attributes for fresh tomatoes, were affected by bruising in the first two experiments. There were no fruit firmness or color differences in the third

Table 3
Quality attributes of fresh-cut tomato (cv Bobcat) slices during 10 days at 5 °C. Slices were prepared from ripe fruit that had been damaged at the breaker stage. NO No damage, 2F = 3 drops of a 67 g stainless steel ball from 66 cm, 3F = 3 drops of a ball from 99 cm, D = dropping fruit from 99 cm onto the blossom end. Data are means from slices of 9 tomatoes. N.S., not significant. LSD values are in brackets (*=$P > 0.05$; **=$P > 0.01$).

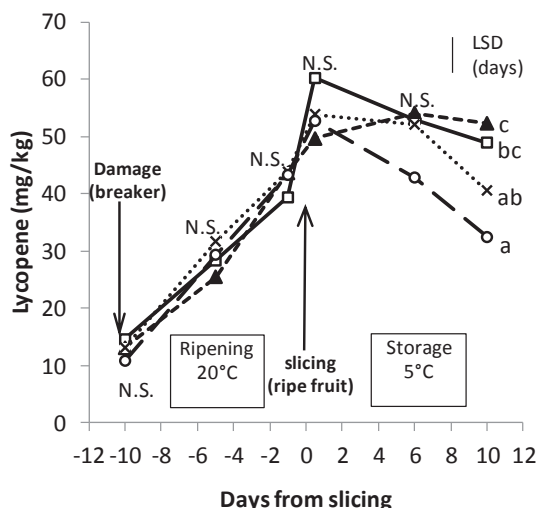| Treatment	Days after slicing	Visual quality	Translucency	Color of the slices (Hue)	Aroma
NO					
	0	9.0	1.0	35.0	4
	6	5.9	3.1	34.7	1
	10	5.4	4.2	34.6	1
2F					
	0	9.0	1.0	35.6	4
	6	5.3	3.2	31.8	1
	10	4.8	4.1	36.5	1
3F					
	0	8.1	1.6	34.5	4
	6	5.4	3.3	35.3	1
	10	5.4	3.6	39.0	1
D					
	0	8.6	1.3	32.3	4
	6	4.7	4.1	32.7	1
	10	3.8	4.8	37.1	1
Treatment		**(0.3)	N.S.	N.S.	
Days		**(0.3)	**(0.4)	N.S.	
Treatment × days		**(0.5)	**(0.7)	**(4.8)	
N = 12					

Fig. 4. Evolution of lycopene content of tomato (cv Bobcat) fruit at 20 °C and fresh-cut slices at 5 °C. NO(□) = No damage, 2F(▲) = 3 drops of a 67 g ball from 66 cm, 3F(x) = 3 drops of a ball from 99 cm, D(○) = Dropping fruit from 99 cm onto the blossom end. Downward arrow indicates application of damage at breaker stage and upward arrow indicates slicing of ripe fruit. Different letters on a given day indicate significant differences at $p < 0.05$ (DMR test); NS = not significant. The bar on the top right indicate the LSD for days (LSD.05 = 6.0).

Fig. 5. Appearance of slices from tomato fruit of cv 901 that were undamaged (NO = □)or severely damaged (SD = ●). Fruit were damaged at the breaker stage by dropping a 67 g stainless steel ball from 99 cm 8 times per fruit. Photos were taken immediately upon slicing after 3 h, 1, 5 or 10 days of fruit ripening at 20 °C.

experiment, perhaps related to the smaller fruit size and commercial handling. Larger fruit are generally composed of larger cells with less cell wall material and reduced tissue strength (Harker, Redgwell, Hallet, Murray, & Carter, 1997).

Bruising tomato fruits is reported to induce ethylene production and early ripening (MacLeod, Kader, & Morris, 1976) and mature-green and breaker stage tomatoes are less susceptible to bruising than fruit at other ripening stages (Van linden et al., 2008). However, in the present study no differences in respiration and ethylene production rates were found except for a transitory initial increase in ethylene. Perhaps damage to the tomato fruit in the present study was not severe enough (in the McLeod et al. work tomatoes were dropped 4 or 8 times) or perhaps this is due to variability among cultivars.

