Chemical and Sensory Quality of Processed Carrot Puree As Influenced by Stress-Induced Phenolic Compounds

S. T. Talcott† and L. R. Howard*,†

Department of Horticultural Sciences, Texas A&M University, College Station, Texas 77843-2133

Physicochemical analysis of processed strained product was performed on 10 carrot genotypes grown in Texas (TX) and Georgia (GA). Carrots from GA experienced hail damage during growth, resulting in damage to their tops. Measurements included pH, moisture, soluble phenolics, total carotenoids, sugars, organic acids, and isocoumarin (6-MM). Sensory analysis was conducted using a trained panel to evaluate relationships between chemical and sensory attributes of the genotypes and in carrots spiked with increasing levels of 6-MM. Preharvest stress conditions in GA carrots seemed to elicit a phytoalexic response, producing compounds that impacted the perception of bitter and sour flavors. Spiking 6-MM into strained carrots demonstrated the role bitter compounds have in lowering sweetness scores while increasing the perception of sour flavor. Screening fresh carrots for the phytoalexin 6-MM has the potential to significantly improve the sensory quality of processed products.

Keywords: *Strained carrots; phenolic acids; flavor; stress; isocoumarin*

INTRODUCTION

Modern breeding techniques and cultivar selection have aided vegetable processors to improve desired quality attributes. However, environmental and postharvest stress factors can alter the functional characteristics of these commodities. Carrots challenged by stress conditions can synthesize various phytoalexinic compounds including scopoletin, eugenin, falcarinol, falcarindiol, and 6-hydroxymellein, which is the precursor to the bitter principle isocoumarin (Marinelli et al., 1990). When carrot tissue is wounded, synthesis of phenolic compounds will also increase along with formation of wound barriers such as lignin and suberin (Howard et al., 1994). Many phenolic compounds, which are ubiquitous in higher plants, are phytoalexins formed via the shikimic acid pathway. These compounds can serve to protect plant tissue from microbial (Babic et al., 1993) and oxidative damage (Cilliers and Singleton, 1990). Carrots have a diversity of phenolic acids present at various concentrations, and high levels have been associated with bitter flavors (Sondheimer, 1957a,b). Common phenolic compounds found in carrots include chlorogenic acid, caffeic acid, *p*-hydroxybenzoic acid, and various cinnamic acid derivatives (Babic et al., 1993). Sarker and Phan (1979) found that when carrots were exposed to ethylene, phenolic content increased 7-fold during storage and surface browning was associated with an abundance of phenolics in the carrot peel. Storage under aerobic conditions creates ideal conditions for mold growth and enzyme action, which can lead to biotic stress-induced reactions (Marinelli et al., 1994). Many of these phytoalexins can be removed by peeling carrots prior to processing (Mercier et al., 1994), which also alters carrot quality depending on the type and duration of the heating steps. Total phenolics were found to increase with thermal processing (Yan, 1989), whereas strained carrot quality was negatively impacted by preprocessing operations at elevated temperatures (Howard et al., 1996). These studies demonstrate that raw carrots must be evaluated in a processed form for assessment of quality attributes.

Bitter flavor in strained carrots is a major problem for processors. Sondheimer (1957a) first isolated and identified a bitter compound from carrots known as 3-methyl-6-methoxy-8-hydroxy-3,4-dihydroisocoumarin, more commonly known as isocoumarin or 6-methoxymellein (6-MM). Induced by numerous mold species (Hoffman et al., 1988; Kurosaki and Nishi, 1983), by exposure to UV light (Mercier et al., 1994), and from pectinolytic enzymes (Marinelli et al., 1990; Movahedi and Heale, 1990), 6-MM is a secondary metabolite that inhibits the growth of many microorganisms. However, exposure to ethylene is the most common stimulus for its formation in carrots. Both phenolics and 6-MM have been associated with bitter flavors in stored and processed carrots (Sondheimer, 1957a; Cantwell et al., 1989; Sarker and Phan, 1979). The minimum levels of these compounds that impart bitter flavors in carrots are vital information to food processors. The objectives of this study were to determine how environmental stress impacted the chemical and sensory properties of processed strained carrots and to determine the sensory impact of the phytoalexin 6-MM on strained carrot flavor.

