Contribution of Some Volatile Compounds to Sweet Potato Aroma

Charles S. Tiu, Albert E. Purcell,* and Wanda W. Collins[1]

Twelve experimental lines of sweet potatoes representing a wide range of sensory properties were evaluated for flavor and acceptance. Three cultivars, representing high, intermediate, and low flavor, and two commercial cultivars were selected for further study. Volatiles of baked samples were separated by gas chromatography, and peaks eliciting an olfactory response were determined. Data were analyzed by discriminant statistical analyses. It was possible to classify each cultivar on the basis of 27 volatiles. Five volatile compounds were associated with good flavor and eight volatiles were associated with cultivars having poor flavor.

Per capita consumption of sweet potatoes has been declining in recent years (USDA, 1979). No specific quality factor has been cited as a major cause of declining consumption, but there seems to be a general disinterest in sweet potatoes (Fitzgerald, 1976; Law, 1977).

Of those whose do not use sweet potatoes, 52.5% stated they "just don't care for sweet potatoes", and of those who use sweet potatoes only once a year, 35.5% stated that members of the family do not like sweet potatoes (Fitzgerald, 1976).

The National Sweet Potato Collaborators Group has recommended that culinary quality be considered during the selection process for new sweet potato cultivars (Hammett, 1980). The recommended scoring of quality factors allows 40 points for various aspects of color and appearance, 30 points for rheological properties, and 10 points for flavor. Current market cultivars appear to have better appearance and mouthfeel than the old cultivars (Hammett, 1980), but some consumers feel that older cultivars had better flavor (Law, 1977). This suggests that flavor may be related to the apparent disinterest in sweet potatoes.

The flavor of sweet potatoes is a function of various degrees of sweetness (Hamann et al., 1980) and probably volatile components. The volatiles of baked sweet potatoes have been studied; although some have been identified, none have been related to flavor (Purcell et al., 1980; Kays and Horvat, 1983).

This study attempts to relate some volatile constituents to flavor and to clarify sweet potato cultivars by gas chromatographic profiles.

MATERIALS AND METHODS

Selection and Handling of Sweet Potatoes. Twelve experimental cultivars, which had been previously evaluated in a cultivar selection program, were selected to represent a wide range of sensory acceptability. The twelve cultivars were grown in North Carolina by standard horticultural practices (Wilson et al., 1980). After harvest the roots were cured at 27 °C and near 100% humidity for 7 days and stored for 2 months before shipment to Brigham Young University, Provo, UT. Roots with a 63–90-mm diameter were prepared for shipment by wrapping each root in paper and packing them snugly in a 0.5-bu basket. The baskets were marked "DO NOT CHILL BELOW 55 °F. Notify receiver immediately upon arrival". When received, the roots were immediately unwrapped and inspected. Diseased or damaged roots were discarded, and healthy roots were stored at 15 °C until used (about 3 months).

Preparation of Samples. Before each day of testing, three roots of each cultivar were washed with warm water, punctured to avoid explosion, and baked for 90 min at 190 °C in an electric convection oven. Roots more than 7.5-cm diameter were baked for an additional 5 min.

The baked roots were cooled at room temperature and split lengthwise into equal halves. Edible portions were scooped out of the peels, put into glass beakers, and mashed to homogeneous mixtures. The heavy concentration of fibers that were sometimes noted at each end were not considered part of the edible portion and were therefore not taken. Two teaspoons (approximately 3 g) each of four mashed sweet potato samples was placed on a paper plate and coded. Eight samples of each line were prepared in the same way for a total 96 samples per panel. Samples were covered with polyethylene film and stored at 2 °C until used. The samples were heated in a microwave oven (General Electric Model ET90 002) for 45 s before being presented to the panel. Although it is possible that heating in a microwave oven released some volatiles from the samples, preliminary testing indicated that the gas chromatograms were not significantly different than those of samples that were cooled at ambient temperatures. Panelists were able to give more consistent evaluations of uniformly warm samples than of samples that had cooled or been kept heated between cooking and serving.

