EVALUATION OF PROCESSING TOMATOES FROM TWO CONSECUTIVE GROWING SEASONS: QUALITY ATTRIBUTES, PEELABILITY AND YIELD

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ABSTRACT

Peelability is an important quality parameter in the selection of tomato cultivars (cvs.) for whole peeled and dice processing. Six processing tomato cvs. were evaluated in two consecutive years to examine the effects of cv., maturity and physical attributes on peelability and yield. Physical attributes of the raw tomatoes (size, weight, pericarp wall thickness, color) and processed paste quality (pH, titratable acidity, soluble solids, Bostwick consistency, serum viscosity, color) were determined. Large variations in physical attributes and paste quality were observed in selected tomato cvs. and maturities. In general, most of the attributes indicative of paste quality were more desirable at the less mature (e.g., pink) stage and declined with maturity. Statistical analysis suggests that there were significant differences in percentage of peeled tomatoes, peel index, and yields of whole peeled and diced tomatoes between two consecutive growing years.

INTRODUCTION

Although cultivar (cv.) is probably the most important factor affecting the quality of processed tomato products, other major parameters are tomato maturity, growing location and climate, and processing conditions. Dry matter of tomatoes is generally between 5 and 10%. However, in mature tomatoes three quarters of the dry matter is made up of solids, mainly sugars (~50%), organic acids (>10%), minerals (8%) and pectin (~7%) (Davies and Hobson

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1981; Petro-Turza 1986–1987). These dry matter components contribute to the flavor, color and textural quality attributes of tomatoes and processed tomato products. Tomato product flavor is influenced by an appropriate balance between sugar content and acidity. As tomatoes mature, there is generally an increase in sugar and a decrease in acidity. In mature tomatoes, the acidity arises primarily from the presence of citric acid, followed by malic acid. In addition to the solids content, tomato product consistency is also influenced by pH, electrolytes and processing conditions such as hot break temperature and product finishing (Thakur *et al.* 1996). Consistency has important economic implications because product yield is inversely related to the soluble solids content of tomatoes. Color is considered a major attribute of tomatoes and tomato product quality, and relates primarily to the lycopene content. Most specifications for tomato paste include minimum values for color and degrees Brix or soluble solids.

After peeling, tomatoes may be canned whole in juice as a premium product, sliced, diced or crushed and packaged in either cans or aseptic containers, or finally sent to the paste processing line immediately following peeling if the peeled product does not meet governmental or individual company specifications. Diced tomato market received increasing attention in the 1980–1990s, with greater demand for high value salsa, pizza and spaghetti sauces as well as other formulated tomato products. High value whole peeled, diced and crushed tomato products allow for greater profit margins, but attributes for determining whether raw materials meet specifications for these high value tomato products have not been determined. Tomato cv., maturity and process operations, which remove peel in an efficient manner, are particularly important. However, Barringer *et al.* (1999) found that tomato maturity did not correlate to total tomato peeling losses. When processors receive tomatoes at a processing facility, very little is generally known about the raw material. The decision to peel tomatoes rather than direct the tomatoes to paste processing may be based on historical knowledge of the cv. and grower, or on inspection station data.

In this study, six processing tomato cvs. were evaluated to determine the effects of cv., maturity and physical attributes on the peelability and yield of whole peeled and diced tomatoes. The first objective was to evaluate how much the ease of peel removal (peelability) varied between selected cvs., and whether maturity affects peelability. The second objective was to establish whether selected physical attributes, such as peel index or thickness of pericarp walls, could be utilized as indicators of the potential for those tomatoes in whole peeled and diced products.

MATERIALS AND METHODS

Raw Material

In 1995, six tomato (*Lycopersicon esculentum*) cvs., BOS Halley 3155 (Orsetti Seed Co.), H 8892 (Heinz Tomato Products), FM 9208 (Ferry Morris Seed Co.), LaRossa (Rogers Seed Co.), Brigade (Asgrow) and Nema 512 or N 512 (Seminis Seed Co.) were planted in replicate blocks on the University of California Vegetable Crops Experiment Station in Davis. Second set clusters with a target number of open flowers were tagged using twist ties for all cvs. on the same day. Tomato maturation was closely monitored and the tomatoes were hand harvested from tagged clusters at the pink, red (generally 5–7 days after pink) and overmature (2 weeks after the red maturity) stages.

In the 1996 season, the same five cvs. were selected, with the addition of N 512. In these five cvs., individual tomatoes were tagged at the pink stage, and tagged tomatoes were hand harvested at the red (approximately 5–7 days later), red plus 2 weeks (red + 2) and red plus 3 weeks (red + 3) stages of maturity. With the exception of weather (Table 1), all the agronomic conditions adopted were equivalent for both seasons.

