Physical, Compositional, and Sensory Properties of French Fry-Type Products from Five Sweetpotato Selections

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Strips from five sweetpotato (SP) cultivars (cv.) representing two different texture/flavor types were prepared and frozen. They were fried and their flavor and texture evaluated by sensory panels. Selected physical and compositional analyses were performed on raw and fried SP. An untrained preference panel tended to score the flavor of the sweeter types highest and the texture of the firm types higher than sweet types. A trained profile panel identified and scored flavor notes and texture categories. This research indicated that the intensity of the flavor notes sweetness and starch and the intensity of texture notes first-bite moistness and first-bite hardness were highly correlated with some of the compositional parameters. Correlation between compositional parameters and the flavor and texture note intensities listed above could be developed into a system to predict those sensory properties in newly developed selections without having to resort to sensory analyses.

Keywords: *Texture profile analysis; flavor profile analysis; composition; sugars; alcohol-insoluble solids; fat content*

INTRODUCTION

For French-fried potatoes made from white potatoes, textural attributes of most importance are crispness, mealiness, and firmness (Jaswal, 1989). Generally, fries made from white potato tubers of high specific gravity have the most desirable textural properties. A great deal of research has been done to determine the underlying reasons. The factors responsible, however, remain in dispute (Jaswal, 1989). The sweetpotato is of a different botanical family from the white potato and has many different properties. In contrast to the white potato, which from a processing standpoint is comprised of the perimedullary and pith regions, the sweetpotato is much more uniform anatomically (Artschwager, 1924). Moreover, many sweetpotato selections/cultivars have an active system of amylolytic enzymes which rapidly degrade starch once its gelatinization temperature has been reached, producing the reducing sugar maltose and dextrinous material. This being the case, it is unlikely that textural properties of French fries made from sweetpotatoes will be similar to those of fries made from white potatoes.

Sweetpotato (SP) breeding programs in the United States have generated selections with a wide range of processing properties. Morrison et al. (1993) reported that selections, when cooked, can be separated into four distinct sweetness categories, dependent upon the sugar content of the raw roots and the tendency toward maltose formation during cooking mediated by endogenous amylolytic enzymes. Other workers have related the textural property of mouthfeel in baked SP to α-amylase activity in the raw root (Walter et al., 1975) and to starch and cell wall breakdown (Sterling and Aldridge, 1977; Shen and Sterling, 1981). Rao et al. (1975) found that the apparent viscosity of puree made from baked roots was correlated with sensory "moistness" scores. However, there are no published reports relating textural and flavor attributes of cooked SP with the physical and compositional properties of raw and/or blanched roots. Such data could possibly be used as predictors of flavor and/or textural properties when the roots are cooked.

The objective of the present research was to compare selected physical and compositional properties of raw, blanched, and fried SP selections with the sensory attributes of the fried selections. The term selection in this context means that roots are still being evaluated in a breeding program and have not yet been released for commercial production. For this study, we chose selections that had very different organoleptic characteristics when cooked. Two selections were of the sweet−soft type, and three were of the less sweet−firm types. Here, the terms soft and firm refer to shear force measurements.

MATERIALS AND METHODS

The SP selections A12, NC1135, A144, NC1714, and A1689 were harvested at 120−130 days after transplant, cured for 7 days at 31 °C and 85% relative humidity, and then stored at 13 °C and 85% relative humidity until used. Approximately 45 days after harvest, for each selection, three replicate samples of six roots each were removed for analysis. The remainder were lye peeled, cut into strips 0.9 cm square, variable length strips, blanched in boiling water containing 1% sodium acid pyrophosphate, and partially dehydrated in a forced-air drier (Walter and Hoover, 1986). The packaged strips were then frozen and held at −20 °C until analysis and frying.

