# Relationship between Sensory and Instrumental Analysis for Tomato Flavor

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ABSTRACT. **The major components of flavor in tomato (*Lycopersicon esculentum* Mill.) and other fruit are thought to be sugars, acids, and flavor volatiles. Tomato overall acceptability, tomato-like flavor, sweetness, and sourness for six to nine tomato cultivars were analyzed by experienced panels using a nine-point scale and by trained descriptive analysis panels using a 15-cm line scale for sweetness, sourness, three to five aroma and three to seven taste descriptors in three seasons. Relationships between sensory data and instrumental analyses, including flavor volatiles, soluble solids (SS), individual sugars converted to sucrose equivalents (SE), titratable acidity (TA), pH, SS/TA, and SE/TA, were established using correlation and multiple linear regression. For instrumental data, SS/TA, SE/TA, TA, and *cis*-3-hexenol correlated with overall acceptability ($P = 0.05$); SE, SE/TA ($P \leq 0.03$), geranylacetone, 2+3-methylbutanol and 6-methyl-5-hepten-2-one ($P = 0.11$) with tomato-like flavor; SE, pH, *cis*-3-hexenal, *trans*-2-hexenal, hexanal, *cis*-3-hexenol, geranylacetone, 2+3-methylbutanol, *trans*-2 heptenal, 6-methyl-5-hepten-2-one, and 1-nitro-2-phenylethane ($P \leq 0.11$) with sweetness; and SS, pH, acetaldehyde, acetone, 2-isobutylthiazole, geranlyacetone, β-ionone, ethanol, hexanal and *cis*-3-hexenal with sourness ($P \leq 0.15$) for experienced or trained panel data. Measurements for SS/TA correlated with overall taste ($P = 0.09$) and SS with astringency, bitter aftertaste, and saltiness ($P \leq 0.07$) for trained panel data. In addition to the above mentioned flavor volatiles, methanol and 1-penten-3-one significantly affected sensory responses ($P = 0.13$) for certain aroma descriptors. Levels of aroma compounds affected perception of sweetness and sourness and measurements of SS showed a closer relationship to sourness, astringency, and bitterness than to sweetness.**

Flavor, which is comprised of aroma and taste (Shewfelt, 1993), is an important part of food quality. The aroma or odor of a food product is detected when its volatiles enter the nasal passages at the back of the throat and are perceived by receptors of the olfactory system (retronasal) (Meilgaard et al., 1991). Taste is the sum of the sensory attributes arising from the stimulation of the gustatory receptors on the tongue (American Society of Testing and Materials, 1992, 1996). Lack of characteristic tomato flavor is a common complaint of consumers when purchasing supermarket tomatoes (Bruhn et al., 1991) especially in areas that are far from tomato growing regions. However, the importance of taste and aroma in tomato flavor has never been firmly established. It has been suggested that the soluble solids/titratable acid ratio (De Bruyn et al., 1971; Stevens, 1972), total sugar, or total acids content (Jones and Scott, 1984; Stevens et al., 1977, 1979) are important. Malundo et al. (1995) demonstrated that at given levels of sweetness there are optimal acid concentrations. Levels of acids above this optimal concentration resulted in decreased flavor acceptability. Kavanaugh and McGlasson (1983) reported that volatile aroma compounds interacted with sugars and acids to give a characteristic tomato flavor.

More than 400 aroma compounds have been identified in tomato fruit and have been the subject of several reviews (Buttery and Ling, 1993a, 1993b; Buttery et al., 1989; Petro-Turza, 1987). Flavor active compounds have been identified by gas chromatography–mass spectrometry (GC–MS) without preparing pure isolates, therefore not allowing sensory observation (Acree, 1993). With few sensory observations on these flavor compounds, their flavor contributions are poorly understood, much less their interactive effects. However, Buttery (1993) has reported on volatiles present at concentrations greater than one part per billion in tomato fruit (narrowing >400 volatiles down to 30), and has done odor

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threshold studies to determine which of these are likely to contribute to tomato aroma (narrowing 30 down to 17). Many of these compounds were tested in this research as well as other water soluble compounds that were found to be present at higher levels by static headspace technique (Baldwin et al., 1991a, 1991b; Nisperos-Carriedo and Shaw, 1990) than by Tenax trapping methods used by Buttery (1993).

Fresh-market tomato breeders have improved yield, disease resistance, fruit size and color leading to productive plants and attractive fruit. However, the perishable nature of tomatoes makes long distance shipment difficult. Thus, many production districts harvest fruit when green to reduce losses. The prevalence of immature green fruit in the harvests and refrigeration of fruit on the way to market have contributed to consumer dissatisfaction with tomato flavor. Immature green-harvested fruit do not ripen with good quality compared to mature green-harvested tomatoes (Kader et al., 1978; Maul et al., 1997). Refrigeration of tomatoes can lower flavor volatiles (Baldwin et al., 1992a; Buttery et al., 1987) and alter flavor (Kader et al., 1978). Breeders have found a ripening inhibitor gene (*rin*) and developed firm hybrids combining a *rin* parent with a normal ripening parent to allow for harvest of fruit beyond the mature green stage (Baldwin et al., 1995; Mutschler and Guttieri, 1987). Another breeding approach has been to develop highly firm breeding lines without a ripening attenuating gene. These breeding lines are referred to as ultrafirms (Baldwin et al., 1995). Molecular biologists, on the other hand, have down-regulated ripening-related enzymes resulting in firmer, delayed ripening tomato fruit (Gray et al., 1992).

These breeding and molecular approaches have the potential for indirect improvement of tomato flavor by providing fruit that can be harvested at advanced maturities (i.e., beyond mature green). In addition, use of *rin* hybrids, ultrafirm, and transgenic fruit still necessitate selection of breeding material with high quality flavor characteristics. Despite advances in flavor analysis, breeders and molecular biologists have no clear flavor target for selection and manipulation of tomato flavor quality, much less a way to measure their success in this endeavor. What is lacking is an integrated understanding of tomato flavor and methods to measure this complex trait.

Currently, the most common methods of measuring tomato flavor include both formal and informal sensory studies, measurement of soluble solids (SS), pH, titratable acidity (TA), and the SS/TA ratio. In this study, various instrumental measurements of sugars, acids and flavor volatiles were compared to data obtained from both experienced and trained sensory panels over three seasons. The purpose of this comparison was to identify which instrumental measurements best reflect sensory observations for different aspects of tomato flavor.