Harvested tomatoes were washed in soapy tap water (1 g dishwashing detergent in 8 L H_2O) and rinsed in tap water. Tomatoes were surface sterilized by 3 min contact with bleach solution (15 g commercial bleach/8 L H_2O), rinsed once in tap water and twice in deionized water. Tomatoes were dried with cotton towels and sorted to remove defects, such as bruises, scars, mold and yellow eye. Only defect-free or "perfect" tomatoes were evaluated further.

TABLE 1.
TEMPERATURES RECORDED DURING THE SUMMERS OF 1995 AND 1996 AT THE UNIVERSITY OF CALIFORNIA VEGETABLE CROPS EXPERIMENT STATION

	Average temperature (C)		No. days with max. temp. ≥ 32.2C (90°F)	
	1995	1996	1995	1996
June	29.4	31.7	8	14
July	33.2	35.8	9	27
August	34.0	35.6	21	22
September	31.9	31.1	14	15

Compiled from data published by the National Oceanic and Atmospheric Administration, National Weather Service.

Physical Analyses of Raw Material

Tomatoes were evaluated for a number of physical attributes identified as potential indicators of peelability and yield. Tomato fruit height, width, shoulder height and stem scar diameter were measured on whole tomatoes (Fig. 1). The tomato was then cut in two halves, and pericarp wall thickness (three locations) and thickness of the red layer below the peel (three locations) were measured using digital calipers and expressed as mm. For each tomato harvested, external color was determined at three locations. In the 1995 season, color was observed at the stem scar, equator and blossom end; in 1996, the three readings were observed around the equator (Fig. 1). For each tomato cv. and each harvest day, batches of 10 tomatoes were used for external color measurement. Tomato color was determined in the $L^*a^*b^*$ color space using a Minolta Chroma Meter CR200 (Minolta Corp., Ramsey, NJ) and expressed as hue angle.

Peeling. Three to six replicate batches of 20 tomatoes were preweighed and arranged in a single layer in a small pressure chamber and exposed for 75 s to a steam pressure of 15 psig steam (250F) followed by 22 in. vacuum. Following the steam and vacuum treatment, tomatoes were passed over mechanical disc peeler and pinch rollers (Imdec Inc., Woodland, CA). The percentage peeled was evaluated both after the steam and vacuum treatment, and after the mechanical peel eliminators. All peeled tomatoes were cut into 2-in. (5.08 cm) dices using an Urschel Vegetable cutter and dicer. Diced

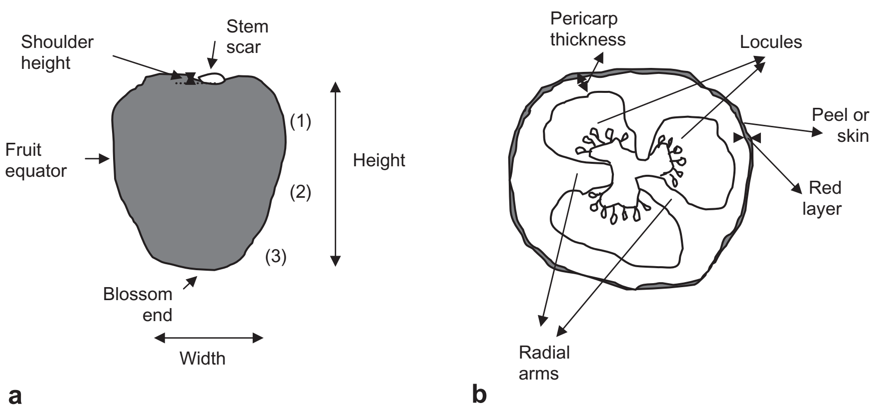

FIG. 1. (A) REPRESENTATION OF A TOMATO INDICATING SOME OF THE DIMENSIONS TAKEN FOR PHYSICAL CHARACTERIZATION; (B) TRANSVERSAL CUT OF A TOMATO ILLUSTRATING SELECTED REGIONS AND PARAMETERS MEASURED IN THIS STUDY

tomatoes were drained for 60 s on a mesh sieve under the dicer, weighed and used for texture evaluation. Dice yield (w/w) was also calculated.

Peel index, a measure of peel remaining on tomatoes, was obtained by hand peeling skin attached to tomatoes after the mechanical peeling operation and placing the extraneous peel over a standardized grid to determine its area in square inches. Peeling losses were calculated as follows: [(total weight of tomatoes − weight of whole peeled tomatoes)/total weight of tomatoest)] × 100; dicing losses were calculated as: [(weight of whole peeled tomatoes − dice weight)/weight of whole peeled tomatoes] × 100.

