SENSORY ATTRIBUTES AND CONSUMER ACCEPTANCE OF SWEET POTATO CULTIVARS WITH VARYING FLESH COLORS

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ABSTRACT

The sensory characteristics of sweet potatoes ($n = 12$ cultivars) with varying flesh color (orange, purple, yellow) and the impact of flesh colors on consumer acceptance were evaluated. A lexicon was developed for sweet potato flavor followed by consumer acceptance testing conducted with and without blindfold conditions to identify if color or visual cues impacted consumer acceptance. Cluster analysis was performed on overall liking scores followed by external preference mapping to identify the drivers of liking for sweet potatoes. The lexicon differentiated sweet potatoes. Appearance (visual appearance) positively impacted liking scores of products that were not well liked but had a lower impact on liking when the sweet potato was well liked suggesting that flavor and texture were the driving attributes for liking. Three consumer clusters were found for overall liking. All clusters liked smooth texture, brown sugar and dried apricot flavor and sweet taste and disliked bitter, umami, astringent mouthfeel, vanilla aroma and residual fibers. Clusters were differentiated by the liking of visual moistness and color homogeneity, white potato, canned carrot and dried apricot flavors, chalky, firmness, denseness and fibrous texture. Sweet potatoes with unfamiliar colors were accepted by all consumers but different sensory characteristics appealed to different consumer groups.

PRACTICAL APPLICATIONS

Sweet potatoes (*Ipomoea batata*) are nutritious and have numerous health benefits. The orange-fleshed cultivars are the most familiar to consumers, but other cultivars with varying flesh color have been identified. The sensory properties of these various sweet potatoes and the drivers of liking are not established. The development of a sensory lexicon for sweet potatoes allowed for characterization of sensory properties and assisted in the understanding of key consumer liking attributes for sweet potatoes. These results can assist sweet potato breeders or marketers in understanding the impact of color and the importance of flavor and texture of sweet potatoes for the consumer fresh market.

INTRODUCTION

Sweet potato (*Ipomoea batata*) is the sixth most important crop worldwide after wheat, rice, maize, potato and cassava and is a staple to many developing countries (FAOSTAT 2008; Truong *et al.* 2011). The largest sweet potato production is in Asia and the Pacific Islands (93% of global production). China accounts for 80% of global sweet potato production (Truong *et al.* 2011). Comparatively, the production of sweet potatoes in the U.S.A. is very small, only 0.8% of the total world sweet potato production (Truong *et al.* 2011).

Orange-fleshed sweet potatoes are the most common cultivars and are a good source of β-carotene, dietary fiber and minerals. However, sweet potato cultivars with diverse colors possess other positive health benefits including sources of anthocyanins, phenolic compounds and other bioactive compounds (Giusti and Wrolstad 2003; Suda *et al.* 2003; Kano *et al.* 2005; Truong *et al.* 2011). The purple-fleshed sweet potato is a good source of anthocyanins, which possess anti-oxidant activities (Giusti and Wrolstad 2003; Suda *et al.* 2003; Kano *et al.* 2005). Different colored cultivars of sweet potatoes have gained popularity in developed countries like Japan because of their additional health benefits. Orange-fleshed sweet potatoes are commonly accepted by consumers in the U.S.A., but cultivars with other flesh colors are a new concept to U.S. consumers. Consumption in the U.S.A. is very small with only 2.3 kg per capita. Research efforts are focused on converting the nutritious sweet potato into various forms (i.e., puree, flour) to be used as a functional ingredient (Truong and Avula 2010).

The sensory properties and consumer acceptance of these different colored sweet potatoes have not been determined. A consumer survey in Tanzania showed that high starch, good taste, cooking quality and flesh color were all major drivers in consumer acceptance of sweet potatoes (Tomlins *et al.* 2004). In the U.S.A., previous sensory research in the U.S.A. on sweet potatoes has concentrated on texture, and a defined sensory flavor lexicon to document sensory properties of differing cultivars has not been developed. Truong *et al.* (1997) described texture to be composed of three factors: moistness-firmness, particles and fiber. Leighton *et al.* (2010) applied descriptive sensory analysis to differentiate five sweet potato cultivars with white and orange flesh. However, the language applied was simple and used the descriptor "sweet potato" to describe sensory differences. Further, blue- and yellow-fleshed cultivars were not included, and consumer perception was not determined. Understanding the sensory differences and consumer perception of sweet potato cultivars with varying flesh color will aid the sweet potato industry in effective marketing of specific cultivars in effort to increase consumption. The objectives of this study were to evaluate the sensory characteristics of sweet potatoes with varying flesh colors, to determine if color impacts consumer acceptance and to identify drivers of liking for sweet potatoes.