Sensory Evaluation. Sweet potato samples were presented to a sensory panel as an incomplete block design (Galinat and Everett, 1949; Hanson et al., 1951; Marquardt et al., 1963).

The panel consisted of 24 persons selected from faculty and students of the College of Family Living, Brigham Young University (Tiu, 1981). All of the panelists had previously served on other sensory panels. Before the start of testing, the panelists were shown the method by which samples would be presented. Terminology and use of scoring cards were explained. The panelists were divided into twelve groups consisting of one male and one female to nullify any differences that might be due to sex. Samples were served to the panelists in groups of four on 3 separate days. The experiment was repeated to give two complete and equal observations for the experimental design.

Both blocking of cultivars and grouping of panelists were performed separately at random.

Panelists were asked to score for good flavor and acceptability. Acceptability was defined as the overall reaction about how good or how bad a sample was.

Flavor was described as sweetness, pleasant aroma, and any other pleasant stimulus to taste buds or olfactory sensors. Evaluations were recorded as slash lines on con-

Department of Food Science and Nutrition, Brigham Young University, Provo, Utah 86402.

[1]Present address: Department of Horticultural Science, North Carolina State University, Raleigh, NC 27605.

0021-8561/85/1433-0223$01.50/0

tinuous scales, 7 cm in length. The line for overall acceptance was labeled "dislike very much" on the left and "like very much" on the right. The line for scoring flavor was designated "Intensity of sweet potato flavor" with "very low" on the left and "very high" on the right. Scores were obtained by measuring the distance in centimeters from the left side of the score line to the slash line.

The statistical analysis system (SAS) was used to perform the analysis of variance in numerical scores. When differences due to factors and interactions were significant, the means were analyzed by the Newman-Keul procedure. Correlations between factors were determined by multiple regression analysis.

Analysis of Volatile Components. An experimental cultivar in the highest flavor category, one in the lowest category, one that was nearest to the median score, and two commercial cultivars Jewel and Centennial were selected for gas chromatographic analyses. Tissues were prepared in the same way except that samples, 40 g, were immediately frozen until analyzed.

Collection of Volatiles. Samples, 40 g, were placed into jacketed sample jars heated to 90 °C. Volatiles were swept from the jar with a stream of helium and trapped on Tenax precolumns as previously described (Purcell et al., 1980).

Gas Chromatography. Volatiles were separated by placing a precolumn into the injection part of a Perkin-Elmer Model 3920 B gas chromatograph. With the injectior port at 250 °C volatiles were driven from the precolumn and trapped in a trap cooled with liquid nitrogen. When the liquid nitrogen was removed, the volatiles were separated on an 80-m glass capillary column coated with SF-96 silicone. The carrier gas, helium, was adjusted to 4 mL/min. The column was held at 25 °C for 4 min, and the temperature was increased to 190 °C at 4 °C/min. The exit end of the column was equipped with a T fitting to send half of the effluent into a flame ionization detector and the other half to the outside of the chromatograph where eluted compounds could be smelled by a person (sniffer) with his nose close to the exit. The recorder of the gas chromatograph was connected to an Auto Lab Model 6300 integrator to quantify the area under the peak.

Sniffers were asked to describe the odors and intensity of odors from the various peaks. There were eight sniffers and terminology used in describing the peaks varied, but the most prevalent key words were selected to describe the odor associated with the peaks. Intensity of olfactory response also varied and a median response was estimated. Chemical compounds represented by the peaks were determined by mass spectroscopy and the use of standards as previously described (Purcell et al., 1980).

Statistical Analysis. Those peaks that consistently elicited an olfactory response were selected for statistical analysis. Data from 20 chromatograms of each of the five selected cultivars were analyzed by discriminant analysis (Giri, 1977; Henry and Block, 1979; Isphording and Flowers, 1980). An IBM 360 computer was used for computation according to a commercially available program, Statistical Package for Social Sciences (SPSS) (Klecka, 1975). This program allows discriminant analysis to be performed by entering all variables or through different stepwise methods in which the best set of discriminant variables were selected.