Paste Quality Evaluation. A "microwave break" method developed in the Department of Food Science & Technology at University of Calfornia, Davis (Leonard *et al.* 1980) to simulate a commercial hot break was utilized to prepare tomato juice. This allows for determinations on juice to be related to paste using predictive equations. Tomatoes were cut in half from stem to blossom end; one-half of each tomato was placed in a Pyrex dish to achieve a net weight of approximately 1300 g. The dish containing the tomatoes was immediately weighed, covered and heated in a commercial (1400 watt) microwave oven for 6 min at 100% power, followed by 6 min at 50% power. After cooking, the dish was placed in ice water to cool. Cooled tomatoes in the dish were reweighed, and water was added to equal the initial weight, in order to compensate for evaporative losses during cooking. Seeds and skins were extracted using a lab pulper with a 0.033-in. screen. Duplicate lots of 1300 g tomatoes were microwaved, and the juice was evaluated for Bostwick consistency, color, soluble solids content, pH, titratable acidity and serum viscosity. Color was determined on deaerated pulp using an Agtron E-5M colorimeter, the colorimeter used by the Processing Tomato Advisory Board at inspection stations in California. Other analyses were carried out according to Leonard *et al.* (1980).

Statistical analyses were interpreted using multivariate analysis of variance (SAS 2000). Differences were expressed at appropriate significance levels ($P \leq 0.05$, 0.01 or 0.001), depending on the results.

RESULTS AND DISCUSSION

Physical Attributes of Fresh Tomatoes

Tomato dimensions and other physical evaluations of raw tomatoes are presented in Table 2. In the 1995 season, tomato weight was quite variable; the largest variation was observed in pink tomatoes of cv. N 512 (72.0 ± 32.8 g). Tomato weight increased with maturity, and the most pronounced increase was

TABLE 2.
MEAN PHYSICAL ATTRIBUTES OF TOMATOES GROWN IN THE 1995 AND 1996 SEASONS

Cultivar	Maturity	Weight (g)		Height (mm)		Width (mm)		Height/ Width		Shoulder height (mm)		Stem scar diameter (mm)		Wall thickness (mm)		Red layer (mm)		External color hue angle (degrees)	
		1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
FM 9208	Pink	56.4		52.4		44.9		1.2		1.7		6.0		6.3		2.3		65.72	
	Red	87.5	80.8	61.0	56.8	50.6	50.4	1.2	1.1	1.8	2.0	8.2	7.0	7.1	7.7	2.6	2.5	39.75	48.28
	Red + 2	82.7	72.7	57.5	56.5	49.9	49.1	1.2	1.2	1.9	1.1	8.5	7.4	7.7	8.2	2.8	3.3	40.48	37.51
	Red + 3		78.7		56.5		49.6		1.1		1.1		8.2		7.2		2.5		40.54
LaRossa	Pink	65.8		72.1		44.0		1.6		1.2		4.8		7.1		2.8		61.27	
	Red	77.1	83.0	70.7	77.6	44.5	44.9	1.6	1.7	1.3	1.2	6.8	5.7	6.3	7.6	2.5	2.9	40.05	48.28
	Red + 2	75.4	70.0	73.9	71.3	43.5	42.3	1.7	1.7	1.2	1.7	5.9	5.9	7.2	7.2	2.6	3.21	40.03	40.06
	Red + 3		76.1		70.6		44.2		1.6		1.3		6.7		7.0		2.8		38.28
H 8892	Pink	68.1		62.5		46.4		1.4		1.7		6.1		6.5		2.5		70.59	
	Red	78.0	74.7	61.4	61.1	47.6	48.4	1.3	1.3	1.9	2.2	7.2	6.7	6.8	7.0	2.7	3.0	40.71	44.32
	Red + 2	77.0	70.3	63.2	60.5	47.4	46.6	1.3	1.3	1.6	2.0	7.3	6.5	6.1	6.0	2.5	1.8	37.99	40.37
	Red + 3		81.3		62.6		48.6		1.3		1.7		7.8		7.2		3.0		40.82
Brigade	Pink	69.6		54.9		49.0		1.1		1.9		6.0		6.9		2.4		62.56	42.79
	Red	80.0	73.2	56.9	56.3	50.4	50.0	1.1	1.1	2.1	2.2	7.1	8.5	7.6	7.3	2.6	2.4	39.65	40.07
	Red + 2	86.4	75.7	58.9	57.4	50.8	48.3	1.2	1.2	1.9	2.1	8.0	8.2	7.4	7.4	2.6	3.1	40.03	
	Red + 3		73.5		56.1		49.8		1.1		1.8		8.4		6.8		2.3		
Halley 3155	Pink	66.5		58.7		46.5		1.3		1.5		5.7		6.8		2.4		57.66	46.60
	Red	89.6	100.9	65.3	68.3	50.9	52.0	1.3	1.3	1.5	1.3	7.2	7.0	7.1	8.1	2.3	2.8		40.57
	Red + 2	91.2	83.4	66.5	63.3	50.0	50.4	1.3	1.3	1.5	1.2	6.8	7.9	7.6	7.3	3.1	2.2	39.84	
	Red + 3																		
N 512	Pink	72.0		52.9		49.8		1.1		2.0		7.0		6.4		2.8		60.36	
	Red	79.7		55.0		50.6		1.1		2.0		8.4		6.0		2.1		42.36	
	Red + 2	96.4		54.8		53.9		1.0		2.4		9.7		6.0		2.2		39.41	