Visual quality was affected by bruising only in the most damaging treatments. Slices from D (expt.2) and SD (expt.3) treatments had a reduction of 40 and 60% in shelf-life compared with control slices, while no significant differences were found in shelf-life of slices from other damage treatments.

Translucency or water-soaked appearance is a major defect in fresh-cut tomato (Aguayo et al., 2004). Jeong, Brecht, Huber, and Sargent (2004) proposed that translucency is associated with fruit ripeness stage and ethylene production rate, but not due to storage at low temperature. Lana, Tijskens, and van Kooten (2006) also showed that slices from fruit at more advanced stages of ripeness had a more rapid onset of translucency. Since our objective was to slice full red fruit, translucency was expected and it increased with storage time at low temperature as reported previously (Lana et al., 2006). The damage treatments, however, only accelerated the onset of translucency in one of the three experiments. Damage appears to play a less important role in translucency defect in sliced tomatoes compared with other factors such as stage of ripeness, cultivar and storage time.

Loss of aroma is common in fresh-cut fruit products (Beaulieu & Gorny, 2004; Francis et al., 2012; Kader, 2002). Loss of typical aroma occurred after about 6 days in the tomato slices. Bruise damage caused a more rapid reduction in typical aroma scores in one of the two experiments in which this quality parameter was evaluated
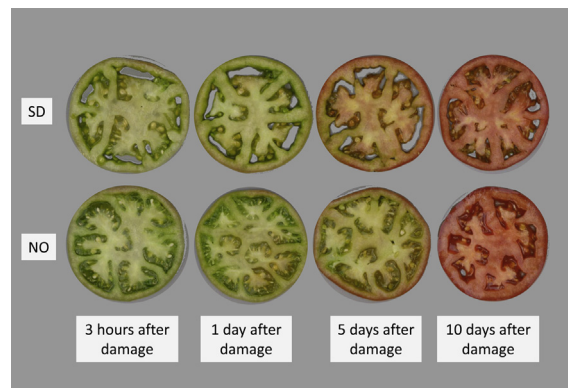
and this difference could have been related to differences in cultivars (Stevens, Kader, & Albright-Holton, 1977). The reduction in aroma is consistent with the work of Moretti et al. (2002) in which impact bruising altered the typical aroma of tomato fruits and also led to increases in off-odor volatiles.

The initial increase in lycopene after slicing (expt.2) could have been related to an increased ethylene production of the sliced fruit. Yokotani et al. (2004) showed that at 22 °C there was increased ethylene production within 2 h of cubing tomatoes, and ethylene is known to stimulate ripening and lycopene formation (Collins, Perkins-Veazie, & Roberts, 2006; Lana, van Kooten, Deker, Suurs, & Linssen, 2005). However, lycopene formation is temperature dependent, with no synthesis below 8 °C (Collins et al., 2006). The initial increase in lycopene in the present study was more likely related to a time lag in biosynthesis due to the shift from the ripening temperature (20 °C) to the slice preparation temperature (10 °C) and finally to the slice storage temperature (5 °C) (Lana et al., 2005).

The literature is inconsistent regarding lycopene content after slicing and storage. Some authors reported a decrease in lycopene in slices of some tomato cultivars but not others (Odriozola-Serrano et al. 2008a, 2008b; Lana et al., 2005). The stability of lycopene and other carotenoids in foods also depends on oxygen availability, light, pH and packaging conditions (Boon, McClements, Weiss, & Decker, 2010; Shi & Le Maguer, 2000). In this study it is possible that an increase in oxygen availability at the cut surface as well as low temperature resulted in the decreased lycopene content with storage time.

No differences were found in average lycopene content between the two cultivars in this study. After 10 days at 5 °C, lycopene content from both cultivars was higher in slices from undamaged than damaged fruit. This is consistent with the findings of Javanmardi and Kubota (2005) and Odriozola-Serrano et al. (2008b). The present study showed that the lycopene content of slices from red fruit can be affected by mechanical damage applied at an early stage of ripeness (breaker stage). Since the present and previous studies show that lycopene decreases in slices at 5 °C, it is important that tomato fruit be sliced as ripe as possible to ensure the highest possible lycopene concentration and human health value.