MATERIALS AND METHODS

Sweet Potatoes (*I. batata*)

Twelve sweet potato cultivars with varying flesh colors (white, yellow, orange, purple) were used in this study: Beauregard (orange), Covington (orange), Harnandez (orange), Carolina Ruby (orange), NC414 (purple), NC415 (purple), Okinawa (purple), Purple 04-069 (purple), Japanese (yellow), Puerto

Rican (yellow), O-Henry (yellow), DM02-180 (yellow). Three of the cultivars, Beauregard, Covington and Hernandez, are the major commercial cultivars that are widely grown in the U.S.A. for fresh root markets and processing industry. Five other cultivars, Carolina Ruby, O-Henry, Okinawa, Japanese and Puerto Rican, are specialty sweet potatoes that have been produced in limited quantity mainly for fresh market. The remaining clones (NC414, NC415, Purple 04-069 and DM02-180) were selected from the Sweet Potato Breeding Program at North Carolina State University (NCSU) (Raleigh, NC). Nine of the sweet potato cultivars were grown at the experimental fields of the Department of Horticultural Science in Clinton, North Carolina. Okinawa and Japanese sweet potatoes were obtained from Pride of Sampson, Inc. (Clinton, NC), and Puerto Rican sweet potatoes were from Scott Farms, Inc. (Lucama, NC). All the harvested roots were cured at 30C, 80–90% relative humidity for 7 days and stored at 13–16C and 80–90% relative humidity for 2–3 months before samples were taken for the experiments.

Color Measurement

Sweet potato roots were baked at 204C for 90 min (Walter 1987). The baked roots were cooled to room temperature, peeled and pureed using a food processor. The pureed samples were dispensed into a 60×15 mm covered Petri dishes (Becton Dickinson Labware, Franklin Lakes, NJ). Instrumental color of the samples was measured with a Hunter colorimeter (Hunter Associates Laboratory Inc., Reston, VA). Results were expressed as tristimulus values, L^* (lightness, 0 for black, 100 for white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b$ = blueness, $+b$ = yellowness). The instrument (45°/0° geometry, D25 optical sensor) was calibrated against a standard white reference tile ($L^* = 92.75$, $a^* = -0.76$, $b^* = -0.07$). Six measurements were taken for each sample.

Sample Preparation for Sensory Evaluation

Sweet potato roots of uniform shape and weight (200–300 g) were randomly selected, carefully washed and dried. The roots were pricked with a fork six times and then wrapped in aluminum foil. Fifteen roots were baked together in a conventional oven at 204C for 90 min as described by Walter (1987). After baking, roots were stored at 5C overnight to cool and become firm. Firmness was necessary to preserve the texture when slicing the roots. The next day, the roots were removed from the refrigerator and peeled. A 2 cm segment was sliced off each end and discarded. The remaining flesh was sliced into 2.5 cm cylindrical segments and then the segments were quartered. Samples were then tempered to 21C for descriptive analysis or warmed to ~50C for consumer

evaluation. Preliminary evaluations confirmed that these procedures did not impact flavor profile of the roots.

Sensory Evaluation

Descriptive Analysis. Testing was conducted in accordance with the NCSU Institutional Review Board for Human Subjects approval. Samples were evaluated by a 10-member trained panel (eight women, two men, ages 22–46 years). Each panelist had previous experience with descriptive analysis (a minimum of 50 h each) and the Spectrum scaling technique (Meilgaard *et al.* 2007). Panelists were trained on flavor and texture attributes of sweet potatoes during 20 1-h sessions. Previous research has minimally addressed texture properties of sweet potatoes (Truong and Walter 1994) and flavor properties (Leighton *et al.* 2010). Thus, initial sessions were focused on identification of sensory vocabulary for sweet potatoes. Panelists were presented with coded samples of each sweet potato segment in 118.3 mL lidded cups (Sweetheart Cup Co., Owings Mills, MD) along with possible references for flavor and texture attributes. A sensory lexicon for appearance, aroma, flavor and texture of sweet potatoes was created from the terms generated at these sessions (Table 2). During subsequent training, panelists evaluated and discussed samples in order to ensure panelist and panel consistency and understanding of the lexicon. Analysis of variance (ANOVA) of data collected from the last part of training indicated that the panel and panelists could consistently use the attributes to differentiate the products.

