Correlations between Sensory and Objective Parameters of Carrot Flavor

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Stepwise multiple regression of five sensory parameters and 21 objective variables demonstrated that sugars and individual or summed total volatile terpene compounds are important in determining raw carrot flavor. The relative importance of each objective variable varies by the location in which carrots are grown and the genetic background of the carrot. Harsh, turpentine-like flavors are associated with the presence of the volatiles, particularly γ-terpenine and total volatiles, and a reduction in sugars. The reverse is true for sweetness and overall preference which are enhanced by sugars and diminished by volatiles. Overall carrot flavor is heightened by a reduction in total volatiles. Sucrose levels correlate positively and reducing sugars negatively with volatile terpene levels. For the growing sites represented, genetic variation was significant for reducing sugars, terpinolene, sucrose, α-phellandrene, limonene, and total volatiles, while environmental variation was significant for dry weight, refractive index, carotenoids, sucrose, total sugars, and terpinolene.

Simple sensory-objective relationships are not commonly encountered in the analysis of vegetable flavors. Even when such relationships are established, they can only be fully relied upon after reconstitution of the sensory response with the purported causative ingredients (e.g., Guadagni, 1968; Parliment and Scarpellino, 1977).

This work relates five flavor attributes of raw carrots with 21 objective parameters. To represent organoleptic extremes in genetic and environmental variation for carrots, four diverse genetic stocks grown in the three major U.S. carrot-producing regions were analyzed.

EXPERIMENTAL SECTION

Sensory Evaluation. Two open-pollinated carrot cultivars (Imperator 58 and Nantes, Asgrow Seed Co.) and two inbred lines from the USDA carrot breeding program (B3615 and B6274) were grown in Florida, Texas, and California. Plant material and methods of sensory evaluation have been described (Simon et al., 1980). Slices from the middle third of 20–30 roots of each line were mixed separately and evaluated by 25–30 trained panelists for descriptive profiling in the Sensory Evaluation Laboratory, Department of Food Science, University of Wisconsin. Panelists evaluated the intensity of difference (Mahoney et al., 1957), harsh flavor, sweetness, overall carrot flavor (Stone et al., 1974), and overall preference for each entry from a single location on a single day. Imperator 58 was used as a reference for the Florida-grown carrots while B6274 served this function for the other two locations.

Objective Parameters. Objective measurements were made for the refractive index of freshly expressed carrot juice (RI), percent dry weight, glucose, fructose, sucrose, and carotenoids of the fresh carrots from all locations. The quantity of 13 volatile components was determined by GLC for Texas-grown and California-grown carrots.

Refractive index of carrot juice was measured with an Abbe refractometer. Percent dry weight was that proportion of the fresh weight remaining after lyophilization.

Glucose, fructose, and sucrose levels were determined by high-pressure liquid chromatography (Conrad and Palmer, 1976) (Waters Associates; carbohydrate analysis column; eluted with acetonitrile water at 75:25; flow rate 2 mL/min; RI detector at 2× sensitivity). Excellent agreement to colorimeter mensuration (Hosfield et al., 1977) was realized.

Total carotenoids were measured colorimeterically at 450 nm after extraction from lyophilized samples with hexane [modification of procedure by Umiel and Gabelman (1971)] and were expressed as micrograms of β-carotene per gram of dry weight.

Volatiles from Texas- and California-grown carrots were quantitatively determined by trapping those carried from 100-g blended samples on Tenax GC columns for 1 h at 60 °C and analyzing on a 3 m × 32 mm o.d. stainless steel column packed with 5% SF-96 and 0.0025% Igepal CO-880 on 80/100 mesh AW-DMCS Chromosorb G (Simon et al., 1980). Duplicate samples were chromatographed at 1× and 2.5× relative attenuation and were quantified by comparison to authentic compounds.

Data were analyzed on a Univac 1110 computer at the University of Wisconsin—Madison, using the BMD P2 R stepwise regression program (Dixon, 1975).