MATERIALS AND METHODS

Materials and Processing. Commercially processed strained carrots (*Daucus carota* L.) were purchased at a local market. Carrot genotypes were grown at the Texas A&M Experiment Station, Welsaco, TX, and at a trial plot in Georgia (GA). Genotypes were planted at the same time and received

* Author to whom correspondence should be addressed [telephone (501) 575-2978; fax (501) 575-2165; e-mail lukeh@comp.uark.edu].

† Present address: University of Arkansas, Institute of Food Science and Engineering, 272 Young Avenue, Fayetteville, AR 72704.

10.1021/jf981135f CCC: $18.00
Published on Web 03/26/1999

similar water and fertilization treatments at each growing location. Commercial genotypes selected included Cumberland (TX), Convert (TX and GA), Fayette (TX and GA), Danvers 126 (TX), and Royal Cross (GA). Experimental hybrids included XPH-3910 (TX and GA) and PSX-3489 (TX). GA-grown samples experienced severe hail damage during growth that resulted in damage to their tops. Carrot tops were allowed to regrow, and the roots reached maturity before harvest. All samples were received for processing within 2 days after harvest and were thermally processed on the day of arrival. Carrots were hand peeled and trimmed, steam blanched, cooled in ice water, blended with 75% water (blanch weight), and heated to 60 °C. Jars (11 oz) were filled with the strained carrots, capped, and retorted at 121 °C for 30 min in a rotary retort at 19 rpm (F_0 > 6.0; Stock Pilot-Rotor 900, Stock America Inc., Milwaukee, WI).

Chemical Analysis. Total water-soluble phenolic acids, sugars, organic acids, and total carotenoids were measured as previously described (Howard et al., 1996). pH was measured using a Corning model 125 pH meter. Total solids were measured by drying strained carrots in a forced-air oven (2 h at 135 °C). Individual water-soluble phenolics were extracted in water (10 g/10 mL) using a Tekmar model-TP 18 Tissuemizer (Cincinnati, OH) and then centrifuged at 8000*g* for 10 min. The supernatant was collected and centrifuged again at 10000*g* for 10 min and 2 mL passed through a Waters C_{18} Sep-Pak (Millipore, Milford, MA) to remove nonpolar compounds. The isolates were filtered through a 0.45 μm filter and injected into a Spectra Physics model P2000 HPLC system fitted with a 150 mm × 3.9 mm C_{18}-silica gel column (Nova-Pak, Waters, Milford, MA). Detection was at 280 nm using a Perkin-Elmer LC295 UV−vis detector (Norwalk, CT). Mobile phase A contained 98% water and 2% acetic acid, and mobile phase B contained 68% water, 30% acetonitrile, and 2% acetic acid (Ramamurthy et al., 1992). A linear gradient of 0−30% mobile phase B was run for 30 min at 1.5 mL/min. The column was washed with 100% mobile phase B and equilibrated with 100% mobile phase A prior to the next sample injection. Peak identification was determined by spiking authentic standards (Sigma Chemical Co., St. Louis, MO), and quantification was performed using a standard curve. 6-MM was quantified by extracting carrots (3 g/25 mL) with acetone and sonicating for 5 min. Methanol (25 mL) was added to the solution and sonicated for an additional 5 min. Extracts were filtered through Whatman No. 4 filter paper, rinsed three times with 20 mL of acetone, and rotary evaporated to 1 mL. Remaining solvent was evaporated under nitrogen to dryness. 6-MM residue was dissolved in 5 mL of methanol and filtered through a 0.45 μm filter for HPLC analysis. Samples were injected into the same HPLC apparatus used for phenolic acids with detection at 267 nm as described by Martinelli et al. (1990). Mobile phase was methanol and water (60:40) run isocratically at 1 mL/min. Quantification was performed using purified 6-MM as an external standard.