## Materials and Methods

**Fruit (1994).** Tomato cultivars were grown in a completely randomized block design with three blocks and ten plants per plot at the University of Florida Gulf Coast Research and Education Center in Bradenton, Fla., in Spring 1994, 1996, and 1997. In 1994, ripe fruit of 24 cultivars were sampled in the field from two blocks, and informally evaluated for flavor by four people. From this, seven cultivars were selected for sensory and instrumental–chemical analysis to represent as wide a range as possible in tomato flavor quality based on field screening and previous studies (Baldwin et al., 1991a, 1991b). The cultivars were Fla 7579, 'Daniella' (*rin* hybrid), CLN 65-349D-2-0, 'Solar Set', 'Olympic', 'Sunny', and 'Rutgers'.

Stage six (USDA Color Chart: >90% of the surface showing red color) (USDA, 1975) fruit were harvested for the seven cultivars from all three blocks and stored 2 d at ambient temperature. Fruit with 100% red color, as determined for each cultivar in preliminary studies (Baldwin et al., 1995), were separated into two groups for sensory and chemical analysis.

For sensory analysis, fruit were washed and cut into wedges. Entries, representing 10 fruit, were given a code and presented to panelists in an environment controlled laboratory. Thirty-eight experienced panelists (male and female from 20 to 60 years of age), who had previous experience in evaluation of tomato and were familiar with the various tomato cultivars analyzed and terminology used, rated the entries for overall acceptability, tomato-like flavor intensity, sweetness, and sourness. A nine-point scale was used for each category, where 9 = considered high and 1 = low for detection of tomato-like flavor intensity, sweetness and sourness. For overall acceptability, 9 = the most and 1 = the least acceptable. Panelists were given water and unsalted crackers to clear their palates between samples.

Fruit from the same harvest were used for instrumental/chemical determinations. Analysis of headspace flavor volatiles was done by GC (Baldwin et al., 1992b). Composite samples for each cultivar consisted of 14 to 20 fruit per sample, from each of three replicate plots. Fruit were homogenized in a blender (Waring Products Corp., New York) at high speed for 30 s. Three minutes after homogenation, 25 mL of the homogenate was blended for 10 s with 10 mL saturated (room temperature) $CaCl_2$ to stop enzymatic reactions that can cause further changes in volatile levels (Buttery et al., 1987). The resulting homogenate was immediately flash frozen in liquid $N_2$ and held at –60 °C until analyzed for volatiles. Flavor volatile components were analyzed using a Perkin Elmer GC (model 8500; Perkin Elmer, Norwalk, Conn.) equipped with a HS-6 headspace sampler and flame ionization detector (FID) detector and injected onto a 0.53 mm × 30 m Stabilwax column of 1.0 µm film thickness (Resteck Corp., Bellefonte, Pa.). The different compounds were identified by comparison of retention times with those of standards and by enrichment of tomato homogenate with authentic samples. Concentrations were calculated by using regression equations, determined by injecting five different concentrations of each standard to obtain a peak height calibration curve as described previously (Nisperos-Carriedo et al., 1990). Volatile components that are abundant, or that have been reported to have significance for tomato or other fruit flavors (Baldwin et al., 1992a, 1992b; Buttery et al., 1971, 1987, 1989) were analyzed including: acetone, methanol, ethanol, 1-penten-3-one, hexanal, *cis*-3-hexenal, *trans*-2-hexenal, 2+3-methylbutanol, *trans*-2-heptenal, 6-methyl-5-hepten-2-one, *cis*-3-hexenol, 2-isobutylthiazole, 1-nitro-2-phenylethane, geranylacetone, and β-ionone.

The remaining homogenate was stored at –20 °C until prepared for analysis of SS, pH, and TA (Jones and Scott, 1984). HPLC analysis of individual sugars (glucose and fructose) was done according to method of Baldwin et al. (1991a, 1991b). Individual sugars were analyzed from 40 g of homogenate extracted in 800 $g \cdot L^{-1}$ ethanol on a Sugar Pak column (Waters, Millipore Corp., Milford, Mass.). Levels of percent glucose and fructose were converted to sucrose equivalents (SE) (Koehler and Kays, 1991), a term of relative sweetness based on sucrose where percent values for these sugars were multiplied by 0.74 and 1.73, respectively, and combined.

**Fruit (1996).** Eighteen cultivars were grown, harvested, and sampled in the field as described for 1994. Fruit from nine cultivars, representing a range in tomato flavor quality, were

Table 1. Experienced sensory panel ratings using a nine-point hedonic scale (1 = low, 9 = high) for 1994 tomato cultivars 'Solar Set', 'Sunny', 'Olympic', 'Rutgers', 'Daniella', CLN-65-349D-2-0 (CLN), and Fla 7579.

| | Sensory rating | | | |
|---|---|---|---|---|
| Cultivar | Overall acceptability | Tomato-like flavor | Sweetness | Sourness |
| Solar Set | 5.5 ab[z] | 5.4 a | 4.9 ab | 4.6 ab |
| Sunny | 4.5 c | 4.5 abc | 4.3 b | 5.0 a |
| Olympic | 5.0 abc | 4.8 abc | 5.4 a | 3.6 c |
| Rutgers | 4.3 cd | 4.1 cd | 4.5 ab | 3.8 bc |
| Daniella | 4.6 bc | 4.3 bcd | 4.4 b | 4.0 bc |
| CLN | 3.5 d | 3.5 d | 3.2 c | 5.1 a |
| Fla 7579 | 5.8 a | 5.2 ab | 5.2 ab | 4.4 abc |

[z]Means with the same letter within a row are not significantly different ($P \leq 0.05$).

selected and brought to the laboratory and stored overnight at ambient temperature. The nine cultivars analyzed were 'Solar Set', 'Olympic', Fla 7060, 'Rutgers', ultrafirm inbred (7171 x 7403)$F_2$ (ultrafirm 1), ultrafirm inbred 95425-2 (ultrafirm 2), and three *rin* hybrids. The *rin* hybrids had two or three backcrosses to Fla. 7060: *rin* 1 and 2 (Fla. $7060_3$ x *rin*, Fla. $7060_2$ x *rin*); and *rin* 3 was a hybrid resulting from the *rin* parent with two backcrosses to 7060, the other 'Solar Set' parent (Fla. $7060_2$ x *rin* x Fla. 7171, *rin* 3). The Fla 7060 *rin* hybrids were utilized to look at the *rin* gene in different highly flavored backgrounds (comparable to 'Solar Set' and Fla. 7060).

Composite samples, representing 17 to 30 fruit (5 to 10 fruit from each of 3 field plots), were finely chopped in a Cuisinart (East Windsor, N.J.) equipped with a standard blade (16 cm diameter curved serrated stainless steel) for 15 pulses (≈15 s). A subsample (≈300 mL) was removed and held 180 s and processed as described above for volatile, SS and TA analysis (one sample/ cultivar for SS, TA, and SE; three samples/cultivar for volatiles). The objective measurements were the same as for 1994 except that acetaldehyde and phenylethanol aroma compounds were also quantified.