Measurement of ion leakage is used to estimate membrane integrity in response to environmental stresses. In tomato it has been used mostly to estimate chilling injury (Bergevin, L'Heureux, Thompson, & Willemot, 2006; Biswas, East, Hewett, & Heyes, 2011; Luengwilai, Beckles, & Saltveit, 2012; Saltveit, 2002), but
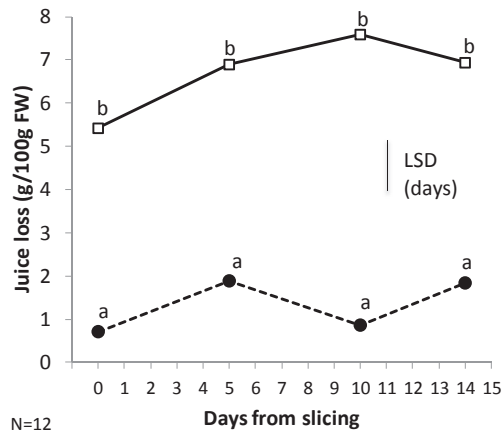
Fig. 6. Total juice loss of fresh-cut slices of red tomatoes (cv 901) during storage at 5 °C. Fruit were undamaged (NO = □) or severely damaged (SD = ●) at the breaker stage. Different letters on a given day indicate significant differences at $p < 0.05$ (DMR test). The bar on the right indicate LSD for days (LSD .05 = 1.2).

also to differentiate undamaged from bruised tomatoes (Moretti et al., 1998). No information exists, to our knowledge, about how ion leakage can change after slicing previously damaged fruit. In this study, ion leakage of bruised tomatoes increased immediately after damage and was higher than that of the control fruits at the table ripe stage. After slicing, ion leakage increased in slices from both undamaged and damaged fruit. By the end of storage, however, ion leakage was lower in slices from the damaged fruit. Although this result presumably indicates better membrane integrity, it may be related more to the development of mealiness as discussed later.

Fresh-cut tomato slices are characterized by their relatively rapid deterioration and short shelf-life (Hong & Gross, 2001; Jeong et al., 2004). Because of the internal structure of the fruit, high juice loss often occurs after cutting and negatively affects slice integrity. In all three experiments, total juice loss was affected by damage to the fruit at the breaker stage. Juice loss of the slices from damaged fruit was inversely proportional to the damage intensity. The damage treatments resulted in less juice loss at the moment of slicing and during storage at 5 °C, although some differences were found between the 2 cultivars for the same damage treatment. Bruise susceptibility depends on cultivar and associated differences in structure and composition (Li, Li, & Liu, 2010; Mohsenin, 1970; Stevens et al., 1977; Van linden et al., 2006).
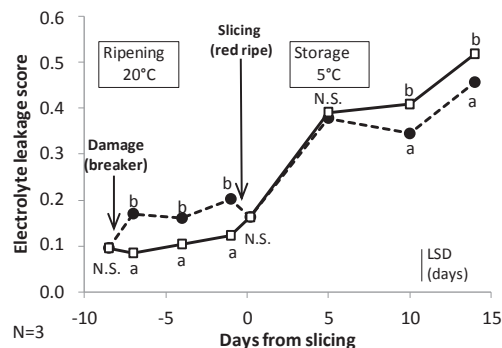

Fig. 7. Ion leakage of pericarp discs prepared from severely damaged (SD = ●) and undamaged (NO = □) tomatoes. Left arrow indicates the application of damage at breaker stage and right arrow indicates the slicing of ripened fruit. Different letters on a given day indicate significant differences at $p < 0.05$ (DMR test); NS = not significant. The bar on the bottom right indicates the LSD among days (LSD.05 = 6.7).
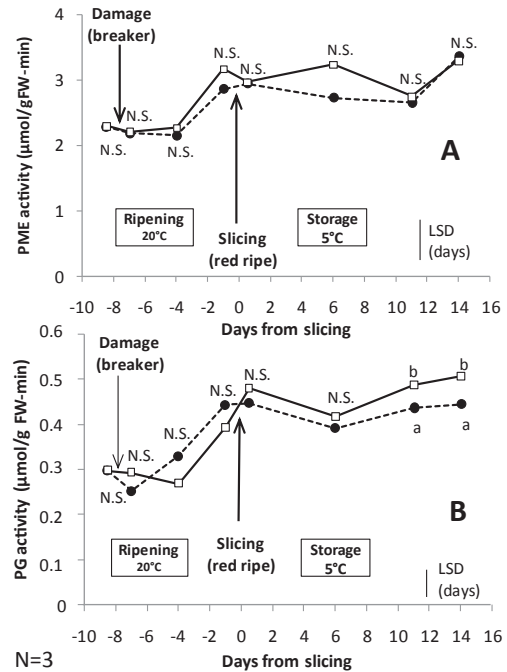