Descriptive analysis of sweet potatoes was conducted by each panelist in triplicate replications in a randomized balanced design. Visual, aroma/flavor and texture properties were evaluated in separate sessions with separate ballots and different coded samples. Panelists individually evaluated peeled sweet potato slices presented in lidded 118.3 mL plastic cups in sensory booths. All sample cups were labeled with a three digit code and samples were tempered to 21C. This temperature was chosen because panelists could best detect subtle differences in flavor when samples were tempered to this temperature.

Panelists evaluated five samples per session, and they were given room temperature deionized water and unsalted crackers to cleanse their palate between samples. Each cultivar was evaluated three times on different days. In addition to the coded samples, references of a purple flesh (2005 NC 415) and an orange flesh (2005 Beauregard) sweet potato were provided to panelists as "warm-ups." These "warm-up" or calibration samples were previously profiled by the panel. Each panelist was presented with these two samples in cups with labels "warm-up 1" and "warm-up 2" along with their specific sensory profiles, which had been previously discussed and agreed on. Panelists tasted these samples and looked at their sensory profiles before initiating individual profiling of coded samples. Visual evaluation by each panelist was conducted on the same set of samples within each replication to minimize root-to-root variability. Attribute intensities (0- to 15-point Spectrum scale) were recorded using Compusense Five version 4.7 (Compusense, Guelph, Canada).

Consumer Acceptance. Consumer acceptance testing was conducted in accordance with the NCSU Institutional Review Board for Human Subjects guidelines. Sweet potatoes were prepared as described previously for consumer testing and were presented at 50C, a temperature similar to what consumers would normally encounter. Our objectives were to identify consumer key drivers for sweet potatoes but also to specifically examine the impact of color on acceptance. To this end, sweet potato consumers ($n = 90$) were recruited to evaluate the 12 sweet potato samples in two separate sessions. In one session, the consumer was blindfolded to evaluate samples, and in the other session, samples were presented under white lights. The order of presentation format (blindfold versus no blindfold) was randomized and balanced between the sessions and consumers, and the order of sample presentation was randomized and balanced among the consumers. For the blindfolded session, the consumer was briefed on the 9-point hedonic scale and its use prior to sample tasting. An individual handed the sample cup to the consumer and then went through the ballot questions for each sample and recorded responses on paper ballots. For samples presented under white light (no blindfold), Compusense was used for data collection. Subjects were given ambient temperature deionized water to cleanse their palates between samples. A 3 min rest period was enforced between samples.

Participants were asked to evaluate color liking (no blindfold only), overall liking, texture liking and flavor liking for each sample. All liking attributes were evaluated on a 9-point hedonic scale where 9 was anchored with "like extremely" and 1 was anchored with "dislike extremely." Subjects received food treats and a $5 gift certificate for their participation.

Statistical Analysis

Descriptive Analysis. ANOVA was performed on the descriptive analysis data with means separation conducted using Fisher's least square difference on XLSTAT version 2009 (Addinsoft, Paris, France). Principle component analysis (PCA) using the correlation matrix was also applied to the descriptive data to visualize how products were differentiated across sensory attributes (XLSTAT version 2009, 1995–2009). Varimax rotation was performed on the PCA with two factors in order to more clearly demonstrate the direction of product differentiation.

Consumer Acceptance. Consumer liking scores (overall liking, flavor liking, texture liking) were subjected to ANOVA using Proc Glimmix (version 9.2, SAS, Cary, NC) with least square means used for means separation to investigate the effect of treatment, blindfold and (treatment × blindfold) interaction on overall, flavor and texture liking. The effect of blindfold and treatment were used as fixed effects while panelists were designated as random effects.

Prior to external preference mapping (PREFMAP), clustering (segmentation) of consumers was performed on no blindfold and blindfolded data separately with agglomerative hierarchical clustering using a dissimilarity matrix with Euclidean distance with Ward's method used in the agglomeration (XLSTAT). ANOVA was performed on these overall liking scores using Proc Glimmix with least squared means used for means separation as previously described. Cluster and treatment were designated fixed effects and consumers were designated random effect.

External PREFMAP was conducted using a circular model on blindfolded and no blindfolded clusters. The factor scores on the first two components of the PCA with varimax rotation derived from descriptive analysis were used as the X configuration. The clusters derived from no blindfold and blindfold data were used as preference data (Y). It is common to perform PREFMAP on the first two PCS as a greater number of factors included increase the complexity of interpretation (McEwan 1996; Lawless and Heymann 1998).