Concurrently, the remainder of the chopped tomato mixture was placed into 113-mL plastic cups with lids (30 g/cup) and immediately served at room temperature to a descriptive analysis panel in a controlled environment taste panel room. The panel had been previously trained by Sens Tek (Sens Tek Inc., Tampa, Fla.) and was comprised of seven judges. Each sample was rated before the next was processed to avoid loss of volatiles. All nine cultivars were analyzed in a single session in random order. The descriptive analysis panel was extensively trained to identify, measure, and monitor numerous characteristics in fresh tomatoes (Einstein, unpublished data). Before this analysis the panel had met weekly in multiple sessions for 6 months. The intensity of each attribute, or descriptor, was evaluated using a 15-cm line scale (0 cm = not detected, 15 cm = high intensity). Descriptors used in this evaluation for aroma were overall aroma intensity, grassy, ripening, ripe, and green vine. Taste descriptors included overall taste intensity, sweet, sour, raw green, ripe, bitter, and astringent. Aftertaste descriptors included overall aftertaste intensity, afterbitter, and aftersour. Previous training exercises and other data had shown that the panel was able to successfully differentiate among fresh tomato samples representing different genetic material, maturity, and/or horticultural conditions.

**Fruit (1997).** Cultivars were grown, pre-screened by six people, and harvested as described above. Six cultivars were selected to represent a range in flavor. Composite samples, representing five fruit (from three field plots), were rated the same day by an experienced panel of 52 participants for sweetness and overall flavor on a nine-point scale as described for the 1994 fruit. The six cultivars analyzed were 'Solar Set', 'Olympic', Fla7962B, two *rin* hybrids (*rin* 1 and 2), and one ultrafirm tomato (bred and selected for firmness). A subsample was simultaneously homogenized and processed for chemical analysis as described for 1994 SS, pH, TA, and volatiles (one sample/cultivar). A subgroup of 10 tomatoes per cultivar was transported to the University of Georgia on the day of harvest, held at ambient temperature overnight and sampled by a trained descriptive panel of seven judges the following day. Tomatoes were homogenized (Baldwin et al., 1992b) and aliquots of the tomato homogenate sampled by the trained panelists were also processed for chemical analysis as described for 1994 (each sample was a composite of 10 fruit, one sample/cultivar). This panel was trained to identify, measure, and monitor numerous characteristics in fresh tomato fruit using a 15-cm line scale (0 cm = not detected, 15 cm = high intensity). Descriptors used in this evaluation included sourness, sweetness, saltiness, bite, astringency, and ripe, citrus and spoiled aroma.

**Statistics.** Results were analyzed as a completely randomized design with cultivar as treatment using the General Linear Model (PROC GLM) procedure of the Statistical Analysis System (SAS Institute, Cary, N.C.). Significant differences in sensory attributes and instrumental measurements among cultivars were determined by Duncan's multiple range and least significant difference (LSD), respectively ($P = 0.05$). Correlations between sensory data and between sensory data and instrumental and chemical analyses were determined using the SAS analysis, PROC CORR. Regression analysis, to determine the relationship between sensory responses with instrumental measurements of flavor volatiles was done by multiple linear regression using another SAS procedure, PROC STEPWISE (backward elimination). Significance levels for sensory correlations and regressions were determined as appropriate for statistical analysis of sensory data ($P = 0.15$) (Meilgaard et al., 1991).

## Results and Discussion

The objective of this research was to identify which instrumental measurements best reflected the sensory observations for different aspects of tomato flavor. We explored relationships between taste descriptors and measurements of SS, TA, SE, and ratios of SS or SE to TA. We also explored relationships between aroma descriptors and measurement of volatile compounds. We did not find correlations between sugar and acid measurements and aroma descriptors, but did find correlations between taste descriptors and volatile concentrations.

**The 1994 season.** Seven tomato cultivars were rated by an experienced panel for overall acceptability, tomato-like flavor,

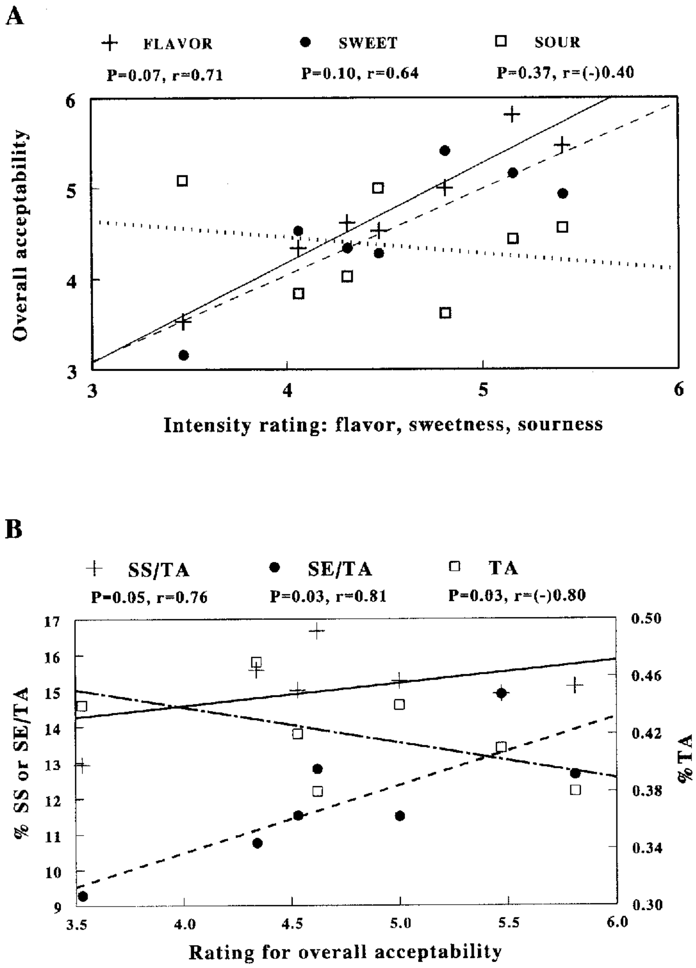



Fig. 1. Seven tomato cultivars were rated by an experienced sensory panel on a nine-point scale (1 = low, 9 = high). Correlation of panel rating of overall acceptability with (**A**) sensory ratings for tomato-like flavor (✚), sweetness (●), and sourness (❑); and (**B**) the ratio of percentage soluble solids to titratable acidity (SS/TA, ✚), percentage sucrose equivalents to TA (SE/TA, ●), and TA (❑).

sweetness and sourness and significant differences were found (Table 1). Tomato-like flavor intensity ratings for these cultivars were almost identical to the rating for overall acceptability, indicating the close relationship between flavor and tomato quality. Panel data for sweetness were also similar, with the exception of 'Olympic'. Cultivars that rated highest for overall acceptability and tomato-like flavor ('Solar Set' and Fla. 7579) were rated intermediate for sourness and relatively high for sweetness. It would appear from the panel data that an acceptable tomato is high in tomato-like flavor intensity and sweetness, but intermediate in sourness. This is in agreement with Malundo et al. (1995) who reported that increasing sugar concentrations in tomato samples increases flavor acceptance, but that acid levels reach an optimum at a given sugar concentration. Increasing acid concentration above this level results in a decrease in consumer ratings.