between the pink and red stages. The largest differences from the pink to red maturity stage were observed in cv. FM 9208, exhibiting over a 55% increase. With the exception of N 512 tomatoes, which had a substantial weight increase (~21%) between the red and red + 2 weeks harvests, other cvs. exhibited minor weight changes. In the 1996 season, three harvests were also evaluated, but the pink stage was not included. Instead, an overmature red + 3 weeks harvest was added. For most tomatoes, there was a considerably large weight variation (e.g., ±8–16 g) at any one harvest.

Measurements of shoulder height and stem scar diameter were correlated with peelability. Processors commonly believe that tomatoes with deep shoulders and large stem scars present more difficulty in peeling. This was not confirmed in this study. Both measurements varied even in tomatoes of the same cv. at equivalent maturity stage or in the same cv. from one harvest to the next. Thickness of the pericarp wall, which contributes significantly to the yield of tomato products, ranged between 6 and 8 mm, depending on cv. and maturity. There was no clear trend related to change in pericarp thickness with maturity, although some cvs. exhibited an increase in pericarp thickness to a certain level, followed by a decline. Statistical analysis indicated that in 1995 there was a positive correlation between pericarp thickness and peelability. A positive correlation was not observed in 1996.

A correlation between microstructural tomato features and ease of peeling was reported previously (Mohr 1990). Presumably, a steep, cell-sized gradient near the outer surface of the tomato and the absence of small cells are the main features associated with peelability. A considerable effect of the growing season was also reported. In the present study, we also evaluated thickness of the red layer (Fig. 1), constituting the rows of small cells immediately adjacent to the skin having a deeper red color most likely because of the larger concentration of lycopene per unit area. The red layer represented approximately 37–38% of the pericarp wall. Large variations were recorded between the 2 years of study. No correlation was observed between peelability and red layer thickness either in 1995 or 1996.

External color was expressed in terms of hue angle, considered the most important measure in the perception of tomato quality (Shewfelt and Prussia 1993), because external fruit color relates better to perception of color by the human eye. Basically, all the tomato cvs. analyzed in 1995 developed a similar color when mature (Table 2), with average hue angles generally close to 40C. Color at the red stage was less intense in tomatoes of the 1996 season than in 1995. This variation could be related to climatic conditions (Table 1) during growing and ripening. In normal red cvs. of tomatoes, temperatures greater than 30C lead to inhibition of lycopene synthesis. Nonetheless, when the temperature decreases to less than the threshold, pigment synthesis is restored. These effects of temperature depend on the tomato cv. (Britton 1998). In 1995, tomato color was observed at three locations on the tomato surface, including bottom, equator and top (near the stem scar) of the tomato (Fig. 1). At the pink stage, color starts to change at the bottom (blossom end) of the tomato. At the later maturity stages (red and red + 2), when color measurements taken at various tomato locations were compared, hue differences were less pronounced. In mature tomatoes, average hue angles were close to 40C at all the tomato regions observed. Consequently, when using red mature tomatoes, color may be measured at any location around the tomato. Nevertheless, to ensure reproducible measurements, consistency is advisable, particularly when batches of tomatoes of different maturities are being analyzed.