RESULTS AND DISCUSSION

Instrumental Color

Instrumental color measurements are summarized in Table 1.

Descriptive Analysis

The sensory attributes identified included 3 appearance attributes, 8 texture attributes and 16 aroma, flavor and basic taste attributes (Table 2). The lexicon differentiated the sweet potatoes (Table 3; Fig. 1). The differentiation for many terms was pronounced between different color cultivars with some variations in cultivars within the same color. For some terms, the differentiations were based solely on the cultivars with no particular association to flesh color. For appearance, all orange sweet potatoes, two of the purple sweet potatoes (samples 5 and 6) and a yellow sweet potato, sample 11, had high color homogeneity compared with other yellow and purple sweet potatoes (samples 7 and 8). Orange sweet potatoes had higher visual surface moisture compared with other colored sweet potatoes ($P < 0.05$), whereas purple sweet potatoes had higher visual fibrousness compared with other

TABLE 1. SWEET POTATO INSTRUMENTAL COLOR MEASUREMENTS

Sample	Cultivar	Flesh color	Color		
			*L**	*a**	*b**
1	Beauregard	Orange	58.3	23.2	61.6
2	Covington	Orange	58.8	23.4	65.2
3	Hernandez	Orange	54.0	27.5	69.2
4	Carolina Ruby	Orange	59.5	21.4	59.7
5	NC 414	Purple	15.3	19.7	−12.1
6	NC 415	Purple	15.9	17.1	−11.7
7	Okinawa	Purple	28.6	11.7	−11.8
8	Purple 04-069	Purple	19.4	21.7	−12.3
9	Japanese	Yellow	75.9	−0.4	21.9
10	Puerto Rican	Yellow	54.8	12.3	56.9
11	O-Henry	Yellow	63.5	−5.6	39.2
12	DM02-180	Yellow	64.0	−1.5	25.5

Color measurement: $L*$ (lightness, 0 for black, 100 for white), $a*$ ($-a* =$ greenness, $+a* =$ redness) and $b*$ ($-b =$ blueness, $+b =$ yellowness).

colored cultivars. Sweet potatoes were also different in texture attributes. Purple sweet potatoes were perceived as more firm, dense, less moist and higher in chalkiness compared with other colored cultivars ($P < 0.05$). Yellow sweet potatoes 9 and 12 had similar textural characteristics to the purple sweet potatoes. Orange sweet potatoes were scored lowest in firmness, denseness, chalkiness and moistness compared with other colored cultivars, with yellow sweet potato 10 also having similar texture characteristics.

Orthonasal aroma and flavor also differentiated the samples. Most of the cultivars with orange and purple color had higher overall aroma and brown sugar aroma compared with yellow sweet potatoes except for yellow sweet potato 10. Orange sweet potatoes were characterized by distinct intensities of canned carrot aroma and flavor and dried apricot/floral aroma and flavor ($P < 0.05$). Purple sweet potatoes were characterized by high vanilla aroma. All purple sweet potatoes and yellow sweet potatoes 9 and 12 were characterized by high (white) potato flavor and white baked potato flavor. Brown sugar flavor was a term that was different for individual cultivars and was not distinct between different colors. For basic tastes, orange and purple sweet potatoes were characterized by some sour taste. All of the sweet potatoes were sweet tasting, with samples 6 and 8 less sweet than other samples. Sweet potatoes 5, 6 and 8 had some bitter and umami characteristics, and all of the potatoes were astringent to some degree.

Principal component (PC) 1 explained 48% of the total variability, while PC2 explained 28% of the total variability (Fig. 1). A combination of attributes derived from texture, aroma, visual, basic tastes and flavor terms were loaded on each PC and suggests that sweet potatoes were differentiated by a combination of sensorial modalities. Texture terms fibrousness, moistness and residual fiber; flavor terms earthy/