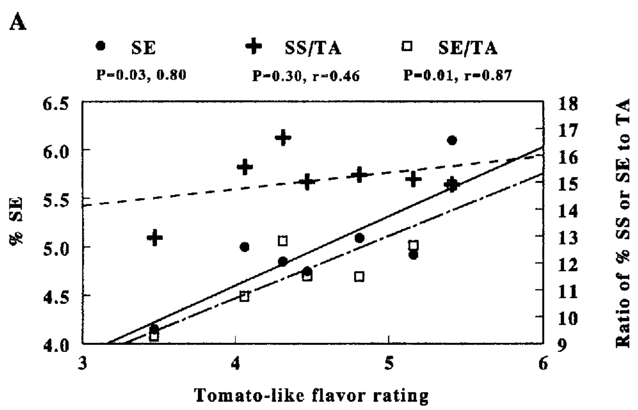
Measurements of SS and TA and their ratio are used by breeders and others to select for desirable sweet and sour flavor characteristics in tomatoes and other fruit, since these analyses are convenient and require minimal equipment. However, their relationships to perception of sweetness and sourness or even to tomato acceptability have never been clearly established. Solids in tomato fruit contain more than sweet sugars and can include acids and other nonsugar compounds (Davies and Hobson, 1981). Of all the objective measurements taken on the 1994 fruit, significant differences were found among cultivars for only SS, SE, and the volatiles hexanal, *cis*-3-hexenal, *cis*-3-hexenol, 2+3-methylbutanol, ethanol and methanol ($P = 0.05$, data not shown). In this study SS measurements were compared to analysis of individual sugar components (glucose and fructose) converted to SE along with measurement of TA and pH. Since perception of sweetness and sourness is each influenced by the amount of acids and sugars present, respectively (Malundo et al., 1995), the ratios of SS or SE to TA were also analyzed.

Correlation analyses were performed on the sensory data for overall acceptability, tomato-like flavor, sweetness, and sourness versus chemical and instrumental analyses for SS, SE, TA, pH, SS/TA, SE/TA, and individual flavor volatiles to determine which measurements best predicted the sensory data. Correlation analyses were also performed to see if any individual attributes related to overall acceptability. Sensory flavor and sweetness ratings showed significant ($P = 0.1$) positive correlations with overall acceptability and relatively high $r$ values while sourness did not (Fig. 1A). Sensory flavor and sweetness ratings were also highly correlated ($P = 0.01$, $r = 0.85$, data not shown) Measurements for SS, SE, TA, SS/TA, SE/TA, and pH were also correlated to overall acceptability of which SS/TA, SE/TA and TA were significant (Fig. 1B). SE and SE/TA were significantly correlated with sensory data for tomato-like flavor intensity, shown compared to SS/TA (Fig. 2A). When measurements of SS and SE were compared for correlation with sensory data for sweetness intensity (Fig. 2B), SE showed a better correlation ($P = 0.11$). Of all the measurements taken only SS and pH were significantly correlated to sensory data for sourness (Fig. 2C). In a previous study, Resurreccion and Shewfelt (1985) found no correlation between sensory measures and objective measurement of initial pH, TA, or SS for tomatoes.

The 1994 sensory data for overall acceptability, tomato-like flavor, sweetness and sourness were then correlated with values for concentrations of aroma compounds (Fig. 3). Sensory rating of overall acceptability and sweetness were found to be negatively correlated to the flavor volatiles *cis*-3-hexenol and *cis*-3-hexenal, respectively (Fig. 3 A and B). Sensory rating of tomato-like flavor was positively and negatively correlated to geranylacetone and 2+3-methylbutanol, respectively (Fig. 3C). Sensory rating for sourness was negatively and positively correlated with concentrations of the volatiles acetone and hexanal, respectively (Fig. 3D).

The volatile *cis*-3-hexenal is reported to have the highest odor units of tomato volatile components so far identified (Buttery et al., 1989, 1971) and was, therefore, considered to be important to flavor. Odor units (Guadagni et al., 1963) determine at what level a compound must be present in food to be detected by smell, but they do not, however, indicate whether the impact of the component is positive or negative to overall flavor quality. Neither do these units indicate the effect of interaction with other volatiles, sugars, acids or other flavor compounds. The volatiles *cis*-3-hexenol, 2+3-methylbutanol, and hexanal have all been shown to have odor units above zero which indicates that they are present in tomatoes at levels above their odor threshold (Buttery, 1993) and are assumed to contribute to tomato flavor. Geranylacetone, on the other hand, has a relatively low odor unit, and thus may or may not contribute significantly to tomato flavor directly, but may have an effect through interactions with other flavor components.

Regression analysis indicated that 2+3 methylbutanol, 6-methyl-5-hepten-2-one and 2-isobutylthiazole together contributed to overall acceptability and perception of sourness (Table 2). The above compounds plus *cis*-3-hexenal contributed to perception of tomato-like flavor intensity and *cis*-3-hexenal influenced percep-



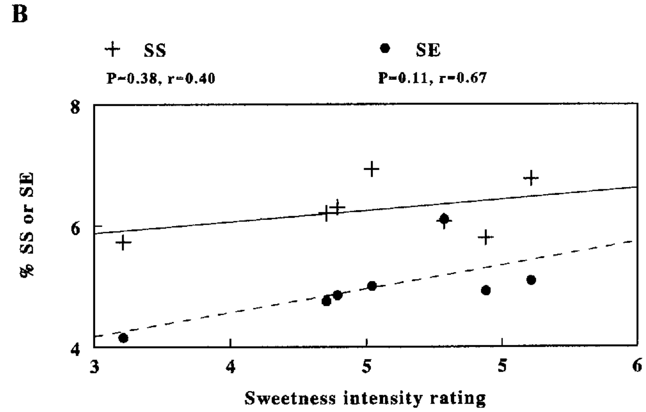
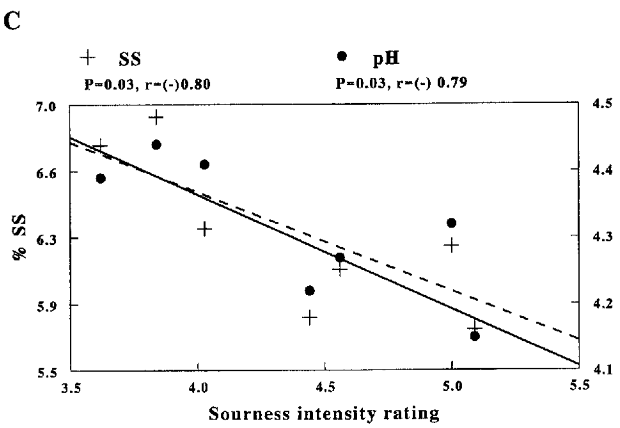