Isocoumarin was extracted and purified from shredded carrots (11.4 kg) that were placed in a sealed container and sprayed uniformly with 500 mL of 0.002 mM 1-aminocyclopropane-1-carboxylic acid. Carrots were partitioned in layers to maximize surface area inside the container, and 20 mL of ethylene gas (1000 mL/L) was injected into the container and sealed. Carrots were stored at 10 °C for 10 days and flushed twice daily with pure oxygen to maintain aerobic respiration. Shredded carrots were extracted three times with *n*-hexane and dichloromethane (1:1) for 15 min each and pooled extracts rotary evaporated to 75 mL. Extract was gravity filtered through a silica column (4.5 cm × 50 cm, prewashed with hexane) using a linear gradient of acetone in hexane to separate and elute 6-MM. Fractions were collected and identified by monitoring absorbance at 267 and 302 nm (ratio = 2.47). Positive fractions were combined and the process repeated several times to remove impurities. Final extract was dried under nitrogen to give a pale yellow crystal. The residue (~1.5 g) had a final purity of 93% as confirmed by its molar extinction coefficient at 267 nm in ethanol (Sondheimer, 1957b).

Sensory Analysis. Strained carrot attributes (cooked carrot aroma, cooked carrot flavor, sweetness, bitterness, sour flavor, preference, and saltiness) were determined using a trained sensory panel (six men and three women). Preference testing was used to gain an overall impression of each genotype due to their genetic diversity. Panelists were initially selected on the basis of their ability to successfully rank increasing concentrations of standard taste solutions. Selected panelists were further trained using these standard solutions and commercial carrot products as references. Panelists were trained for cooked attributes using Del Monte canned sliced carrots (Del Monte Foods, San Francisco, CA) as compared to boiled and fresh sliced carrots. Training for the remaining attributes was performed using various concentrations of sucrose, caffeine, citric acid, and sodium chloride in solution representing ranges typically found in strained carrots. Standard solutions were available at all times during strained carrot evaluations. Panelists were then trained using four commercial brands of strained carrots under white and red light. Commercial products selected were Gerber 1st Foods (Gerber Products Co., Fremont, MI), Heinz 2 (H. J. Heinz Co., Pittsburgh, PA), Beech-Nut Stages 1 (Beech-Nut Nutrition Corp., Canajoharie, NY), and Earth's Best certified organic carrots (Earth's Best, Inc., Boulder, CO). Panelists were allowed to discuss and select terms, which were later applied for genotypic evaluation, to describe each product.

Sensory analysis was conducted under red light at room temperature (23 °C). Panelists were instructed to cleanse their palate between samples using unsalted crackers and water. Samples (20 mL) were presented randomly in three-digit coded 50 mL white plastic cups. Plastic spoons were provided for product evaluation. Panelists were allowed to swallow the samples, with no more than six samples evaluated in a single session. All samples were evaluated in duplicate. An unstructured line scale, used in training, was used to evaluate the samples with 0 cm = none and 9 cm = intense, with additional space provided for comments.

Statistical Analysis. Chemical data represent the mean of three subsamples with a jar from each genotype representing a subsample. Sensory data represent the mean of two subsamples with a jar from each genotype representing a subsample. Chemical and sensory data were analyzed by analysis of variance (SAS Institute, Inc., 1985), and mean separation was conducted by Duncan's multiple-range test (P < 0.05). Stepwise linear regression analysis was performed to predict sensory scores from chemical data.

RESULTS AND DISCUSSION

Chemical Data. Chemical and sensory analyses were conducted on the 10 genotypes to identify chemical components that impacted strained carrot flavor. Data are expressed on a dry weight (DW) basis to compensate for differences in moisture content. Moisture content ranged from 94.03 to 94.84 g/100 g in TX cultivars and from 95.97 to 96.20 g/100 g for GA cultivars (Table 1). These differences indicated that the reduced solids content in GA genotypes may be related to field stress as roots utilized reserve nutrients for regrowth of their tops.