RESULTS AND DISCUSSION

Objective Variable Values. Variation in components determined by laboratory analysis was observed among entries and among locations (Table I). This is most evident for fructose, glucose, sucrose, total sugars, refractive index, terpiolene, and total volatiles. Values for percent dry weight, refractive index, sugars, and volatiles compare satisfactorily to published values (Carlton and Peterson, 1963; Buttery et al., 1968).

Objective Variables Correlations. A tendency for overall flavor, overall preference, and intensity of difference to be correlated was observed (Simon et al., 1980). Certain objective parameters also demonstrated a relative lack of independence (Table II). The strongest correlation occurred between fructose and glucose to the extent that they can be considered as one parameter, denoted as reducing sugar. For a given location, reducing sugar and sucrose were inversely correlated but not for any line over the three locations. For a given entry, sucrose was correlated to dry weight and refractive index in addition to a frequent association with carotenoids and total sugars. Dry weight and refractive index also were correlated for Florida- and Texas-grown carrots. It is interesting that reducing sugar constituted a larger fraction of the total sugars in Florida-grown carrots than in those from California or Texas and that refractive index and reducing sugars were correlated in samples from Florida. For Texas-grown carrots,

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Table I. Magnitude of Objective Variables Measured for Four Carrot Entries Grown in Three Locations

	entry and location[a]											
	B6274			B3615			Imperator 58			Nantes		
variable	F	T	C	F	T	C	F	T	C	F	T	C
% dry wt	10.6	12.2	16.9	11.2	13.4	15.8	10.6	14.1	14.3	10.2	12.0	14.9
refractive index	6.4	8.2	11.3	8.0	9.8	11.5	6.8	10.1	10.8	6.0	8.9	10.5
carotenoids (μg/gdw)	670	794	902	389	782	973	472	860	1096	540	993	1210
fructose (mg/gfw)	12.1	17.5	8.6	3.4	2.8	0.1	13.1	11.0	10.5	11.9	14.1	10.8
glucose (mg/gfw)	15.4	20.8	10.3	1.9	2.0	0.1	14.5	12.1	10.8	13.8	17.0	13.4
sucrose (mg/gfw)	10.7	21.3	55.0	40.7	58.8	71.2	16.3	54.7	51.8	18.8	30.1	57.8
total sugars (mg/gfw)	38.2	60.6	73.9	46.0	63.6	71.4	43.9	77.8	73.1	44.5	61.2	81.7
α-pinene (2000 × ppm)	*b*	29	24	*b*	8	5	*b*	4	9	*b*	36	9
β-pinene	*b*	18	8	*b*	57	41	*b*	39	70	*b*	25	21
myrcene	*b*	220	286	*b*	428	477	*b*	238	524	*b*	246	452
α-phellandrene	*b*	27	36	*b*	73	76	*b*	20	44	*b*	21	29
sabinene	*b*	228	162	*b*	424	378	*b*	76	156	*b*	153	309
limonene	*b*	224	163	*b*	388	360	*b*	183	240	*b*	176	156
γ-terpinene	*b*	400	310	*b*	669	540	*b*	255	460	*b*	388	424
terpinolene	*b*	1534	2209	*b*	3759	4278	*b*	2348	2610	*b*	1742	2450
terpinen-4-ol	*b*	38	17	*b*	73	83	*b*	25	55	*b*	41	66
bornyl acetate	*b*	53	14	*b*	314	46	*b*	53	29	*b*	43	41
caryophyllene	*b*	314	30	*b*	554	311	*b*	63	51	*b*	232	373
γ-bisabolene (A)	*b*	11	0	*b*	34	10	*b*	3	0	*b*	14	0
γ-bisabolene (B)	*b*	69	40	*b*	323	41	*b*	46	34	*b*	143	85
total terpenoids	*b*	3165	3314	*b*	7104	6670	*b*	3353	4297	*b*	3260	4416

[a] F, Florida; T, Texas; C, California. [b] Not measured.