RESULTS AND DISCUSSION

According to the experimental design, there were 48 sensory observations for each cultivar (24 panelists × 2 times evaluated). There was no true replication; thus, effects due to individual panelists, panelist and cultivar interaction, and interaction due to cultivar and observations appear as an error term. There was no significant difference in scores due to sex of the panelists.

Table I. Mean Sensory Scores of 48 Samples for 12 Sweet Potato Lines Scored for Overall Acceptability, Good Flavor, Off-Flavor, and Mouthfeel

line	acceptability	flavor
720[b]	5.1[a,a]	4.6[a]
607	4.7[ab]	4.1[ab]
328	4.4[abc]	4.2[ab]
715	3.9[bcd]	3.7[abd]
702	3.8[bcd]	3.8[abc]
728	3.7[bcd]	3.1[c]
705	3.5[cd]	3.5[bc]
641	3.3[d]	3.1[c]
703	3.2[d]	2.8[c]
710	3.1[d]	3.1[c]
727	1.6[e]	1.7[d]
709[c]	1.0[e]	.2[e]

[a] Numbers with the same superscript are not significantly different according to the Newman–Keul comparison analysis. [b] Line 720 received the highest score for acceptability and flavor. [c] Line 709 had the lowest score for acceptability and flavor.

The 24-member panel was able to determine differences due to cultivar and was able to assign significant differences in good flavor and acceptability (Table I).

Regression analysis showed a significant correlation between acceptability and flavor ($P < 0.001$). Flavor alone accounted for 58% of the observed difference in acceptability ($r = 0.76$, $r^2 = 1.58$).

The chromatograms of volatile constituents were similar to those obtained by Purcell et al. (1980). The sniffers, i.e., people detecting odors eluted from the chromatographic column, detected 27 peaks that coincided with an olfactory response (Table II). Discriminant analysis of the integrator data from these 27 peaks showed that Wilks stepwise analysis produced the most nearly perfect classification of the five cultivars (Table III).

In this analysis with five groups, there were four disciminant functions (Table IV). Each group (Cultivar) is treated as a point, and each discriminant function is a unique dimension describing the location of that group relative to the others. The eigenvalues are special values computed in the process of deriving the discriminant functions. Eigenvalues and their associated canonical correlations provided two measures for judging the importance of each discriminant function. The sum of the eigenvalues is 100, expressing total variance. Each individual eigenvalue expresses the relative importance of the association function.

The canonical correlation expresses how closely the discriminant functions and groups are related. Squares of the canonical correlations represent proportions of variance in the discriminant functions explained by the groups. The high canonical correlations signify strength of the first and second function. The Wilks λ (U-statistic) reflects the nearness to which classification approaches perfection; as it approaches 0 classification becomes perfect.

Relative differences in characteristics of each volatile were indicated by the individual discriminant function coefficient. Plots of the first two discriminant values illustrated separation of the cultivars into categories (Figure 1). Each cultivar is represented by a point whose coordinates are the first two discriminant functions. The cultivar points closely cluster around their group centroids, which are well separated. This separation indicates that flavor characteristics of the five cultivars are distinctly different.

Table II. Odor Descriptions of Gas Chromatographic Peaks of Sweet Potato Headspace Aroma