Fig. 2. Seven tomato cultivars were rated by an experienced sensory panel on a nine-point scale (1 = low, 9 = high). Correlation of panel rating of (**A**) Tomato-like flavor with sucrose equivalents (SE, ●) and ratio of percentage soluble solids (SS, ✚) or SE (❑) to titratable acidity (TA); (**B**) sweetness with measurements of percentage SS (✚) or SE (●); and (**C**) sourness with percentage SS (❑) or initial pH (●).




tion of sweetness. It is interesting to note that 2-isobutylthiazole may possibly be an important contributor to tomato flavor, since it is unique to tomato among fruit and has relatively high odor units (Buttery, 1993; Buttery and Ling, 1993b).

**The 1996 season.** Sensory analysis was performed by a trained descriptive panel. Of all the aroma and taste descriptors, only overall aroma at $P \leq 0.05$, and aroma ripe and aroma green vine at $P = 0.15$ showed significant differences between cultivars (Table 3). Of the 17 aroma volatiles quantified, all but β-ionone showed significant differences among cultivars ($P = 0.05$, based on three replicate samples, data not shown).

Taste descriptors showed significant correlations to sugar, acid, and volatile data, but in some cases the *r* values were not particularly impressive (discussed as ≥ |0.7|). Overall taste intensity was correlated with SS/TA and geranylacetone although *r* values were not high (Table 4). Sweet was correlated with *trans*-2-hexenal and *cis*-3-hexenol of which the former had an *r* value >0.7. The descriptor sour was correlated with acetaldehyde, acetone, β-ionone, ethanol and *cis*-3- hexenol with *r* values >0.7. Raw green was correlated with *trans*-2-hexenal; bitter with *cis*- 3-hexenal and 1-penten-3-one; and astringent with SS and SE, of which only SS had an *r* value >0.7.

For aftertaste descriptors (discussed as ≥ | 0.7 | ), overall aftertaste intensity correlated with acetaldehyde, β-ionone, and ethanol, with the former two volatiles having *r* values >0.7 (Table 5). Aftersour correlated with acetaldehyde, hexanal, and 2-isobutylthiazole, with hexanal having an *r* value >0.7. Afterbitter correlated with SS, acetaldehyde, 1-penten-3-one, β-ionone, ethanol, methanol, and 2+3-methylbutanol, with β-ionone and 2+3-methylbutanol showing *r* values >0.7.

No aroma descriptors showed meaningful correlations to SS, TA, SE or the ratios of SS or SE over TA. For volatile analysis, the aroma descriptor overall aroma intensity correlated significantly with the aroma compounds acetaldehyde, *trans*-2-hexenal, acetone, β-ionone, ethanol, methanol, *cis*-3-hexenol, 2+3-methylbutanol, and 1-nitro-2-phenylethane (Table 6), with 3 volatiles (*trans*-2-hexenal, β-ionone, and 2+3-methylbutanol) showing *r* values <0.7. The aroma descriptor ripening showed a positive correlation to *cis*-3-hexenal; and the descriptor ripe to *cis*-3-hexenol and ethanol, for which the latter compound *r* value was <0.7.

**The 1997 season.** There were significant differences for overall sweetness and flavor for the experienced panel and for the descriptors sweet, sour, salty, and citrus aroma (Table 7) for the trained panel ($P \leq 0.05$).

Measurements of SS showed a significant correlation with trained panel rating for both sourness and saltiness (Fig. 4A). In 1994, experienced panel rating for sourness correlated with measurement of initial pH, while in 1997 pH correlated negatively with experienced panel perception of sweetness (sourness was not rated) (Table 8). Experienced panel rating for tomato-like flavor showed significant correlation to panel rating for sweetness and to levels of 6-methyl-5-hepten-2-one (Table 8) as was found with experienced panel data from 1994 (Table 2). Experienced panel rating for sweetness also correlated with 2+3-methylbutanol, *trans*-2-heptenal, 6-methyl-5-hepten-2-one, and 1-nitro-2-phenylethane (Table 8). All of these correlations resulted in *r* values of ≥0.7.

The flavor volatiles hexenal, *cis*-3-hexenal, and *trans*-2-hexenal negatively correlated with trained panel perception of sweetness, while geranylacetone was positively correlated to this descriptor (Fig. 4B). Methanol, and β-ionone were negatively correlated with trained panel rating for citrus aroma while *cis*-3-hexenol was positively correlated to this descriptor (Fig. 4C). *cis*-3-Hexenal (positive), geranylacetone and β-ionone (both negative) also showed strong correlations to saltiness (Fig. 4D). In addition, acetone ($P = 0.08$) and 6-methyl-5-hepten-2-one ($P = 0.13$) were negatively correlated to spoiled aroma (data not shown). All of these correlations had *r* values >0.7 except for 6-methyl-5-hepten-2-one.