Paste Quality Evaluation

Color. Color is probably the first quality factor judged by tomato product consumers. Thus, an attractive deep red color is a major quality attribute for tomato products (Thakur *et al.* 1996). Lower Agtron E readings correspond to deeper (more saturated) red color. Agtron readings of 48 or smaller are related to well-colored tomatoes (Luh *et al.* 1973). In the 1995 season, with the exception of tomatoes at the pink stage, all cvs. were substantially smaller than 48. Overall, juice color was more saturated in 1995 than in 1996 (Table 3). Approximately 21–48% larger Agtron values were recorded for the red stage and 0.7–13.6% larger at the red + 2 stage. Only Halley 3155 at the red + 2 maturity exhibited smaller Agtron readings in 1996 than in 1995. Overall higher temperatures recorded during the summer of 1996 (Table 1) may have influenced the tomato paste color.

Consistency. Although second only to color, consistency is probably the most important quality parameter considered in consumer acceptability of tomato products. Consistency is also important for several unit operations (heating, pumping, mixing) involved in tomato processing (Sharma *et al.* 1996). Consistency of tomato paste is typically determined using a Bostwick consistometer. U.S. Department of Agriculture grade C for tomato sauce establishes that tomato product flow should be less than 18 cm/30 s (USDA 1994). Smaller Bostwick values indicate a thicker, higher consistency tomato product; therefore, smaller numbers are preferable. All cvs. produced pastes with Bostwick flow below 18 cm/30 s, except for Brigade at the red + 2 weeks harvest in 1995 (actual value of 18.1 cm/30 s) (Table 3). In both harvesting seasons studied, the smallest consistency values were determined for cv. H 8892; in 1995, cv. N 512 also produced thicker paste. Most of the 1996 pastes exhibited greater consistency (lower Bostwick) than in 1995 and also higher values for serum viscosity. Consistency of tomato products is dependent on the total solids content of tomato products, which include soluble solids (mainly

TABLE 3.
PASTE QUALITY EVALUATION (MEANS) OF TOMATOES GROWN IN 1995 AND 1996

Cultivar	Maturity	Soluble solids (°Brix)		pH		Titratable acidity		Bostwick flow (cm/30 s)		Serum viscosity (s)		Color (Agtron)	
		1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
FM 9208	Pink	5.05		4.24		0.501		14.25		9.69		92	
	Red	4.98	4.8	4.33	4.37	0.409	0.338	17.08	15.88	5.41	10.13	29.25	37.1
	Red + 2	4.78	4.6	4.51	4.63	0.331	0.265	16.6	16.19	3.64	6.36	31	33.2
	Red + 3		5.15		4.78		0.252		15.21		5.54		32
LaRossa	Pink	5		4.29		0.473		12.75		9.7		72.75	
	Red	5.48	5.25	4.38	4.61	0.393	0.326	16.55	13.35	6.03	7.89	30.25	44.7
	Red + 2	5.35	5.6	4.52	4.76	0.324	0.254	16.73	15.51	3.84	6.59	29.5	32.45
	Red + 3		5.5		4.77		0.231		17.07		5.36		32
H 8892	Pink	5.08		4.3		0.376		10.53		12.35		82.5	
	Red	5.25	5.15	4.36	4.47	0.318	0.33	13.2	11.65	10.33	11.79	28.75	36.9
	Red + 2	5.15	4.95	4.54	4.6	0.298	0.269	14.08	14.76	7.6	8.79	27.25	29.05
	Red + 3		5.5		4.7		0.255		14.13		7.98		28.65
Brigade	Pink	5.08		4.26		0.423		11.25		12.95		76.75	
	Red	5	5.4	4.33	4.45	0.389	0.32	16.25	14.19	6.17	9.21	29.75	38.05
	Red + 2	5	4.8	4.52	4.55	0.332	0.259	18.1	17.15	4.72	5.79	30	30.2
	Red + 3		5.2		4.69		0.245		17.68		4.76		32.15
Halley 3155	Pink	5.65		4.27		0.399		12.75		8.08		84.5	
	Red	5.53	5.65	4.36	4.47	0.334	0.353	15.1	15.11	5.61	8.16	29.75	36.05
	Red + 2	5.5	5.15	4.54	4.54	0.293	0.324	14.38	16.03	4.7	5.36	30.25	28.65
	Red + 3		5.9		4.63		0.301		15.55		6.15		31.4
N 512	Pink	4.7		4.32		0.348		11.3		9.47		59.75	
	Red	4.83		4.34		0.363		13.65		10.29		29.5	
	Red + 2	4.2		4.42		0.333		13.63		6.19		27.75	

sugars and organic acids) and insoluble solids (polysaccharides such as pectins and hemicelluloses, protein). Many investigators have found that tomato maturity has a considerable effect on consistency; more mature tomatoes tend to produce higher Bostwick values, for example, thinner, low quality paste. Other factors such as cv., growing location, processing conditions, solids, electrolytes and pH may affect consistency. Tomato cv. may be the most important factor (Thakur *et al.* 1996).