Table II. Significant Correlations between Objective Parameters of Four Carrot Lines Grown in Three Locations

location/line	significant correlations[a]
Florida	fructose (FR) (−)[b]-glucose (GL) (−)-sucrose (SU) (+); FR(−)-GL(−)-refractive index (RI) (+); dry weight (DW) (+)-RI (+)
Texas	FR(−)-GL(−)-SU(+); SU(+)-RI(+)-DW(+). total sugars (TS) (+)-DW(+); FR(−)-GL(−)-myrcene (+)-terpinolene (TE) (+)-bornyl acetate (+)-total volatiles (TV) (+)
California	FR(−)-GL(−)-SU(+). FR(−)-GL(−)-TE(+)-α-phellandrene (PH) (+)-γ-bisabolene (A) (BIA) (+); SU(+)-TE(+)-BIA(+)-TV(+). α-pinene (AP) (−)-γ-terpinene (GT) (+)-terpinen-4-ol (TOL) (+)-BA(+)
B6274	FR(−)-GL(−); SU(+)-DW(+)-RI(+); TS(+)-RI(+)-carotenoids (CAR) (+)
B3615	FR(−)-GL(−); SU(+)-TS(+)-DW(+)-RI(+)-CAR(+)
Imperator 58	FR(−)-GL(−); SU(+)-TS(+)-DW(+)-RI(+); FR(−)-GL(−)-RI(+)-CAR(+)
Nantes	FR(−)-GL(−); SU(+)-TS(+)-DW(+); TS(+)-RI(+)-CAR(+)
overall	FR(−)-GL(−)-SU(+)-TS(+)-DW(+)-RI(+)-CAR(+); FR(−)-GL(−)-PH(+)-TE(+)-TV(+)

[a] Significant correlation at the 5% level exists between any two members of a group. [b] Parameters with the same sign are positively correlated, those with opposite signs are negatively correlated.

sucrose was the predominant sugar and correlated with refractive index. As has been suggested (Carlton and Peterson, 1963), dry weight, refractive index, total sugars, and sucrose are often positively correlated with each other and negatively correlated with reducing sugars. In this study, similar correlations were observed, but they were not significant for all lines or locations. The observed correlations suggest an overall sugar balance between sucrose and reducing sugars for carrots grown at a given location, with the more abundant sugar accounting for variation in refractive index.

The negative correlation between reducing sugars and certain volatiles, and the positive correlation between sucrose and volatiles for Texas- and California-grown carrots, suggests a precursor role for sucrose in volatile synthesis. This relationship also suggests the possibility of predicting volatile production from sugar levels. In general, there was a positive correlation between individual volatiles and total volatiles. An exception is α-pinene which was negatively correlated with the other volatiles in California-grown carrots and tended to be so for those from Texas and Florida.

Sensory-Objective Correlations by Location. Significant correlations between sensory parameters and objective variables for the three locations are recorded in Table III. Since clear patterns failed to emerge, all significant correlations are listed. Significant simple correlations were noted. Addition of more terms improved these correlations, as determined by the *F*-test in stepwise regression. The recurrence of sugars and total volatiles in these regression equations suggested that they influence the sensory parameters considered.

The variation in reducing sugars and sucrose was correlated with differences detected in intensity of flavor differences of Florida- and Texas-grown carrots, sweetness in Florida-grown carrots, and overall preference over the three locations. This suggests a discernible difference for sugars, with higher sugar carrot preferred regardless of whether available sugar is sucrose or reducing sugar.

As expected, sugars were important in sensory ratings for sweetness, but interaction with volatiles was also important. This was demonstrated for both Texas- and California-grown carrots where reducing sugar plus limonene and total sugars plus myrcene were highly correlated with sweetness, respectively. The same sort of interaction has also been observed in tomato flavor (Stevens et al., 1977). Since the volatile contribution to sweetness was negative, perhaps volatiles act to mask sugars. Addition of fructose to raw carrots significantly enhanced sweetness, with a small reduction in harsh flavor (Simon et al., 1980).