Sugars/Organic Acids. Total sugar content (43.7−86.1 g/100 g; Table 1) was highest in Fayette (GA), Convert (TX), and XPH-3910 (TX) cultivars, with sucrose being the predominant sugar present (25.50−69.85 g/100 g) followed by glucose (5.75−14.35 g/100 g) and fructose (4.65−12.56 g/100 g). Organic acid concentration (8.40−13.10 g/100 g) was highest in Fayette (GA), Convert (GA), and Royal Cross (GA), with malic acid being the predominant acid (4.13−6.99 g/100 g) followed by citric (1.91−2.98 g/100 g), pyroglutamic (1.15−2.25 g/100 g), and succinic acids (0.30−1.70 g/100 g). However, only minor differences in pH were noted among

Table 1. Physicochemical Attributes (Dry Weight) of Strained Carrots As Affected by Genotype[a]

genotype	moisture, g/100 g	total sugars, g/100 g	total acid, g/100 g	pH	viscosity, cP	sugar:acid	total carotenoids, mg/kg	6-MM, mg/kg	total soluble phenolics, mg/kg
Cumberland (TX)	94.39 g	58.38 b	10.37 c	5.43 cd	800 bc	5.63 bc	1672 cd	nd[b]	5507 cd
Convert (TX)	94.03 i	61.80 b	8.98 d	5.49 b	900 b	6.88 a	1813 bc	nd	5102 d
XPH 3910 (TX)	94.65 f	60.22 b	8.82 d	5.37 fg	893 b	6.83 a	1959 b	nd	5546 cd
Fayette (TX)	94.42 g	55.90 bc	8.40 d	5.39 efg	786 bc	6.65 a	1615 d	4.69 d	5207 d
PSX 3489 (TX)	94.84 e	43.73 d	8.85 d	5.40 def	800 bc	4.94 cd	1124 f	2.43 d	5978 c
Danvers (TX)	94.17 h	55.34 bc	8.98 d	5.44 c	1086 a	6.16 ab	1620 d	19.05 d	5088 d
XPH 3910 (GA)	95.66 d	51.24 c	10.36 c	5.41 cdef	693 c	4.95 cd	1310 e	121.7 c	7124 b
Convert (GA)	95.97 c	51.04 c	11.39 b	5.36 g	800 bc	4.48 d	1583 d	212.2 b	7243 ab
Fayette (GA)	96.20 a	86.11 a	13.07 a	5.42 cde	860 b	6.59 a	3154 a	104.2 c	7699 a
Royal Cross (GA)	96.07 b	59.99 b	10.81 bc	5.55 a	667 c	5.55 bc	771 g	403.9 a	7459 ab

[a] Values within columns with similar letters are not significantly different (Duncan's multiple range test, $P < 0.05$). [b] None detected.

Table 2. Individual Phenolic Acid Concentrations (Dry Weight) in Strained Carrots As Affected by Genotype[a]

genotype	*p*-hydroxybenzoic acid, mg/kg	vanillic acid, mg/kg	caffeic acid, mg/kg	chlorogenic acid, mg/kg	syringic acid, mg/kg	total phenolics, mg/kg
Cumberland (TX)	48.86 b	nd[b]	10.19 a	10.37 c	2.11 fg	82.80 bc[c]
Convert (TX)	49.20 b	nd	6.85 b	3.07 c	3.02 ef	62.15 d
XPH 3910 (TX)	12.61 e	nd	6.16 b	2.88 c	3.22 ef	24.87 f
Fayette (TX)	29.65 cd	nd	nd	4.23 c	4.60 d	43.01 e
PSX 3489 (TX)	51.14 b	12.33 ab	nd	2.04 c	2.38 fg	73.98 bcd
Danvers (TX)	11.27 e	10.95 b	2.95 c	35.40 b	7.31 c	67.89 cd
XPH 3910 (GA)	20.97 de	nd	7.59 b a	55.25 a	1.67 g	85.47 b
Convert (GA)	54.34 b	10.87 b	11.14 a	9.54 c	3.78 de	89.68 b
Fayette (GA)	43.71 bc	13.35 a	7.60 b	9.92 c	9.11 b	85.66 b
Royal Cross (GA)	100.32 a	2.07 c	6.46 b	36.48 b	10.89 a	156.22 a

[a] Values within columns with similar letters are not significantly different (Duncan's multiple range test, $P < 0.05$). [b] None detected. [c] Difference in sum total due to trace levels of phenolic compounds present.