Fig. 8. PME (A) and PG (B) enzyme activities during ripening of tomato fruit at 20 °C and during storage of slices at 5 °C. Fruit of cv 901 had been severely damaged (SD = ●) or undamaged (NO = □) at the breaker stage. The downward arrow indicates damage application and the upward arrow indicates slicing of red fruit. Different letters on a given day indicate significant differences at $p < 0.05$ (DMR test); NS = not significant. The bar on the bottom right indicates the LSD among days (LSD.05 = 0.6 and 0.05 for PME and PG, respectively).

In this study juice loss was not an indicator of slice integrity. Severely damaged tomatoes showed an abnormal internal structure with loss or collapse of locular tissue and hence less juice loss (Fig. 5). Before the damage was applied, the locular tissue score (LT; the portion of the slice surface filled by locular tissue), did not differ among fruit. The locular gel was greatly reduced by severe damage and perhaps was also denser than in undamaged fruit, as suggested Moretti et al. (1998).

Lower ion leakage and lower juice loss in slices from damaged tomato may be due to the development of mealy tissue caused by the combined effect of bruising and slicing. Mealiness is characterized by low cell adhesion, increased cell wall rigidity and increased binding of water within the cell wall matrix. This results in the perception of dryness in the mouth due to intact cells retaining their juice (Jackman & Stanley, 1995). Other studies suggest that this disorder results from an altered pattern of pectin breakdown during storage and subsequent ripening (Dawson, Watkins, & Melton, 1995) and that cell walls of mealy fruit display distinct properties of the pectin component (Devaux et al., 2005).

PG and PME are enzymes associated with cell wall changes involved in fruit softening during ripening (Tucker & Grierson, 1982). In the present work, PG and PME activity increased during ripening and did not change after slicing, consistent with results by Chung, West, and Tucker (2006). PG activity was higher in the bruised treatments, as also reported by Moretti et al. (1998), but after slicing and storage, PG activity was higher in slices from undamaged fruit. PME activity, on the other hand, was not affected by bruising. Van linden et al. (2008) reported that PG and PME activities were little affected by bruising intact fruit. Rugkong et al. (2010) reported reduced PG activity in chilled tomatoes, with no effect on PME activity. In peach fruit, cold storage reduced PG

activity but did not affect PME which supported the hypothesis that altered balance of enzyme activities leads to incomplete cell wall pectin degradation (Crisosto & Labavitch, 2002) resulting in mealiness. In this study, the lower PG activity, lower ion leakage and lower juice loss in the damage treatments, are consistent with development of mealy tissue caused by bruising tomatoes at the early ripening stage.

5. Conclusions

Bruising tomatoes at breaker stage had important effects on many quality parameters of the sliced product from ripened fruit. Visual quality, translucency, lycopene content and total juice loss were all affected by damage inflicted at an early stage of ripening. After a few days at 5 °C, the slices from the moderately damaged fruit had lower visual quality, higher translucency and lower lycopene content than slices from undamaged fruit. Juice loss was lower in slices from damaged fruit and was inversely related to the severity of the damage. Severe damage led to loss of typical internal tomato structure and less locular tissue. Severe damage affected PG activity and membrane integrity, especially after slicing and storage at 5 °C. The severely damaged fruit produced slices with lower juice loss, lower PG activity and higher apparent membrane integrity, all indicative of development of a mealy or less juicy texture caused by the combined effect of bruising and slicing.

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