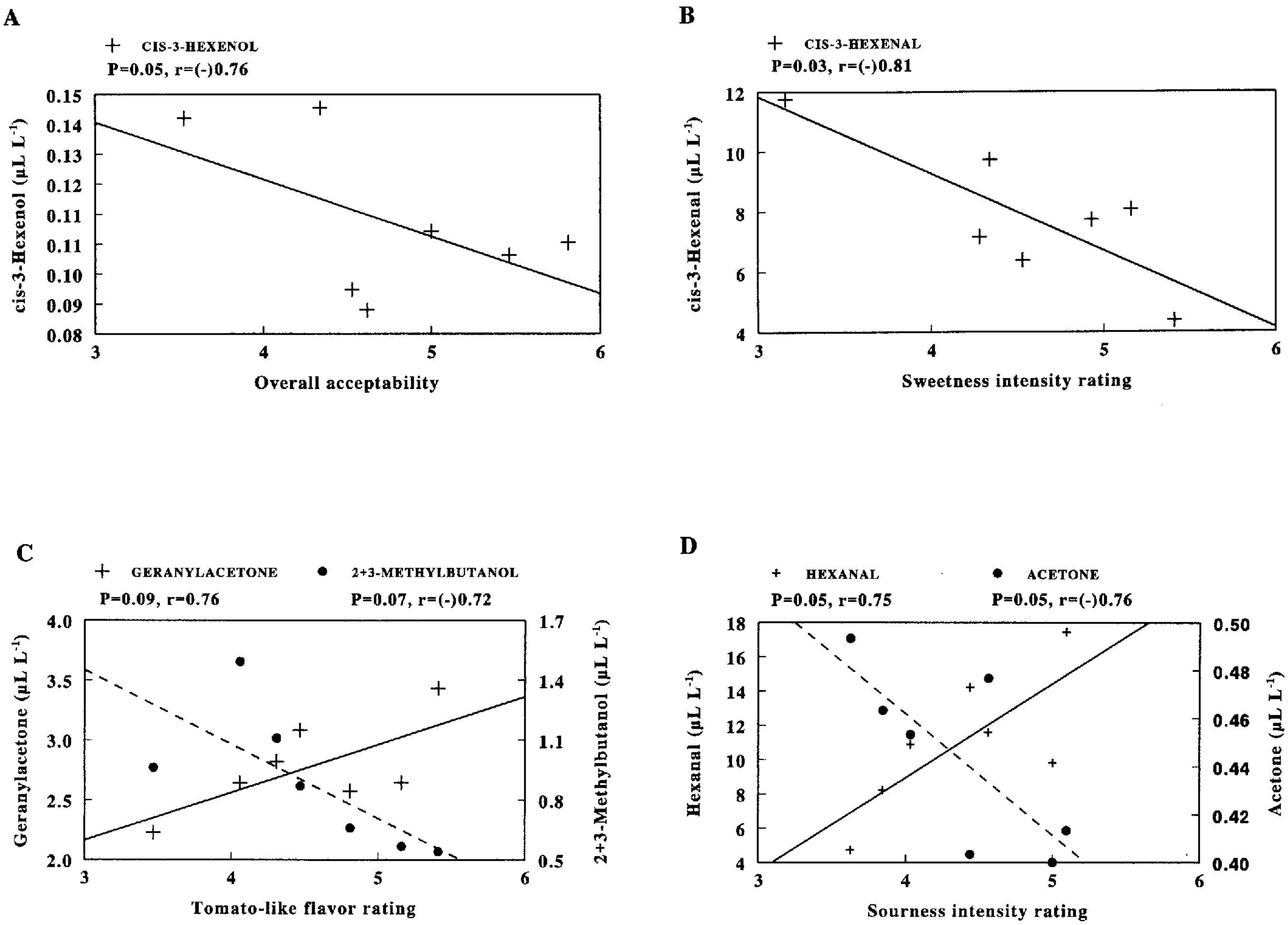



Fig. 3. Seven tomato cultivars were rated by an experienced sensory panel on a nine-point scale (1 = low, 9 = high). Correlation of panel rating of (**A**) Overall acceptability with concentrations of *cis*-3- hexenol (✚); (**B**) sweetness with concentrations of *cis*-3-hexenal (✚); (**C**) Tomato-like flavor with concentrations of geranylacetone (✚) and 2+3-methylbutanol (●); and (**D**) sourness with concentrations of hexanal (✚) and acetone (●).

The results support reported importance to tomato flavor of tomato volatiles with relatively high odor units including hexanal, *cis*-3-hexenal, *trans*-2-hexenal, 1-penten-3-one, 6-methyl-5- hepten-2-one, β-ionone, *cis*-3-hexenol, 2+3-methylbutanol, *trans*-2-heptenal, 2-isobutylthiazole, and 1-nitro-phenylethane (Buttery et al., 1989, 1971). Importance of other volatiles such as acetaldehyde, acetone, ethanol, methanol, and geranylacetone are also suggested since they showed significant relationships to sensory data.

We explored relationships between taste and aroma. Significant correlations and the results of regression analysis between volatile levels and ratings for sweetness, sourness, bitterness, astringency, and saltiness indicate possible interaction between sugars, acids, and other compounds with volatile components in terms of perception of sweetness, sourness, or other aspects of flavor. Some correlations resulted due to one sample or groupings of samples and could always be the result of covariation with

Table 2. Stepwise regression analysis of experienced panel sensory data for 1994 tomato overall acceptability, tomato-like flavor intensity, sweetness, and sourness in relation to concentration of volatile flavor components in headspace of tomato homogenate; probability ($P$) at $P \leq 0.1$.

| Sensory ratings | Volatile component | $P$ |
|---|---|---|
| Overall acceptability | 2+3-Methylbutanol | 0.004 |
| | 6-Methyl-5-hepten-2-one | 0.005 |
| | 2-Isobutylthiazole | 0.006 |
| Tomato-like flavor intensity | *cis*-3-Hexenal | 0.005 |
| | 2+3-Methylbutanol | 0.01 |
| | 6-Methyl-5-hepten-2-one | 0.02 |
| | 2-Isobutylthiazole | 0.08 |
| Sweetness | *cis*-3-Hexenal | 0.03 |
| Sourness | 2+3-Methylbutanol | 0.08 |
| | 6-Methyl-5-hepten-2-one | 0.06 |
| | 2-Isobutylthiazole | 0.05 |

Table 3. Trained sensory panel ratings for aroma descriptors using a 15-cm line scale (0 = low intensity, 15 = high intensity) for 1996 tomato cultivars 'Solar Set', 'Sunny', 'Olympic', Fla 7060, 'Rutgers', ultrafirm 1, ultrafirm 2, *rin* 1, *rin* 2, and *rin* 3.

| | Sensory rating for aroma intensity | | |
|---|---|---|---|
| Cultivar | Overall | Ripe | Green vine |
| Solar Set | 7.57 abcd[z] | 7.16 a | 0.0 b |
| Olympic | 7.73 abc | 6.50 ab | 0.0b |
| Fla 7060 | 8.10 a | 6.83 ab | 0.0 b |
| Rutgers | 7.94 ab | 6.73 ab | 0.0 b |
| Ultrafirm 1 | 7.59 abcd | 6.74 ab | 0.7 a |
| Ultrafirm 2 | 7.14 cde | 6.26 bc | 0.5 a |
| *Rin* 1 | 7.03 de | 6.24 b | 0.0 b |
| *Rin* 2 | 7.40 bcde | 6.34 b | 0.0 b |
| *Rin* 3 | 6.97 e | 5.71 c | 0.0 b |

[z]Means with the same letter within a row are not significantly different ($P \leq 0.05$).