Table III. Objective Variables Exhibiting Significant Correlation with Sensory Parameters in Stepwise Regression Analysis over Three Locations

sensory parameter	location	objective variable
intensity of difference	Florida	– reducing sugar (RS)[a]-sucrose (SU)**[b]
	Texas	– RS*,[b] total volatiles (TV)**, myrcene (MY)**, bornyl acetate (BA)**, γ-bisabolene (B) (BIB)**, RS + TV**, – RS-SU**, -total sugars (TS) + terpinen-4-ol (TOL)**, – TS + β-pinene/sabinene (SA)**
	California	TV*, BA**, TS + BA**, TS + TOL**, TS + limonene (LI)**
	overall	– RS*, – RS-dry weight (DW)**, – RS-DW-carotenoids (CAR)**
harsh flavor	Florida	– RS*, refractive index (RI)*, DW**, – RS + DW**
	Texas	limonene (LI)*, TOL*, α-phellandrene (PH)**, MY**, terpinolene (TE)**, γ-terpinene (GT)**, BA**, TV**, – TS + TV**, – TS + GT**
	California	TV*, GT**
	overall	– RS**, – RS-DW**, – RS-DW + CAR**
sweetness	Florida	RS + SU**
	Texas	– PH*, – α-terpinene (ATE)*, – LI*, – caryophyllene (CA)*, – TV*, RS-LI**
	California	– MY*, – SA**, TS-MY**
	overall	SU*, TS*, RI*, DW*, TS + RI**
overall flavor	Florida	– RS*, SU*, – RS-DW**
	Texas	– RS*, CA*, – RS-TE**, GT-CA**
	California	– ATE*, – TOL*, – CA*, – TV*, – SA**, – GT-CA**, – TS-TV**, – TS-LI**
	overall	SU*, TS*, RI**, TS + RI**
overall preference	Florida	– DW**, SU-DW**
	Texas	– ATE*, – GT*, – CA*, – PH**, – MY**, – TE**, – BA**, – TV**, RS-TV**, TS-TV**, TS-GT**
	California	– SA*, – GT*, – MY**, TS-SA**, TS-PH**, TS-MY**, TS-GT**, TS-TE**
	overall	RS + SU**, RS + DW**

[a] Either fructose or glucose can be substituted for RS. [b] (*) Significant at the 5% level; (**) significant at the 1% level.

Table IV. Objective Variables Exhibiting Significant Correlation with Sensory Parameters in Four Carrot Entries

	entry			
sensory parameter	B6274	B3615	Imperator 58	Nantes
intensity of difference	– total sugars (TS)**[a,b]		– TS**, – sucrose (SU)**, – dry weight (DW)*, – RI*	DW**, SU**, TS*
harsh flavor	– TS**, – carotenoids (CAR)*			
sweetness	SU**, DW**, refractive index (RI)**	– RS**		TS*, RI**, CAR*
overall carrot flavor	TS**, CAR*		– RS**, RI**, DW*	RI*
overall preference	TS**			RI*

[a] Negative sign preceding variable denotes an inverse correlation with sensory parameter. [b] (*) Significant at the 5% level; (**) significant at the 1% level.

The presence of total volatiles and γ-terpinene in the objective variables which correlated with harsh flavor suggests that they elicit harsh flavor sensation. Carrots have fairly high levels of volatiles relative to other vegetables (Buttery, 1977), and the summed effect of all volatiles may elicit a negative organoleptic response when they are in high quantity. A correlation of these volatiles with an undetermined harsh compound could also explain this observation.

Combined reducing sugar or total sugar and total volatile variation accounted for a significant proportion of overall preference and intensity of difference in the Texas-grown samples and for overall flavor in those from California. This may reflect a combined effect of sweetness and harshness in these sensory parameters.

Interpretation of carrot flavor parameters over all locations was complicated by a lack of pattern in objective variable correlation and lack of volatile data from all locations. The best conclusion that can be stated is that sucrose and/or total sugars play an important role in variation of overall preference with increased sugars corresponding to stronger preference. Each location reflected a different sensorily important sugar.

The incorporation of refractive index or dry weight into multiple regression is not easily interpreted. These two variables may reflect sugars, as mentioned earlier, but relationships substantiating this proposition are weak. Carotenoids only appear in the last step of the intensity of difference and harsh flavor overall multiple regression so that they may have entered only because of their orthogonality to dry weight.