Samples were fried by dropping ca. 300 g of frozen strips into Food Lion brand vegetable oil (soy oil and corn oil) at 180 °C and cooking for 3 min. The oil temperature rapidly dropped to ca. 150 °C after strips were added and increased to ca. 155 °C when frying was terminated. The fried strips were drained for ca. 30 s, put into paper-lined containers covered with aluminum foil, and held at 60 °C until evaluated by sensory panels. Strips were served hot to panelists within 15 min of

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Table 1. Flavor and Texture Note Definitions

	Flavor Notes
oil	flavor of soybean oil
sweet	basic (perceived on the taste buds of the tongue) and aromatic sweet (sweet as perceived through the olfactory epithelium in the nasal air passage)
starch	an awareness of the presence of starch (i.e. a floury or chalky flavor—not mouthfeel)
caramel	burned or overcooked sugar
	Texture Notes
first bite	using the front teeth, bite into the sample approximately 0.5 in. from the end and evaluate for
hardness	amount of force necessary to bring teeth together
moistness	amount of moisture and oil perceived
mastication	chew a 1-in. sample taken at least 0.25 in. from the end and evaluate for
cohesiveness of mass	degree to which the mass holds together at six chews
particles	degree to which particles of any size are perceived throughout mastication
adhesiveness	degree to which the sample adheres to any of the mouth surfaces such as teeth, gums, and palate
residual	at the time of and immediately after swallowing evaluate for
ease of swallow	ease with which the sample is gathered up and swallowed
oily mouth coating	amount of oily residue left in the mouth

frying. Shear force was measured on strips that had been cooled to room temperature.

Analysis. *Percent intercellular space* was determined on each of three unpeeled roots using the vacuum displacement procedure of Kushman and Pope (1968). Root specific gravity was measured as part of this procedure.

Cell size was measured on raw tissue slices that had been fixed in 3% glutaraldehyde solution for 1 week, embedded in Paraplast-Plus, and cut to a thickness of ca. 15 μm. The slices were then mounted on glass slides, deparaffinized, stained with safranin, and counterstained with fast green, and cell size was determined using a Wild M20 microscope equipped with an ocular micrometer (Walter et al., 1990). Three slides obtained from tissue from two replicate roots were randomly chosen and selected cell diameters measured. Care was taken to measure only parenchyma cells. To conduct a measurement, the ocular micrometer was randomly aligned across a row of cells, and the cell that fell within the micrometer scale was measured. This procedure was followed until a total of 28 cells was measured for each replicate for each selection.

Dry Matter, Sugar, and Alcohol-Insoluble Solids. Approximately 300 g of sample was grated in a Cuisinart Model DLC 10 food processor. Duplicate 10 g samples were removed and the dry matter content determined after 6 h of drying at 68 °C followed by 18 h at 100 °C.

Duplicate 100 g samples of the grated material were extracted three times with 300 mL of boiling 80%/20% ethanol/water. Filtration was accomplished using a sintered glass, coarse porosity filter. The residue was dried overnight at room temperature and then for 24 h in a convection oven at 100 °C, and the weight of alcohol-insoluble solids (AIS) was measured after drying.

The filtrates from the AIS preparation were combined and the volume was measured. The sugar concentration was measured using the phenol—sulfuric acid procedure of Dubois et al. (1956).

Pectic Substances. A portion of the AIS was ground in a Wiley mill to pass a 60 mesh screen. Duplicate 0.2 g samples were extracted by shaking with 10 mL of water at 300 rpm for 10 min, centrifugation, and decantation of the supernatant. This procedure was repeated twice and the supernatants were combined. This solution contained the water-soluble pectins. The residue was then extracted in the same manner three additional times except that 0.5% sodium metaphospate solution was the extractant. The combined supernatants fraction from this series of extractions was designated phosphate-soluble pectins.

The uronic acid content of both pectin types was measured as described by Walter et al. (1993) using modifications of the method of Scott (1979).

Oil Content. Duplicate, weighed samples of fried strips that had been dried and grated were extracted overnight in a Soxhlet extractor using petroleum ether (bp 35—60 °C) as the extracting medium. Upon completion of the extraction, the solvent was evaporated and the oil content determined by weighing the residue.

Quantitation. Data for the compositional components were presented on an as-is basis. Amounts were calculated for the raw or fried sample itself.

Shear Force. Weighed samples of fried strips ranging from 23 to 26 g were placed in a Kramer shear cell, and the shear force was measured using an Instron Universal testing machine (Walter et al., 1993).