Table 4. Probability ($P$) and Pearson's sample coefficient and linear correlation ($r$) resulting from correlation analysis of 1996 trained panel tomato taste descriptor ratings with instrumental and chemical data.

| Taste descriptor | Chemical analysis | $P$ | $r$ |
|---|---|---|---|
| Overall taste intensity | SS/TA | 0.09 | –0.59 |
| | Geranylacetone | 0.06 | 0.64 |
| Sweet | *trans*-2-Hexenal | 0.02 | –0.73 |
| | *cis*-3-Hexenol | 0.05 | –0.67 |
| Sour | Acetaldehyde | 0.02 | 0.76 |
| | Acetone | 0.02 | 0.72 |
| | β-Ionone | 0.01 | 0.78 |
| | Eethanol | 0.02 | 0.75 |
| | *cis*-3-Hexenol | 0.03 | 0.71 |
| Raw green | *trans*-2-Hexenal | 0.06 | 0.61 |
| Bitter | *cis*-3-Hexenal | 0.05 | 0.66 |
| | 1-Penten-3-one | 0.06 | 0.65 |
| Astringent | SS | 0.01 | 0.80 |
| | SE | 0.06 | 0.64 |

Table 5. Probability ($P$) and Pearson's sample coefficient and linear correlation ($r$) resulting from correlation analysis of 1996 trained panel tomato aftertaste descriptor ratings with instrumental and chemical data.

| Aftertaste descriptors | Chemical analysis | $P$ | $r$ |
|---|---|---|---|
| Overall aftertaste intensity | Acetaldehyde | 0.02 | 0.74 |
| | β-Ionone | 0.01 | 0.78 |
| | Ethanol | 0.06 | 0.65 |
| Aftersour | Acetaldehyde | 0.08 | 0.61 |
| | Hexanal | 0.03 | –0.73 |
| | 2-Isobutylthiazole | 0.08 | –0.60 |
| Afterbitter | SS | 0.05 | 0.67 |
| | Acetaldehyde | 0.07 | 0.62 |
| | 1-Penten-3-one | 0.08 | 0.61 |
| | β-Ionone | 0.02 | 0.73 |
| | Ethanol | 0.09 | 0.59 |
| | Methanol | 0.06 | 0.65 |
| | 2+3-Methylbutanol | 0.02 | 0.77 |

Table 6. Probability ($P$) and Pearson's sample coefficient and linear correlation ($r$) resulting from correlation analysis of 1996 trained panel tomato aroma descriptor ratings with instrumental and chemical data.

| Aroma Descriptors | Chemical analysis | $P$ | $r$ |
|---|---|---|---|
| Overall aroma intensity | Acetaldehyde | 0.02 | 0.75 |
| | *trans*-2-Hexenal | 0.07 | 0.62 |
| | Acetone | 0.01 | 0.78 |
| | β-Ionone | 0.04 | 0.68 |
| | Ethanol | 0.01 | 0.79 |
| | Methanol | 0.02 | 0.74 |
| | *cis*-3-Hexenol | 0.04 | 0.70 |
| | 2+3-Methylbutanol | 0.06 | 0.64 |
| | 1-Nitro-2-phenylethane | 0.01 | 0.80 |
| Ripening | *cis*-3-Hexenal | 0.007 | 0.83 |
| Ripe | *cis*-3-Hexenol | 0.01 | 0.80 |
| | Ethanol | 0.08 | 0.61 |

unknown factors. However, such interactions may also correspond to the flavor descriptors used to describe these volatile compounds such as green (unsaturated bonds with aldehydes or alcohols, such as *cis*-3-hexenal, *cis*-3-hexenol, and *trans*-2-hexenal) compared to fruity (ketones such as acetone, geranylacetone, and β-ionone) (DeRovira, 1996). It is not hard to imagine the green, herbaceous volatiles as perhaps being associated with sourness and the fruity volatiles enhancing perception of sweetness. Ethanol also is reported to enhance perception of sweetness (Rothe and Schrodter, 1996).

When the three studies are compared, some similarities emerge. Tomato-like flavor in the 1994 study (Fig. 3B), overall taste in the 1996 study (Table 4), and sweetness in the 1997 study (Fig. 4B) showed significant correlations to geranylacetone. The volatile 2+3-methylbutanol was significantly correlated to the tomato flavor descriptors tomato-like flavor (1994 study, Fig. 3B), overall aroma (1996 study, Table 6), and sweetness (1997 study, Table 8). 6-Methyl-5-hepten-2-one was significantly correlated with tomato-like flavor for experienced panel data from 1994 and 1997 (Tables 2 and 8, respectively) as well as overall acceptability (1994 study, Table 2) and spoiled aroma (1997 study, data not shown). Sweetness intensity in all three studies showed that either hexanal (Fig. 4B), *cis*-3-hexenal (Table 2, Figs. 3B and 4B), *trans*-2-hexenal (Table 4, Fig. 4B), or *cis*-3-hexenol (Table 4) were significant contributors. These three flavor volatiles are similar in odor description, result from lipid peroxidation, and are converted from one to the other (*cis*-3-hexenal to *cis*-3-hexenol and *trans*-2-hexenal) (Galliard et al., 1977; Riley et al., 1996; Stone et al., 1975) and all had negative slopes in the three studies. Sourness intensity showed a relationship to SS in all three studies (1994, Fig. 2C; 1996, at $P \leq 0.13$, data not shown; and 1997, Fig. 4A). Astringency and bitterness (afterbitter) were also related positively to SS in the 1996 study (Tables 4 and 5, respectively) and negatively to saltiness in the 1997 study (Fig. 4A). It would appear that SS may relate more to perception of acidity, bitterness, astringency, and saltiness than to sweetness. However, it is possible that astringency covaried with sourness or was confused with sourness by the panel. Perception of sourness (including after sour) also was related to the volatiles hexanal (Fig. 3D, Table 5), acetone (Fig. 3D, Table 4), and 2-isobutylthiazole (Tables 2 and 5) in the first two studies by correlation or regression analysis. These relationships did not always have the same slope, however, in all studies. This descriptor was also negatively correlated to pH in the 1994 experienced panel (Fig. 2C), while pH was positively correlated to sweetness (Table 8) in the 1997 experienced panel (sourness was not rated).

In conclusion, SE/TA and SE were slightly more useful in predicting overall acceptability and sweetness, respectively, than SS/TA or SS and both were better than SS/TA in predicting tomato-like flavor. Levels of SS showed a better relationship to sourness than to sweetness along with pH, and was more strongly correlated to this flavor aspect than TA. Certain flavor volatile compounds were found to contribute to overall acceptability, perception of tomato-like flavor intensity, specific aroma descriptors, sweetness, sourness, and other taste descriptors. Interaction of aroma compounds with each other and with sugars, acids and other compounds both chemically and in terms of flavor perception, is a fertile area for additional research.