peak no.	compound[a]	predominant odors	potency[b] of odor
1	2,3-butanedione (diacetyl)	buttery	S
2	*n*-hexane	objectionable	S
3	2,3-pentanedione	buttery	F
4	2-methyl-tetrahydrofuran-3-one	grassy, leafy, mowed lawn	F
5	furfuraldehyde	burnt sugars	F
6	dimethylbenzene (xylene), isobutyronitrile, 2-pyrone	earthy	M
7	2-furyl methyl ketone	baked potato	S
8	benzaldehyde	nutty, almonds	M
9	5-methyl-2-furaldehyde	fragrance, fruity, flowery	F to M
10	unidentified	hay, mushrooms, straw	M
11	unidentified	sour creams, citrus, orange, lime	F to M
12	trimethylbenzene (mesitylene)	carnation, milkweed	S
13	octanal	carnation, flowery	F
14	2-pentylfuran	fresh flowers, pungent aroma	M to S
15	unidentified	vinyl, smoky, hickory	M
16	phenylacetaldehyde	fragrance	M
17	unidentified	flowery, pleasant odor	F to M
18	unidentified	raw peanuts, soya products, cucumber	M
19	unidentified	musty	M
20	unidentified	sweet potato	M
21	*n*-nonanal	lime, citrus, licorice	M
22	lialool	cooked tomatoes, incense	M
23	unidentified	sweet pineapple, fruit, sweet potato cake	M
24	*n*-decanal	hot apple cider, fruity	M
25	unidentified	sweet potato	M
26	unidentified	grape juice, cough medicine, sweet fragrance	M
27	β-ionone	violet	S

[a] Compounds identified by Purcell et al. (1980). [b] S = strong; M = mild; F = faint.

Table III. Chromatogram Classification by Wilks Stepwise Discriminant Analysis

actual group	no. of chromatograms	predicted group 702	710	703	Jewel	Centennial
702 (high)	20	18	0	0	2	0
701 (intermediate)	20	0	20	0	0	0
703 (low)	20	0	1	19	0	0
Jewel (unknown 1)	20	0	0	0	20	0
Centennial (unknown 2)	20	0	0	0	0	20

Table IV. Discriminant Function Coefficients and Related Statistics of Odorous Volatile

	discriminant function 1	2	3	4
eigenvalue	6.25611	4.98479	3.19760	0.52266
% of variance	41.82	33.32	21.37	3.49
canonical correlation	0.92854	0.91264	0.87280	0.58588
Wilks λ	0.00360	0.02614	0.15646	0.65674
coeff of volatile				
2	0.11576	0.80431	−0.18024	0.10278
3	−0.27312	−0.58576	−0.21476	0.31649
4	−0.28281	0.39381	0.08312	−0.22551
5	0.57040	0.63391	0.07343	0.55003
7	−0.25980	−0.07296	0.41310	0.23451
8	0.43073	−0.03804	0.13077	−0.75574
9	−0.31855	−0.01188	0.13077	−0.75574
12	0.46021	0.07463	0.50582	−0.32027
13	−0.21882	0.15583	−0.44166	0.40881
14	0.28868	0.30994	0.01499	0.33219
16	0.23734	0.02384	−0.87131	0.78361
17	−1.11943	−0.41667	0.27879	−0.18820
18	0.52363	0.21627	0.54780	−0.54091
19	0.42700	0.35311	0.85691	0.29121
20	0.37400	−0.22026	0.00833	0.10358
21	−0.04000	0.18600	−0.18738	−0.49420
22	−0.54683	−0.92046	0.73445	−0.17688
23	0.21722	−0.48180	0.28548	0.16815
24	0.25973	−0.19039	−0.74621	0.29091
25	−0.26251	0.43978	−0.02361	0.35457
26	0.30574	0.33004	−0.41127	0.19580

The first function is positively weighted by volatiles 5, 18, 12, 8, 19, 20, 26, 14, 16, 23, and 2. It is negatively