Sensory Analyses. *Texture—Flavor Profile Panel.* Flavor and texture profiles were assessed by a six-member panel previously trained in profile methods of descriptive flavor (Caul, 1957) and texture analysis (Brandt et al., 1963) for various foods including SP. For this study, the panelists were trained specifically on French-fried SP, following the established guidelines (Civille and Szczesniak, 1973) for two 3 h training sessions on two consecutive days. The panel established flavor and texture notes using selection NC1135. Scores for flavor and texture notes were based on a 14-point descriptive intensity scale (Caul, 1957), which was converted to a 1—14 numerical scale for statistical analysis. A score of 1 = not detectable, and a score of 14 = extremely intense. At each session, panelists evaluated three coded samples and a reference in random order. Fried strips of selection NC1135 served as the reference. Reference identity was not disclosed to the panel.

Untrained Preference Panel. Fried samples were subjected to an acceptability test by a 26-member, untrained preference panel consisting of faculty, staff, and graduate students from the Department of Food Science at the North Carolina State University. Although the panel was untrained, only those persons who liked SP were selected. In addition, all panelists were generally familiar with taste panel procedures.

Fried strips were prepared as previously described. Panelists were situated in individual booths illuminated with red light (to mask any sample color differences) in a darkened room. At each of two sittings, three samples (two strips per sample) were served on a partitioned plate with each sample coded with a randomly selected three-digit number. Panelists were asked to score the strips for flavor, texture, and overall acceptability on a 9-point hedonic scale, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. In addition, the questionnaire contained a section for panelist comments for each of the three attributes evaluated. Panelists were asked to rinse their mouths with water between samples.

Statistical Analysis. A randomized complete block design was used. Data were evaluated by analysis of variance and means separations calculated by the General Linear Models Procedure (PROC GLM) of the Statistical Analysis System (SAS, 1989). Differences (P < 0.05) between treatment variables were evaluated by least-squares means procedures. Pearson correlation coefficient analyses were performed using PROC CORR.

Table 2. Untrained Preference Panel Scores[a] for Fried Sweetpotato Strips

selection	flavor	texture	overall
A12	6.26a	4.71c	6.42a
NC1135	5.84ab	4.66c	6.23a
NC1714	6.41a	5.50abc	6.64a
A144	5.03b	6.19a	6.19a
A1689	5.58ab	5.61ab	6.14a

[a] Scored on a hedonic scale with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. For each attribute, scores with the same letter are not significantly different ($P < 0.05$).

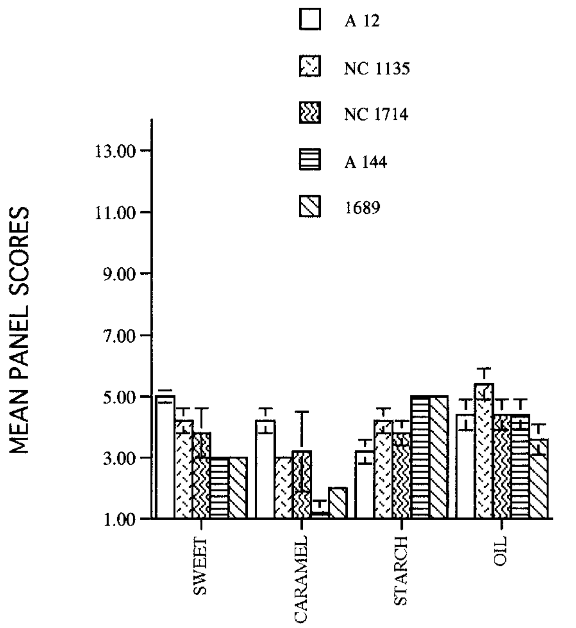

Figure 1. Flavor profile panel mean scores for five sweetpotato selections. A score of 1 means that the flavor note was not detectable, and a score of 14 means that the note was extremely intense. Error bars represent one standard deviation from the mean of scores assessed by six panel members.

RESULTS AND DISCUSSION

The selections chosen for this study were of the soft−sweet type (A12 and NC1135) and the firm−less sweet type (A144, NC1714, and A1689). Type assignment was made from shear force measurements (Table 2) and sugar content (Table 5) of the fried strips.