Table 7. Trained sensory panel ratings for aroma descriptors using a 15 cm line scale (0 = low intensity, 15 = high intensity) for 1997 tomato cultivars 'Solar Set', 'Olympic', Fla 7092B, *rin* 1, *rin* 2, and an ultrafirm.

| | Sensory rating | | | | | |
|---|---|---|---|---|---|---|
| | Experienced panel | | Trained panel | | | |
| Cultivar | Sweetness | Flavor | Sweetness | Sourness | Saltiness | Citrus aroma |
| Solar Set | 4.7 bc[z] | 4.9 ab | 3.4 ab | 2.1 c | 3.0 c | 2.0 b |
| Olympic | 5.3 ab | 5.6 a | 3.6 ab | 4.4 bc | 3.8 abc | 3.6 a |
| Fla 7092B | 5.7 a | 5.4 a | 3.7 a | 4.8 abc | 3.7 bc | 2.6 ab |
| *Rin* 1 | 4.2 c | 4.8 bc | 1.8 bc | 3.8 c | 4.5 ab | 3.1 ab |
| *Rin* 2 | 4.1 c | 4.8 bc | 1.5 c | 7.5 a | 4.8 a | 2.8 ab |
| Ultrafirm | 4.4 c | 4.4 c | 1.6 c | 6.7 ab | 4.1 ab | 3.1 a |

[z]Means with the same letter within a row are not significantly different ($P \leq 0.05$).

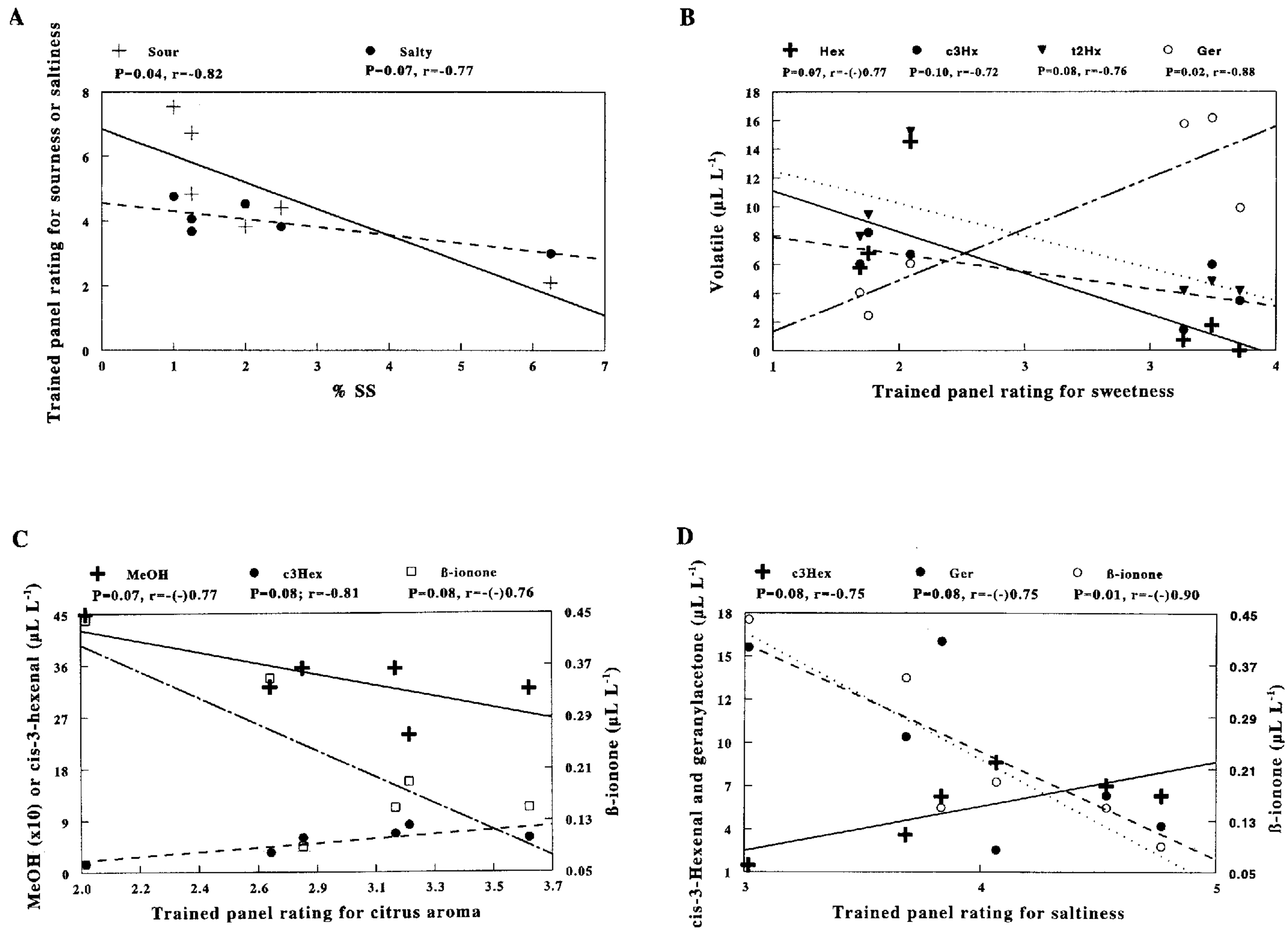



Fig. 4. Six tomato cultivars were rated by a trained descriptive panel on a 15-cm line scale (0 = low intensity, 15 = high intensity). Correlation of panel rating for (**A**) Sourness (✚) or saltiness (●) with % soluble solids (SS); (**B**) Panel rating for sweetness with concentrations of hexanal (Hex, ✚), *cis*-3-hexenal (c3Hex, ●), *trans*-2-hexenal (t2Hex, ▼), or geranylacetone (Ger, ❍); (**C**) Panel rating for citrus aroma with concentrations of methanol (MeOH, ✚), *cis*-3-hexenal (c3Hex, ●), or β-ionone (❑); or (**D**) Panel rating for saltiness with concentrations of *cis*-3-hexenal (c3Hex, ✚), geranylacetone (Ger, ●), and β-ionone (❍).

Table 8. Probability (*P*) and Pearson's sample coefficient and linear correlation (*r*) resulting from correlation analysis of 1997 tomato experienced panel ratings with instrumental and chemical data for tomato-like flavor and sweetness.

| Flavor descriptor | Sensory and chemical analysis | *P* | *r* |
|---|---|---|---|
| Tomato-like flavor | Perception of sweetness | 0.03 | 0.85 |
| | 6-Methyl-5-hepten-2-one | 0.11 | –0.71 |
| Sweetness | pH | 0.01 | 0.78 |
| | 2+3-Methylbutanol | 0.08 | 0.76 |
| | *trans*-2-Heptenal | 0.05 | –0.81 |
| | 6-Methyl-5-hepten-2-one | 0.05 | –0.81 |
| | 1-Nitro-2-phenylethane | 0.10 | –0.73 |

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