genotypes. Results indicated that environmental stress reduced solids content in fresh carrots, resulting in higher total sugars and organic acids on a dry weight basis. Stress during growing will cause sucrose inversion in carrot roots but does not affect total sugar content (Seljåsen et al., 1998). Therefore, the decline in solids observed in stressed carrots was due to utilization of energy reserves other than simple sugars. The decline in solids was reflected by reduced viscosity. Total carotenoids (Table 1) declined with increasing 6-MM and total individual phenolic acids ($R^2 = -0.81$ and -0.86, respectively), indicating a relationship with lipid metabolism and carotenoid oxidation during growth under abiotic stress. Accumulation of organic acids, noted in GA samples, could be expected from increased TCA cycle activity as carrot respiration rate increased in response to abiotic stress. Sugar-to-acid ratio, an important quality index for many fruits and vegetables, ranged from 4.94 to 6.88 in TX genotypes and from 4.48 to 6.59 in GA genotypes. Due to phytoalexin formation during adverse growing conditions, this quality index was found to be insufficient for predicting desirable sensory attributes in carrots.

6-MM/Soluble Phenolics. All GA-grown genotypes had appreciable amounts of 6-MM (104−403 mg/kg DW; Table 1), indicating that abiotic (environmental) stress in the field may have induced production of wound ethylene and subsequent phytoalexin formation. Some roots from these genotypes exhibited minor soft rot upon arrival for processing, indicating that ethylene generation from bacterial contamination may also have contributed to phytoalexin formation. It was unknown if the soft rot occurred prior to harvest, immediately after harvest, or during overnight shipment. 6-MM is produced from a stress-induced methylation reaction of 6-hydroxymellein and is associated with extreme bitter flavors in carrots (Marinelli et al., 1990). Significant levels are usually associated with carrots exposed to improper postharvest handling and storage conditions (Cantwell et al., 1989).

Soluble phenolics were affected by growing conditions with values ranging from 5088 to 5978 mg/kg for TX carrots to a significantly higher range of 7124−7699 mg/kg for stressed GA carrots. The increase of phenolic compounds due to cellular stress has been reported by numerous investigators (Howard et al., 1994; Sarker and Phan, 1979; Babic et al., 1993; Yan, 1989). The sum of individual soluble phenolics (Table 2) increased as 6-MM increased ($R^2 = 0.76$) but did not correlate as well to phenolics by the Folin−Ciocalteu assay ($R^2 = 0.42$). Total individual phenolic acids were higher in GA genotypes (85.5−156.2 mg/kg) compared to TX genotypes (24.9−82.8 mg/kg), due primarily to increased levels of chlorogenic and *p*-hydroxybenzoic acids. Babic et al. (1993) found that *p*-hydroxybenzoic acid and its esters were not initially present in shredded carrots stored in air but increased during storage as certain caffeoylquinic acid esters declined. The predominance of high concentrations of polar phenolics in GA carrots was indicative of the elevated activity of the shikimic acid pathway for phenolic synthesis. Much of the variation in phenolic acid concentration can be attributed to the genetic variation among cultivars. However, identical cultivars grown in TX and GA demonstrated significant differences in chemical profiles. Bibeau et al. (1975) found that despite different growing conditions and environmental factors, pH and organic acid profiles after processing remained the same in Texas and California carrots. Differences in phenolic acid profiles from identical cultivars in this study may have been attributed to adverse growing conditions or improper postharvest handling and storage conditions of GA cultivars.

Sensory Analysis. Taste perceptions for processed

Table 3. Sensory Attributes of Strained Carrots As Affected by Genotype[a]

genotype	sweetness	bitterness	sour flavor	preference
Cumberland (TX)	4.58 a	3.03 b	2.22 c	5.62 a
Convert (TX)	5.25 a	2.41 b	2.22 c	4.82 a
XPH 3910 (TX)	4.63 a	2.07 b	2.35 c	5.21 a
Fayette (TX)	5.19 a	2.66 b	3.05 bc	4.78 a
PSX 3489 (TX)	5.07 a	2.88 b	2.97 bc	5.03 a
Danvers (TX)	4.94 a	2.58 b	2.64 bc	4.36 ab
XPH 3910 (GA)	2.65 b	4.87 a	3.62 bc	3.05 bc
Convert (GA)	1.30 b	5.59 a	5.78 a	2.12 c
Fayette (GA)	1.5 b	4.72 a	4.25 ab	1.95 c
Royal Cross (GA)	1.62 b	4.78 a	4.18 ab	2.17 c

[a] 0 = none; 9 = intense. Values within columns with similar letters are not significantly different (Duncan's multiple range test, $P < 0.05$).