Table 3. Physical Properties of Sweetpotato Selections

selection	shear force[a] (kg)	intercellular vol[b] (%)	cell size[b] (μM)	specific gravity[b]
A12	23.83 ± 5.77	13.17 ± 0.23	84.99 ± 23.31	0.95 ± 0.0
NC1135	29.93 ± 5.8	8.61 ± 1.02	72.06 ± 16.42	1.01 ± 0.02
NC1714	43.4 ± 4.26	10.91 ± 1.23	73.24 ± 16.33	0.96 ± 0.02
A144	45.9 ± 6.89	7.64 ± 0.74	79.34 ± 21.38	1.02 ± 0.01
A1689	35.47 ± 1.33	10.85 ± 0.28	60.64 ± 14.1	0.99 ± 0.01

[a] Fried sweetpotato strips. Three replicate samples; ± standard deviation. [b] Raw sweetpotatoes. Three replicate samples ± standard deviation.

Sensory Panel Results. The descriptive panel recognized and scored 4 flavor notes and 10 texture notes in three categories: first-bite, mastication, and residual. The note moistness appeared in the categories first-bite and mastication, and the note particles was common to the categories mastication and residual. Because panelists' responses to each of these notes were similar in the two categories, the descriptor for each note is shown in one category only (Table 1). The data for the note chewiness is not shown because all selections were scored similarly.

Intensities for flavor notes were <6 on the 14-point scale, while texture note intensities were higher, with some notes being scored at 8 (Figures 1 and 2). With regard to flavor, as expected, the soft−sweet selections A12 and NC1135 had higher scores for sweetness and caramel notes and lower scores for starch than the firm−less sweet selections A144 and A1689. NC1714 was intermediate between the two types. Scores for the flavor note oil appeared to have no relationship to selection type.

For the texture category first-bite, the soft−sweet types tended to be softer and moister than the other types. With regard to the category mastication, the note particles tended to be scored according to type, with soft−sweet types having fewer particles than the firm−less sweet types. In addition, the trend was for the soft−sweet types to have a higher degree of mass

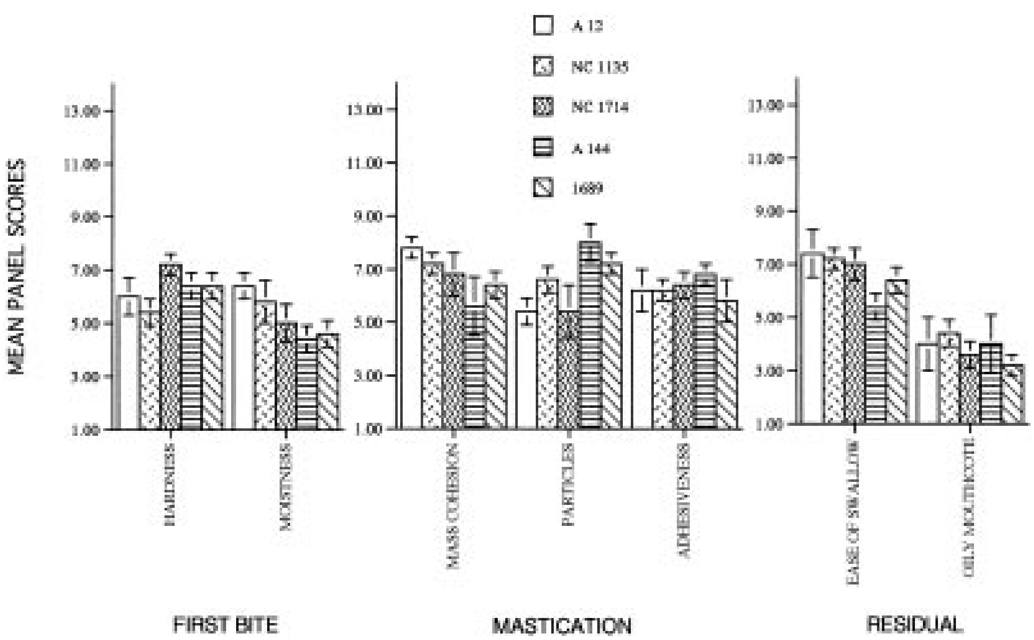

Figure 2. Texture profile panel mean scores for five sweetpotato selections. A score of 1 means that the texture note was not detectable, and a score of 14 means that the note was extremely intense. Error bars represent one standard deviation from the mean of scores assessed by six panel members.