TABLE 2. SENSORY ATTRIBUTES OF SWEET POTATO CULTIVARS

Term	Definition	Reference
Visual		
Color homogeneity	Degree of evenness of color	2005 Beauregard:8–9; 2005 NC 414:5–6
Moisture	Degree of surface moisture	2005 Beauregard:7; 2005 NC 414:4.5
Fibrousness	Amount of stringy fibers present	2005 Beauregard:2; 2005 NC 414:3.5
Texture in mouth		
Firmness	Amount of force necessary to compress the sample fully between the tongue and the palate	2005 Beauregard:4; 2005 NC 414:8
Denseness	Degree to which the sample is solid; compactness of the cross section	2005 Beauregard:4; 2005 NC 414:8
Moistness	Degree to which the sample is moist	2005 Beauregard:8; 2005 NC 414:4
Smoothness	Smoothness of chewed mass	2005 Beauregard:8; 2005 NC 414:7
Cohesiveness	Degree to which sample holds together after chewing	2005 Beauregard:7; 2005 NC 414:8
Fibrousness	Amount of stringy fibers perceived	2005 Beauregard:5; 2005 NC 414:3
Residual fiber	Amount of stringy fibers perceived after swallowing	2005 Beauregard:2; 2005 NC 414:3
Chalkiness	Degree to which the mouth feels chalky, like raw potato, very fine particles, often perceived on the roof of the mouth	2005 Beauregard:0; 2005 NC 414:4.5
Aromatics		
Overall	The overall orthonasal aroma impact	
Brown sugar	Aromatic associated with brown sugar	Dixie Crystals dark brown sugar
Potato	Aromatic associated with white baked potato	Methional, 100 ppm
Earthy/canned carrot	Earthy aromatic associated with canned carrot	Canned carrots, Harris Teeter brand
Dried apricot/floral	Floral aromatics associated with dried apricot	Sun Maid mediterranean dried apricots
Vanilla	Aromatics associated with vanilla and vanillin	Marshmallow fluff
Flavor in mouth		
Brown sugar	In-mouth aromatic associated with brown sugar	Dixie Crystals dark brown sugar
Earthy/canned carrot	In-mouth earthy aromatic associated with canned carrot	Canned carrots, Harris Teeter brand
Dried apricot/floral	In-mouth floral aromatics associated with dried apricot	Sun Maid mediterranean dried apricots
White baked potato	In-mouth aromatic associated with white baked potato	Baked russet potato
Vanilla	In-mouth aromatic associated with vanilla and vanillin	Marshmallow fluff
Sour taste	Basic taste stimulated by acid	0.05% citric acid in distilled, deionized water = 2 intensity
Sweet taste	Basic taste stimulated by sugar	2 and 5% sucrose in distilled, deionized water = 2 and 5 intensity, respectively
Bitter taste	Basic taste associated with caffeine	0.05% caffeine in distilled, deionized water = 2 intensity
Umami	Basic taste associated with monosodium glutamate	0.5% MSG in distilled, deionized water = 3 intensity
Astringent	Sensation of drying, drawing and/or puckering of any of the mouth surfaces	0.02% alum in distilled, deionized water

NC, North Carolina; MSG, monosodium glutamate.

canned carrots, dried apricot/floral; aroma terms earthy/canned carrots, dried apricot/floral, brown sugar and overall aroma; visual terms moisture and color homogeneity; and sour taste (basic taste) were positively loaded on PC1, while the texture terms chalkiness, firmness, denseness; flavor terms vanilla and white baked potato; and aroma term potato were highly negatively correlated on PC1. For PC2, the basic tastes bitter, umami, astringent mouthfeel, visual fibrousness, vanilla aroma and residual fiber were positively correlated, and sweet taste, brown sugar and smooth texture were negatively correlated.

Orange sweet potato cultivars (samples 1–4) were loaded on the positive PC1 coordinate and were characterized by fibrousness, moistness and residual fiber texture earthy/canned carrots, dried apricot/floral flavor and aromas, brown sugar aroma, high overall aroma and visually moist, high color homogeneity and sour taste. These potatoes were not chalky, firm or dense, lacked or were low in white baked potato flavor and aroma and vanilla flavor. Purple sweet potatoes (samples 5–8) also grouped together on the top left quadrant of the PCA biplot, however, not as tightly as the orange cultivars. These potatoes were chalky, dense and firm in texture and were also characterized by white baked potato flavor and aroma and vanilla aroma. Samples 5, 6 and 8 were bitter and astringent. Yellow potato cultivars samples 9–12 were loaded on the negative PC2 coordinate. Thus, these potatoes were characterized by sweet taste, brown sugar and dried apricot flavor and smooth texture. They were also not bitter, umami, astringent, had low or no vanilla aroma and were low in residual fiber and visual fibrousness. Sample 10 (yellow Puerto Rican cultivar) was more similar to orange cultivars (samples 1–4).