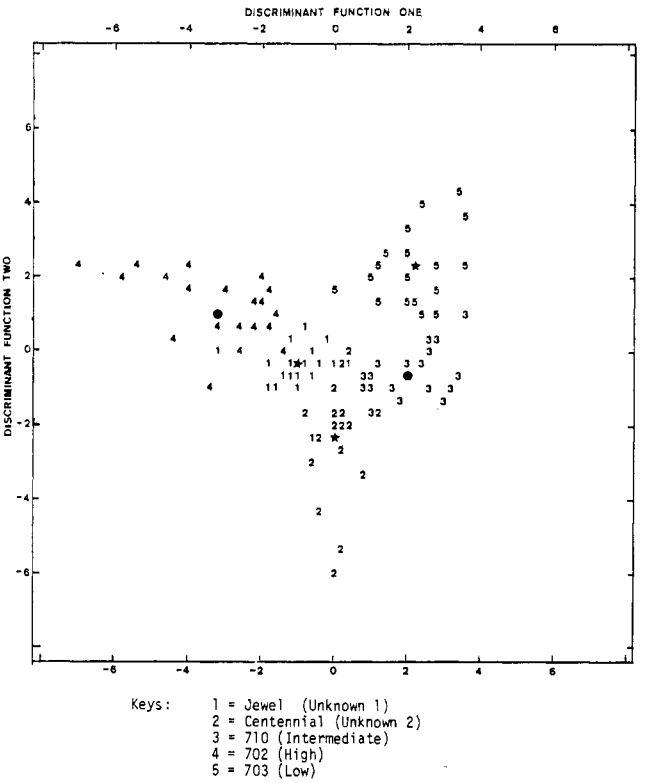

Figure 1. Plot of discriminant scores for 100 chromatograms subdivided into five cultivars of distinct flavor category. Letters indicate individual chromatogram. Stars represent group centroids.

weighted by 17, 22, 9, 4, 25, 7, 13, and 21. Thus, in Figure 1, the cultivar with the highest sensory score (702) had a high content of negatively weighted volatiles while the cultivar with a low sensory score (703) had high amounts of positively weighted volatiles. Cultivars 703 and 710 and Centennial were not separated by the first function; however, they were separated by the second function. Cultivar 703 contained high amounts of constituents that were

positively weighted by the second function while Centennial, which was rated better by the sensory panel, had more of the volatiles that were negatively weighted. These data suggest that volatiles 17, 22, 9, 3, and 7 contribute to good sweet potato flavor while excess amounts of 5, 18, 12, 19, 26, 14, and 2 may cause undesirable flavor. Volatiles 25, 4, 21, and 13, which are negatively weighted in the first function and positively weighted in the second function, may either increase or decrease flavor while increased amounts of 8, 20, and 24, which change from positive to negative, would probably detract from flavor because of the greater importance of the first function.

Lack of association with either a good- or a bad-flavored cultivar does not mean that a compound is not important to sweet potato flavor. If a compound that is very important to sweet potato flavor is present in adequate amounts in all sweet potatoes, there would be no correlation with sensory score and the amount of that compound. Some compounds that were correlated with sensory flavor scores may not contribute much but may be incidentally present with other compounds that do. If the unidentified components of sweet potato aroma can be identified, a few of the 27 constituents might be blended to produce good sweet potato flavor. Such a step would simplify both classification of cultivars by aroma profiles and selection of better flavored cultivars by chemical analysis. The quality of sweet potatoes is genetically controlled (Constantin et al., 1966). Many volatiles associated with the aroma of baked sweet potato are probably not present in raw sweet potatoes but are formed by baking. It is probable that the precursors of desirable aroma are genetically controlled and the amounts might be manipulated by breeding to improve the flavor of sweet potato. This study suggests the possibility of specifying baked sweet potato aroma on the basis of a few volatile compounds, thus enabling selection of cultivars on the basis of specific chemical content in an attempt to improve sweet potato flavor. It may also enable marketing and procurement of sweet potatoes with objectively stated flavor characteristics.

Registry No. Diacetyl, 431-03-8; hexane, 110-54-3; 2,3-pentanedione, 600-14-6; 2-methyltetrahydrofuran-3-one, 3188-00-9; furfuraldehyde, 98-01-1; xylene, 1330-20-7; isobutyronitrile 2-pyrone, 78-82-0; 2-furyl methyl ketone, 1192-62-7; benzaldehyde, 100-52-7; 5-methyl-2-furaldehyde, 620-02-0; mesitylene, 25551-13-7; octanal, 124-13-0; 2-pentylfuran, 3777-69-3; phenylacetaldehyde, 122-78-1; nonanal, 124-19-6; linalool, 78-70-6; decanal, 112-31-2; β-ionone, 79-77-6; 2-pyrone, 504-31-4.