Sensory-Objective Correlation by Entry. Simple correlations between sensory and objective variables by entries (Table IV) demonstrate important differences in sensory attributes among entries. Total sugar was negatively correlated with intensity of difference in B6274 and Imperator 58, while it was positively correlated with this sensory parameter in Nantes. Variation in sweetness was correlated with sucrose, reducing sugars, total sugars, or none of the sugars, depending on the entry under consideration. This emphasizes the need to consider the genetic source when generalizing or predicting organoleptic attributes of raw carrots. For entry B3615, little correlation was observed between sensory parameters and any of the seven objective variables measured over all three locations. The high level of volatiles found in B3615 (Table I) probably accounted for variation in the sensory parameters measured. The suggestion was supported by the significant harsh flavor-volatile correlation over locations (Table III) and the lack of correlation for harsh flavor and any of the seven nonvolatile objective variables for the three entries with the highest volatile levels (B3615, Imperator 58, and Nantes, Table IV).

Analysis of Variance for Objective Variables. Table V displays the relative potential of each objective parameter in the carrots tested to be manipulated by varying

Table V. *F* Values from ANOVA for the Mean Values of Objective Parameters of Four Carrot Entries Grown in Three Locations

	source of variation	
objective parameters	entries	locations
dry weight	0.8	26.2**[a]
refractive index	3.3	55.6**
carotenoids	1.9	26.5**
fructose	18.5**	3.7
glucose	23.0**	3.4
sucrose	5.4*	17.7**
total sugars	0.9	31.3**
α-pinene	2.4	1.2
β-pinene/sabinene	3.6	0.1
myrcene	2.1	7.1
α-phellandrene	25.2*	5.9
α-terpinene	5.2	0.4
limonene	14.1*	0.3
γ-terpinene	2.5	0.0
terpinolene	90.5**	28.3*
terpinen-4-ol	3.6	0.9
bornyl acetate	1.3	1.8
caryophyllene	2.6	1.0
γ-bisabolene (A)	4.3	9.0
γ-bisabolene (B)	1.1	2.3
total volatiles	20.2*	1.5

[a] (*) Significant at the 5% level; (**) significant at the 1% level.

the genotype or the environment. The levels of reducing sugars and terpinolene were genetically most variable and sucrose, α-phellandrene, limonene, and total volatiles displayed some genetic variation. Dry weight, refractive index, carotenoids, sucrose, total sugars, and terpinolene were most variable environmentally. Although the genetic diversity of entries and environmental diversity of growing sites in this experiment were large, it should be noted that these conclusions may only apply to the lines and locations tested. This reservation is most appropriate for the volatiles, which were only represented by two locations.

Volatiles and sugars appear to play an important part in carrot flavor. The true level of their contribution can only be determined by the reconstitution of an attribute with exogenous supplementation.

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The Importance of Hydrophobic Properties of Organic Compounds on Their Taste Intensities: A Quantitative Structure–Taste-Intensity Study

Michael J. Greenberg

The relationship between taste intensity and physicochemical properties of organic compounds was investigated using the Hansch approach, a quantitative structure–activity relationship technique which utilizes linear free-energy relationship (LFER) parameters and multiple regression analysis. Literature taste threshold data for a homologous series of alcohols, ketones, and acids whose members had noncolinear hydrophobic, steric, and polar parameters were successfully correlated only with the hydrophobicity parameter log *P*, the log [*n*-octanol/water partition coeffecient]. Poor correlations were achieved with E_s, the Taft steric constant, and σ^*, the Taft polar constant. This indicates that taste intensity of homologues depends upon their hydrophobic rather than their steric and polar properties. Log *P* also correlated well with taste intensity for a series of lactones, esters, and sulfamates, as well as taste intensity data for a wide variety of organic stimulants of different functionality. Addition of a hydrogen bonding indicator parameter, HB, to the equation relating taste intensity for a nonhomologous series of stimulants significantly improved the correlation.

Taste, like other biological processes, involves a substrate and receptor site interaction. The nature of the substrate–receptor interaction and how this interaction leads to perceived taste quality and intensity has yet to be elucidated. Early studies in taste involved the number, size, shape, and distribution of taste buds in various species as reviewed by Kare (1971).

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Other studies have centered on whether there are four (or more) primary taste qualities (sour, sweet, salty, and bitter) and that there are specific receptors for each. The early work of Hänig (1901) indicated that the bitter mo-

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