Table 4. Linear Regression Results for Strained Carrot Genotypes Based on Dry Weight

sensory attribute (DW basis)	b_0	b_1	variable	R^2
sweet	12.883	−0.00148	soluble phenolics	0.97
bitter	−2.232	0.00089	soluble phenolics	0.77
sour	−3.197	0.00109	soluble phenolics	0.92
preference	11.282	−0.00118	soluble phenolics	0.87

Table 5. Linear Regression Results for Strained Carrot Genotypes Based on Fresh Weight

sensory attribute (FW basis)	b_0	b_1	variable	b_2	variable	R^2
sweet	186.226	−1.921	moisture			0.92
bitter	−107.078	1.162	moisture			0.74
sour	3.195	0.365	6-MM	−0.189	total sugar	0.93
preference	150.893	−1.546	moisture			0.83

strained products were accentuated due to a reduced particle size in comparison to the fresh commodity. Moisture content in relation to flavor components is an important consideration for sensory evaluation as taste perception changes according to the amount and composition of the solids present. For GA-grown carrots, moisture content was higher compared to TX genotypes, which influenced the impact of phytoalexic compounds on strained carrot flavor. Sweetness scores were significantly lower and bitterness scores higher in all GA cultivars compared to TX cultivars ($P < 0.05$; Table 3). Lower sour flavor and higher preference scores were found in TX cultivars compared to GA samples. Preference scores were highest for Cumberland (TX) and XPH-3910 (TX) and lowest for Fayette (GA) and Convert (GA). No differences in cooked carrot aroma, cooked carrot flavor and saltiness were observed among cultivars. Undesirable sensory attributes were attributed to the presence of 6-MM and high levels of soluble phenolics found in GA cultivars. Bitter and sour taste perception increased with total soluble phenolics, moisture, and 6-MM, whereas sweetness and preference scores were negatively impacted by these same variables. Sweet perception was not correlated with high levels of sugars ($R^2 = 0.28$) but rather with the elevated levels of soluble phenolics and 6-MM ($R^2 = -0.97$ and -0.67, respectively).

Regression Analysis. Predicting sensory attributes of carrot genotypes based on physiochemical measurements was conducted on both dry and fresh (FW) bases, because strained carrots were evaluated on fresh weight basis (Tables 4 and 5, respectively). Linear regression analysis demonstrated the contribution of soluble phenolic acids (DW) to both sweetness and preference scores ($R^2 = 0.97$ and 0.87) while also impacting bitter and sour

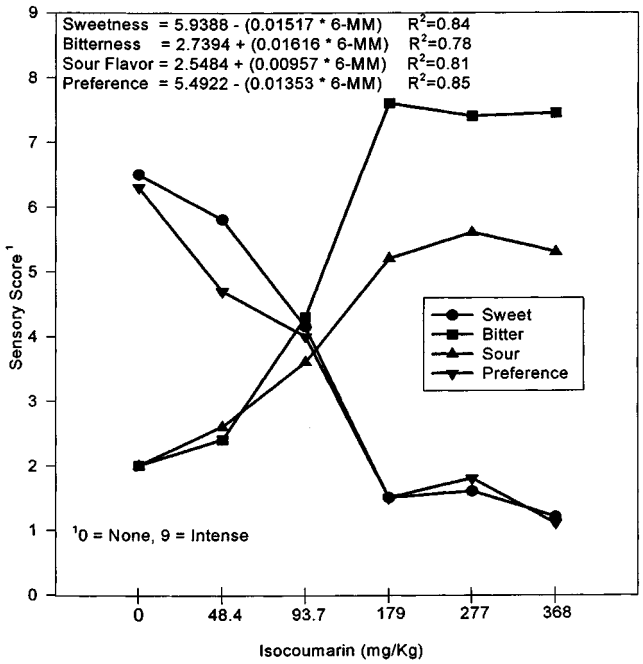

Figure 1. Taste qualities of processed strained carrots as affected by 6-MM concentration. Linear regression analysis was based on DW attributes of 6-MM.