LITERATURE CITED

Constantin, R. J.; Hernandez, T. P.; Miller, J. C. *Proc. Am. Soc. Hortic. Sci.* **1966**, *88*, 498.
Fitzgerald, F. K. *Ecol. Food Nutr.* **1976**, *5*, 107.
Galinat, W. C.; Everett, H. L. *Agron. J.* **1949**, *4*, 443.
Giri, N. C. "multivariate statistical inference"; Academic Press: New York, 1977.
Hamann, D. D.; Miller, N. C.; Purcell, A. E. *J. Food Sci.* **1980**, *45*, 992.
Hammett, H. L. "Processing Report"; LA State University: Baton Rouge, LA, 1980; National Sweet Potato Collaboratores Group Progress Report.
Hanson, H. L.; Kline, L.; Linweave, H. *Food Technol. (Chicago)* **1951**, *5*, 9.
Henry, D. R.; Block, J. H. *J. Med. Chem.* **1979**, *22*, 465.
Isphording, W. C.; Flowers, G. C. *J. Sediment. Petrol.* **1980**, *50*, 31.
Kays, S. J.; Horvat, R. J., 5th International Symposium of Tropical Root and Tuber Crops, Lima, Peru, 1973.
Klecka, W. R. "Statistical package for the social sciences"; McGraw-Hill: New York, 1975; p 435.
Law, J. M. *La. Agric. Exp. Stn., Bull.* **1977**, *No. 706.*
Marquardt, R. A.; Pearson, A. M.; Larzelere, G. H.; Grieg, W. S. *J. Food Sci.* **1963**, *28*, 421.
Purcell, A. E.; Later, D. W.; Lee, M. L. *J. Agric. Food Chem.* **1980**, *28*, 939.
Tiu, C. S. M.S. Thesis, Department of Food Science and Nutrition, Brigham Young University, Provo, UT, 1981.
USDA. "Agricultural statistics"; U.S. Printing Office: Washington, DC, 1979.
Wilson, L. G.; Averre, C. W.; Baird, J. W.; Sorenson, K. A.; Beasley, E. O.; Skroch, W. A. *N.C. Agric. Ext. Serv. Publ.* **1980**, *No. AG-09.*

Received for review February 21, 1984. Revised manuscript received June 4, 1984. Accepted October 15, 1984.

Distribution of Quercetin and Kaempferol in Lettuce, Kale, Chive, Garlic Chive, Leek, Horseradish, Red Radish, and Red Cabbage Tissues

Alexander Bilyk* and Gerald M. Sapers

The quercetin and kaempferol contents of 13 varieties of lettuce were determined. Leaf lettuce varieties contained 2–54 mg of quercetin/kg, while head lettuce varieties contained 1–28 mg/kg, more in the outer leaves than in the inner leaves. These samples also contained 0–2 mg of kaempferol/kg. Chives contained 55 mg of kaempferol and 9 mg of quercetin per kg in green portions and lesser amounts in white portions, while leek contained 20 mg of kaempferol/kg in green portions and no detectable quercetin in either portion. Two varieties of kale contained 7–20 mg of quercetin and 13–30 mg of kaempferol per kg. Other vegetables examined contained lesser amounts of these flavonols. No myricetin was detected in these samples.

Certain flavonols that are widely distributed in fruits and vegetables (Herrmann, 1976) have been shown to be mutagenic by the Ames test (Bjeldanes and Chang, 1977; Hardigree and Epler, 1978; MacGregor and Jurd, 1978) as well as by other assays for mutagenicity (Meltz and MacGregor, 1981; Watson, 1982). Evidence for the carcinogenicity of the mutagenic flavonols has been obtained by Pamukcu et al. (1980) and Hatcher et al. (1983) but not by Fukuoka et al. (1980), Morino et al. (1982), or Taka-

Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Philadelphia, Pennsylvania 19118.