Table 4. Product Moment Correlation Coefficients[a] for Sensory Scores of Fried Sweetpotato Selections on the Physical and Compositional Properties of Fried Sweetpotato Selections

	dry matter (%)	sugar (%)	AIS (%)	water-soluble galacturonic acid
profile flavor				
sweetness		0.9365 (P < 0.0189)		0.955 (P < 0.0115)
profile texture				
first-bite hardness	−0.923 (P < 0.0256)			
first-bite moistness		0.968 (P < 0.0067)	0.937 (P < 0.0184)	
mastication cohesiveness				0.881 (P < 0.048)
preference				
texture			−0.916 (P < 0.029)	

[a] Only statistically significant (P <0.05) correlation coefficients are displayed.

Table 5. Composition[a] of Raw and Fried Sweetpotato Selections

selection	raw % dry matter	fried % dry matter	raw % sugars	fried % sugars	% oil in fried	% AIS in raw	% AIS in fried	% water-soluble GA in raw	% water-soluble GA in fried
A12	23.82 ± 1.4	44.67 ± 0.58	7.09 ± 0.66	22.19 ± 0.98	3.37 ± 0.325	14.73 ± 1.67	18.99 ± 0.11	0.37 ± 0.04	0.21 ± 0.01
NC1135	24.33 ± 0.73	48.00 ± 0.87	4.35 ± 0.39	20.95 ± 1.22	2.45 ± 0.25	16.32 ± 1.33	18.42 ± 0.50	0.31 ± 0.04	0.15 ± 0.00
NC1714	23.15 ± 1.08	43.50 ± 0.50	3.40 ± 0.29	11.00 ± 0.95	4.27 ± 0.24	14.51 ± 1.12	11.57 ± 0.16	0.34 ± 0.07	0.11 ± 0.01
A144	27.47 ± 1.76	44.33 ± 1.89	3.6 ± 0.16	9.85 ± 0.34	2.65 ± 0.20	20.79 ± 1.41	10.47 ± 0.55	0.25 ± 0.03	0.10 ± 0.01
A1689	28.27 ± 1.04	44.00 ± 0.87	3.04 ± 0.16	9.59 ± 0.85	3.32 ± 0.51	23.65 ± 0.24	12.78 ± 0.25	0.25 ± 0.03	0.09 ± 0.01

[a] Compositions calculated as percent by weight on an as-is basis.

cohesion. For the category residual, soft−sweet types tended be easier to swallow and to have a slightly more intense oily mouthfeel than the firm−dry types. For flavor notes NC1714 was closer to the soft−sweet types, but for the texture notes it fit neither category well.

Although the primary objective of this research was to relate physical and compositional parameters and sensory attributes as determined by a trained panel, acceptability data using an untrained preference panel were also obtained. Overall acceptance was "like slightly" to "like moderately" (Table 2), with no selection being preferred over the others. Some selections were scored more acceptable with regard to flavor and texture. Selections A12 and NC1714 had more acceptable flavor than A144, and, conversely, the texture of A144 was more acceptable than that of either A12 or NC1135. The inference one might draw from these data is that the panelists tended to find the flavor of the soft−sweet selections and the texture of the less sweet−firmer selections to be more acceptable.

Moreover, when we grouped the analytical data into the two types and performed analysis of variance, we found that for the texture−flavor profile panel all texture and flavor notes with the exception of mastication adhesiveness were significantly different for the two types. Using data analysis of the same nature, we also found that only the texture was perceived as being different between the two types by the untrained preference panel. These findings further reinforce the sensory differences between the two types of sweetpotatoes

Physical Properties. Fries made from selections A12 and NC1135 were less firm (i.e. had lower shear force values) than did fries of the other three selections (Table 3). For the raw selections intercellular volumes ranged from 7.6 to 13.2%, cell sizes from 60.6 to 85 μM, and specific gravities from 0.95 to 1.02 (Table 3). These physical parameters did not impact instrumental firmness since they had no apparent relationship to shear force. Additionally, there was no relationship between shear force measurements and the sensory profile texture note first-bite hardness, which would be expected to reflect fried strip firmness (Table 4). Possibly the crust firmness was responsible for the observed shear force differences and the panel focused on the total bite sensation. Physical parameters intercellular volume, specific gravity, and cell size were not correlated with any sensory attributes.