flavors ($R^2 = 0.77$ and 0.92; Table 4). Predictive indices for FW attributes (Table 5) demonstrated that moisture content, in relation to phytoalexins, was critical for sweet, bitter, and preference evaluation ($R^2 = 0.92$, 0.74, and 0.83, respectively). Reducing sour flavor in strained carrots is dependent upon low 6-MM and high sugar concentrations ($R^2 = 0.93$). Results indicate a need for monitoring phytoalexin levels in fresh carrots due to their negative sensory implications in the processed product.

Spiking Study. Various concentrations of 6-MM (FW) were spiked into a commercially processed product to evaluate the effects on sensory quality (Figure 1). Concentrations of 6-MM spiked into each sample were confirmed by HPLC analysis. Because 6-MM is not present in carrots that have not experienced some form of biotic or abiotic stress, it is an excellent predictor for sensory quality. Elevated concentrations of 6-MM impacted sweetness, bitterness, sourness, and preference scores ($P < 0.05$). Sweetness scores decreased with increasing concentration of 6-MM ($R^2 = -0.85$), which corresponded to increased bitterness scores ($R^2 = -0.99$). Sour flavor scores increased as bitterness scores increased ($R^2 = 0.98$), indicating that the panelist's perception of sour flavor was accentuated due to the absence of sweetness in the product. Walters and Roy (1996) suggested that common sweet and bitter binding site receptors on the tongue might be responsible for the perceived taste of a particular product. As 6-MM increased in strained carrots, the perception of sweetness declined followed by enhanced perception of sour flavors. Therefore, when 6-MM is present, the sugar-to-acid ratio for quality evaluation of strained carrots is questionable. On the basis of sensory attributes of commercial samples spiked with 6-MM, an additional predictive index for carrot quality would be the ratio of sugars to 6-MM.

Scores for preference and bitterness were unaffected at very high concentrations of 6-MM, indicating a terminal threshold >180 mg/kg. Sensory differentiation

of the product was not possible once this level of bitterness was attained. Sensory perception of 6-MM appeared to follow the equation set forth by Beidler (1954), which assumes that the response from a stimulus has an upper limit which is not exceeded with increasing concentration (Meilgaard et al., 1991). This level of 6-MM in carrots will be unpalatable; therefore, a linear relationship at lower concentrations was established. From this study it can be concluded that 6-MM concentrations >94 mg/kg (recognition threshold) will negatively impact most flavor attributes of strained carrots. However, perception of bitterness may be at a much lower concentration due to the effects of additional phytoalexins produced simultaneously with 6-MM as demonstrated by the TX and GA genotypes.

Using a paired comparison test, panelists also determined the just noticeable difference (JND) of 6-MM in strained carrots at a range from 48 to 71 mg/kg. Minimum concentrations of 6-MM that impart bitterness are important because JND levels can be attained in fresh carrots after 2 days of storage at 15 °C and after 4 days at 5 °C, when carrots are exposed to 500 ppb of ethylene (Cantwell et al., 1989). Additional testing is required to estimate the relationship of 6-MM and bitterness in the presence of additional compounds synthesized during cellular stress.

Conclusions. Monitoring biotic and abiotic stress parameters is a critical control point for maintaining strained carrot quality. Fresh carrots used for processing should be screened for 6-MM prior to use due to its adverse effect on sensory quality. The contribution of phytoalexic compounds to carrot flavor is apparent, and understanding the role these compounds have in processed product is vital for flavor improvement. Breeding carrot cultivars for reduced sensitivity to stress factors, such as ethylene exposure, is advantageous for strained carrot flavor. Therefore, the quality impact of phytoalexic compounds should be determined for each cultivar utilized for processing.

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Received for review October 14, 1998. Revised manuscript received February 10, 1999. Accepted February 15, 1999.

JF981135F