pH and Titratable Acidity. Among the parameters analyzed for the assessment of tomato quality, pH is very important because acidity influences the thermal processing conditions required for producing safe products. Although the pH of mature tomatoes may exceed 4.6, tomato products are generally classified as acid foods (pH $<$ 4.6), which require moderate conditions of processing to control microbial spoilage and enzyme inactivation. In addition, tomato product flavor depends on the accumulation and balance between sugar and organic acid content (Hobson and Grierson 1993). Nevertheless, pH 4.4 is suggested (Monti 1980) as the maximum desirable to avoid potential spoilage caused by thermophilic organisms, and pH 4.25 as the optimum value for processing tomatoes (Monti 1980). In 1995, cvs. at the pink and red stages were less than the pH 4.4 desirable limit (Table 3). In 1996, only FM 9208 at the red maturity stage reached a pH of 4.4.

Processors typically add citric acid to tomato juice to ensure low pH values. As expected, pH increased with the progression of tomato maturity. The effect of growing season is observed by comparing the five tomato cvs. grown in both years of study. All cvs. studied in 1995 exhibited a similar pH at the red stage (4.32–4.38). Most cvs. exhibited small increases (3.2–4.2%) from red to red + 2 harvests, while the smallest increase (1.8%) was recorded for cv. N 512. In 1996, only Brigade, Halley 3155 and H 8892 exhibited pH values equal to or below 4.6 at the red + 2 maturity stage. Tomato pH is dependent on several factors, including cv., maturity stage, cultural practices as well as growing location and seasonal variations (Gould 1992). Potassium content of soils may play an important role on the total tomato acid content (Petro-Turza 1986–1987).

Titratable acidity results (Table 3) present greater tomato acidity in 1995 than in 1996, correlating well with the pH data. There is an inverse relationship between pH and titratable acidity, although sometimes the relationship is inaccurate (Stevens 1972a). Mean acidity of processing tomatoes is around 0.35% (Thakur *et al.* 1996). Less mature tomatoes produce pastes with greater titratable acidity. Pink tomatoes analyzed in 1995 exhibited the largest acidity values. As observed with pH, in 1995, cv. N 512 exhibited the smallest variation in titratable acidity among tomatoes from the pink to red + 2 maturities. For most cvs., titratable acidity continually decreases with late harvests (maturity progression). Halley 3155 was the least variable cv. in the two seasons. Halley 3155 was the only cv. with greater acidity in 1996 than in 1995. Tomato acidity varies continually during tomato development and maturation. Variation in tomato acidity is attributed to maturity stage rather than genetic differences (Stevens 1972b).

Soluble Solids. Tomato breeders devote a significant degree of effort to producing tomato lines with high soluble solids levels. While some wild tomato accessions attain very high (11–15%) concentrations of soluble solids (Triano and St Clair 1995), common processing tomato cvs. exhibit moderate soluble solids contents ranging between 4.5 and 6.25% (Poysa 1993). Seasonal variation as well as horticultural practices may affect tomato soluble solids content (Thakur *et al.* 1996) commonly expressed in degrees Brix (Table 3). Larger degree Brix values are frequently correlated with greater tomato product yield, but in general cvs. with high Brix values tend to be agronomically less productive. In 1995 as well as in 1996 at the red and red + 3 maturities, Halley 3155 tomatoes exhibited the largest Brix values, while cv. LaRossa exhibited the most soluble solids at the red + 2 stage in 1996.

Serum Viscosity. Tomatoes harvested in 1995 exhibited greater serum viscosity at the pink stage, but the viscosity decreased with advancing ripeness for selected cvs., with the exception of cv. N 512. The greatest serum viscosity was determined in tomatoes of cv. Brigade at the pink stage, but at the red and red + 2 harvests the greatest values were obtained from H 8892 tomatoes (Table 3). The H 8892 cv. also produced the greatest serum viscosities in all maturity stages studied in 1996. Sharma *et al.* (1996) concluded that although simple sugar content affects serum viscosity, the water-insoluble solids exhibited a more pronounced effect on serum viscosity. In fact, Bel-Haj (1981) demonstrated that relative serum viscosity depended on break temperature, and that higher break temperatures lead to a greater retention of pectin retention and greater serum viscosity. Overall, with the progression of tomato maturity, Bostwick consistency values increase while the serum viscosity decreases (Table 3). The ratio between Bostwick consistency and serum viscosity changes over maturity, indicating a change in the relationship between these two parameters among selected cvs. The ratio of Bostwick consistency to serum viscosity was less than 1.0 for cvs. H 8892 and Brigade at the pink stage in 1995, and H 8892 at the red stage in 1996. The highest ratios of Bostwick consistency to serum viscosity were observed at advanced maturity stages, particularly for cvs. FM 9208 and LaRossa at the red + 2 stage in 1995 and Brigade at the red + 3 stage in 1996.