Table 6. Product Moment Correlation Coefficients[a] of Comparison of Profile Panel Scores with Hedonic Panel Scores for Five Sweetpotato Selections

	profile flavor		profile texture	
	starch	caramel	first-bite moistness	mastication cohesiveness
preference				
flavor	−0.9387 (P < 0.0181)	0.9152 (P < 0.0293)		
texture			−0.9369 (P < 0.0188)	−0.8935 (P < 0.041)

[a] Only statistically significant (P < 0.05) correlation coefficients are displayed.

Composition. Compositional data are provided as percent by weight on an as-is basis (Table 5). Selection dry matter ranged from ca. 23 to 28% for raw roots and from ca. 43 to 48% in the fried strips (Table 5). Blanching and partially dehydrating raw strips resulted in dry matter increase of from ca. 4 to 16%, depending upon the selection (data not shown). Sugar concentrations of the fried strips were ca. 3−4 times greater than those of the raw strips, depending upon the selection. This change reflects concentration of the sugars via the water content decrease occurring during frying and sugar formation mediated by amylolytic enzymes during blanching and frying. Fried selections A12 and NC1135 had significantly more sugar than did the others. For raw strips, the AIS content was highest in A1689 and A144; however, after frying, the AIS content was reversed. Water-soluble galacturonic acid concentrations decreased by approximately half between raw and fried strips. The explanation for this decrease is unknown.

Table 7. Product Moment Correlation Coefficients[a] for Sensory Scores of Fried Sweetpotato Selections on Physical and Compositional Properties of Raw Sweetpotato Selections

	dry matter (%)	sugar (%)	AIS (%)	water-soluble galacturonic acid (%)	specific gravity
profile flavor					
sweetness		0.889 ($P < 0.044$)			
starch	0.915 ($P < 0.029$)		0.883 ($P < 0.047$)	−0.999 ($P < 0.0001$)	
profile texture					
mastication cohesiveness				−0.895 ($P < 0.0399$)	
mastication particles				−0.95 ($P < 0.0131$)	
preference					
flavor				−0.95 ($P < 0.0133$)	−0.911 ($P < 0.0313$)

[a] Only statistically significant ($P < 0.05$) correlation coefficients are displayed.

As was described above for sensory properties, we grouped the analytical data into two types and performed analysis of variance. We found that, for the two types of sweetpotatoes when fried, the compositional parameters dry matter, sugars, AIS, and water-soluble galacturonic acid and the physical property shear force were all significantly different among types. These results likewise underscore the differences between the two sweetpotato types.

Correlations. Examination of the correlation coefficients of the profile panel on the hedonic panel revealed several interesting relationships (Table 6). The starch flavor was poorly accepted by the untrained preference panel, while the caramel flavor was well accepted. Although the profile panel scores reflected a wide range of sweetness among the selections (Figure 1), there was no statistically significant relationship between those scores and hedonic panel flavor scores. This was due to the high degree of within-selection variability in preference for flavor, as scored by the untrained preference panel.

With regard to the textural properties, the untrained preference panelists did not like a strong sensation of first-bite moistness or of cohesiveness of the mass during chewing (Table 6).

Statistically significant Pearson product moment correlations for sensory scores on physical and compositional properties are provided in Tables 4 and 7 for fried and raw strips, respectively. As expected, sugar concentrations for both were positively correlated with profile panel scores for the flavor sweetness. For the raw roots, dry matter and percent AIS were both correlated with flavor profile panel starch (Table 7). These correlations were as expected since dry matter and AIS both reflect the starch content of the roots, while endogenous sugar content directly affects sweetness. For fried strips (Table 4), texture profile first-bite moistness was correlated with percent sugar and AIS was correlated with texture profile first-bite moistness. The relationship between this texture note and sugar content could be because high sugar content is a characteristic of the sweet−soft type SP, and this type is characterized by a moist mouthfeel. The correlation between percent AIS and first-bite moistness could be because this texture note is defined as the amount of moisture and oil perceived on the first-bite, and AIS concentration affected the amount of cooking oil absorbed, causing the described sensation. Reasons for the remainder of the correlations are not obvious. Further research will be needed to understand and/or verify them.

Conclusions. Prediction of the sensory properties of fried SP using physical or compositional properties of the raw roots would permit plant breeders to rapidly screen large numbers of selections for suitable material. This research indicates that the correlation between compositional parameters and the flavor and texture note intensities listed in the preceding paragraph could be developed into a system to predict those sensory properties in newly developed selections without having to resort to sensory analyses.

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