In general, most of the attributes indicative of tomato paste quality were more desirable at the less mature (e.g., pink or red) stages and declined with maturity. This is illustrated by observing changes in soluble solids content, consistency and serum viscosity in particular. In the case of pH and titratable acidity, pink tomatoes were more acidic, but acidity changed little after tomatoes reached the red maturity stage. Color is not a good discriminator of maturity; because tomato color was fairly stable after the red maturity stage was reached and for an additional 2 weeks.

Statistical analysis was carried out for the tomato paste quality attributes of the five common cvs. grown in both years and harvested at the red and red + 2 maturity stages. With the exception of soluble solids content, the other paste quality analyses were significantly different ($P < 0.0001$) between the 2 years. In 1995, there was lower pH, larger titratable acidity and smaller Agtron color value, while in 1996 there were smaller Bostwick values and greater serum viscosities. These differences in quality attributes may be related to the seasonal weather differences (Table 1), with 1995 being a cooler season that perhaps resulted in less mature, higher acid and less colorful tomatoes.

Peelability. For all tomato cvs. studied, a substantial increase in the percentage of tomatoes peeled was obtained by the use of mechanical peel eliminators after the basic treatment of steam plus vacuum (Table 4). In 1995, for cvs. Brigade, H 8892, Halley 3155 and N 512 at the red maturity stage, peelability roughly doubled after passage through the mechanical rollers. Nevertheless, cv. H 8892 and N 512 did not reach a desirable level of peeling (by industrial standards, a minimum of 65% is desirable). FM 9208 was clearly the most peelable cv., with few tomatoes left unpeeled following the steam plus vacuum treatment. At the red stage it exhibited a relatively high peelability level of 69% prior to the mechanical rollers. H 8892 and N 512 cvs. were the worst performers. In fact, this was not completely unexpected considering that cv. N 512 was bred for resistance to nematode attack, and as a result contains a more resistant peel than common processing cvs., with peels designed only to withstand mechanical harvesting.

Although tomato cv. N 512, the roundest tomato analyzed in 1995 (Table 2), exhibited the smallest percentage of peeled tomatoes at the red + 2 stage, the results obtained in this study do not confirm (Monti 1980) that elongated tomatoes are necessarily easier to peel. In 1996, tomatoes of the LaRossa cv. were the most oblong and exhibited a small peelability at the red stage (Table 4), although LaRossa cv. peeled well in 1995. In 1996, only cv. H 8892 exhibited greater levels of peeled tomatoes than the percentage of peeled tomatoes obtained in 1995. All other cvs. did not peel as easily in 1996 as they did in 1995.

TABLE 4.
PEELABILITY AND YIELD OF WHOLE PEELED AND DICED TOMATOES HARVESTED IN 1995 AND 1996

Cultivar	Maturity	% peeled after steam + vacuum		% peeled after rollers		Peel index		Whole peeled yield (%)		Dice yield (%)		Peeling losses (%)		Dicing losses (%)	
		1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
FM 9208	Red	69.3	60	91.1	87.5	5.3	1.5	59.3	42.8	41.4	34.3	40.7	57.2	30.1	19.4
	Red + 2	48.3	25.8	91.7	53.3	7.3	1	56.4	17.8	38	13	43.6	82.2	32.8	25.4
LaRossa	Red	25	20	78.3	40	5	1.6	48.3	23	33.4	22.9	51.7	77	31.2	12.9
	Red + 2	30		81.7		8.3		47.3		39.7		52.7		30.9	
	Red + 3		45		65		1.7		37.4		29.3		62.6		36.2
H 8892	Red	17.5	37.5	40	65	3.3	4.9	22.9	35.5	15.3	24.3	77.1	64.5	32.9	29.1
	Red + 2	12.5	67.5	62.5	87.5	7.3	2.2	40.6	56	26.4	22.5	59.4	44	35.2	45.1
	Red + 3		50		62.5		0.9		38		23.9		62		31.5
Brigade	Red	36.7	28.3	75	61.7	7.2	3.8	56.7	29.9	32.3	21.7	43.3	70.1	42.8	27.6
	Red + 2	55	45	100	58.3	5	0.3	69.5	38.5	47.1	28.3	30.5	61.5	32.2	26.3
Halley 3155	Red	35	50	81.7	75	17	5.2	60.6	54.2	43.7	46.4	39.7	45.8	27.8	14.5
	Red + 2	18.3	16.6	75	47.3	10	1	54.1	26.9	38.4	23	45.9	73.1	28.6	14.7
	Red + 3		43.3		73.3		0.7		44.9		33.3		55.1		25.8
N 512	Red	23.3		58.3		5.5		39.9		27		60.1		32.3	
	Red + 2	15		70		16		56.8		32.8		43.2		41.8	

Another parameter used by some processors in the evaluation of peelability is the peel index, corresponding to the amount of peel (in.^{2}) that remains attached to the tomato after the complete peeling process. In 1995, peel index was lowest (≤5) at the red stage for cv. H 8892 and LaRossa, indicating that these cvs. require less manual removal of peel tags following passage through the steam peeler and mechanical rollers. In 1996, with only one exception (H 8892 at the red stage), peel index values were much smaller than in 1995. Peel index is not a very precise determinant because of the technical difficulty of evaluating the area of the remaining pieces of peel. Therefore, although widely used by the tomato industry, these determinations are prone to considerable errors.

In the 1995 season, yields of whole peeled tomatoes were largest for FM 9208, Brigade and Halley 3155. Large differences between the red and red + 2 maturity stages were observed for tomatoes of the cv. H 8892 (28.0% and 47.9%). Diced tomato yield was highest for cv. Brigade at the red + 2 stage (47.1%). In 1996, yields were considerably smaller than in 1995, with the exception of tomatoes of the cv. H 8892. Tomato cvs. that produce tomatoes with thick pericarp walls, small locules and few seeds will potentially result in high yields of diced tomatoes. However, only peeled tomatoes were included in the calculation of whole peeled and dice yields, because in a processing environment poorly peeled tomatoes are diverted to the paste process.

In 1996, the only cv. with greater peelability than in the previous season was cv. H 8892. This fact may relate to climatic differences between the two seasons. Higher temperatures in 1996 may have resulted in smaller yields, and consequently overall greater peeling losses than in 1995. Peeling waste amounts to 25–28% of tomato weight processed in commercial canneries (Barringer *et al.* 1999). The "red layer" below the tomato peel may be completely lost during peeling. This red layer is relatively thin (1.4–3.2 mm), and even during careful hand peeling, a mean of 7–10% of the tomato weight is lost. Dicing losses include weight losses caused by seeds and liquefied locular material freed after dicing whole peeled tomatoes and straining the tomato product. Overall, the smallest dicing losses were recorded for Halley 3155, FM 9208, LaRossa and H 8892. In the 1996 season, although peeling losses were higher than in the previous year, overall dicing losses were much smaller than in 1995, in particular for cv. Halley 3155 and LaRossa at the red stage.

Statistical analysis suggests that there were significant differences in percentage of peeled tomatoes, peel index and yield between the two seasons. In 1995, larger percentages of peeled tomatoes ($P < 0.0001$), peel index ($P < 0.005$), whole peeled ($P < 0.0001$) and dice yields ($P < 0.0001$) were obtained. The differences seen for dicing losses, overall smaller in 1996, were statistically different ($P \approx 0.015$).

CONCLUSIONS

Results of this study demonstrate the variation observed in consecutive growing seasons of selected tomato cvs. The impact of the growing season is apparently more significant than anything else, even the genetic background of the cvs. This evidence points to the need for several years of evaluation before conclusions can be drawn on the most appropriate cvs. for peeling, as for any other processing application. In fact, the large effect of the environment on the phenotypic stability of crops is attracting increased interest in plant breeding and crop production (Huehn 1990). Repeating the peeling study for several consecutive years to examine the potential effect of any tomato attribute and/or quality parameter would be desirable. To minimize possible environment interactions, agronomic conditions (location, soil type, planting period, plant density, fertilization, maturity at harvest) should be equivalent.

Tomatoes harvested at the pink or red stage produced thicker pastes with greater serum viscosity and titratable acidity than tomatoes harvested at the red + 2 or red + 3 stages. Soluble solids levels also increased with maturity. Peelability of tomatoes varied among selected cvs., but it was positively correlated with thick pericarp walls, small locules and fewer seeds. Knowledge of selected tomato cvs. and the associated physical attributes may allow tomato processors to produce whole peeled and diced tomato products more efficiently.

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