TABLE 3. DESCRIPTIVE ANALYSIS MEAN SCORES FOR ALL SWEET POTATO CULTIVARS

	Sample											
	1O	2O	3O	4O	5P	6P	7P	8P	9Y	10Y	11Y	12Y
Visual												
Color homogeneity	8.3a	7.5b	8.7a	7.2b	8.5a	8.5a	4.1e	4.6e	4.7de	5.3cd	7.5b	5.8c
Moistness	7.1a	6.5b	6.2bc	6cd	6cde	5.5f	4.1gh	3.7h	4.5g	5.6def	5.5ef	4.3g
Smoothness	1.9d	2.2bcd	2.3bcd	2.1bcd	3.1a	3.1a	2.6ab	3.1a	2.3bcd	2.5bc	2.1cd	1.2e
Texture in mouth												
Firmness	4.2f	3.8f	4.1f	4.9e	6.2c	7.3b	6.4c	8.6a	8.3a	4.8e	5.5d	7.5b
Denseness	4.2g	3.9g	4.2g	5f	6.8e	7.5cd	7de	8.5a	8.2ab	5f	5.4f	7.7bc
Moistness	7.1ab	7.6a	7.1ab	6.7bc	5.6d	4.8e	4.9e	3.6f	4f	6.4c	6.2c	4.9e
Smoothness	7.9ab	7.7abcd	7.8abc	7.3cd	7.8ab	6.6e	8.1a	6f	6.4ef	8.1ab	7.2d	7.6bcd
Cohesiveness	7.2def	6.6g	7.1efg	7efg	8.2ab	7.7bcd	8.4a	6.8fg	6.9fg	7.4cde	6.9fg	7.8bc
Fibrousness	3bc	3.4ab	4a	4.1a	2.3cd	3.2b	2.2d	2.4cd	1.8de	3.4ab	2.4cd	1.2e
Residual fiber	1.6cde	1.6cde	2abc	2.4ab	1.3def	2.5a	1.4def	1.9bc	0.9fg	1.7cd	1.1efg	0.6g
Chalkiness	0.7e	0.9e	0.5e	0.9e	2.5bcd	2.8bc	2.1cd	3.6a	2.9ab	0.9e	1.8d	2.6bc
Aromatics												
Overall	3.3ab	3.3abc	3.5a	3.2abcd	3.1bcde	3de	3cde	2.9e	2.9e	3cde	2.9e	2.9e
Brown sugar	1.8ab	1.7ab	1.7ab	1.8ab	1.8ab	1.5bc	1.8ab	1.6bc	1.1de	1.9a	1.3cd	0.8e
Potato	0.8c	1.1c	0.8c	1.1c	1.8b	1.6b	1.8b	1.8b	2.2a	0.9c	1.8b	2.4a
Earthy/canned carrot	1.9a	2.0a	2.3a	2.0a	0.6e	0.7e	1e	0.7e	1.1d	1.5b	1.1c	0.8e
Dried apricot/floral	1.6a	1.5a	1.6a	1.2ab	0.7c	0.7c	0.9bc	0.6c	0.8bc	1.5a	1.3a	0.6c
Vanilla	ND	ND	ND	ND	2.1a	1.7b	1.8b	1.9ab	0.5c	0.5c	ND	ND
Flavor in mouth												
Brown sugar	1.9cd	2.0bc	2.0bc	1.7cde	1.9bcd	1.5ef	2.2ab	1.4f	1.8cd	2.5a	1.6def	1.8cd
Earthy/canned carrot	2.1a	2.2a	2.2a	2.2a	0.6c	0.8c	0.7c	0.5c	1.4b	1.5b	1.5b	0.5c
Dried apricot/floral	2.4a	2.4a	2.3ab	2.0bc	1.0d	1.0d	1.3d	ND	1.7c	2.2ab	1.8c	2.0bc
White baked potato	0.5e	0.6e	ND	0.9e	2.2bcd	2.3bcd	2.0d	2.5ab	2.7a	1.0e	2.1cd	2.4bc
Vanilla	1.8a	1.7ab	1.4bc	1.2c	0.7d	0.7d	0.7d	0.5d	ND	ND	ND	ND
Sour taste	1.4a	1.0ab	1.0ab	1.0ab	1.1ab	1.1ab	0.8b	ND	ND	ND	ND	ND
Sweet taste	5.2cd	5.4cd	5.4cd	4.5e	5.0cde	3.5f	5.3cd	3.5f	5.5bc	6.5a	5.1de	6.1ab
Bitter taste	ND	ND	ND	ND	1.0c	1.9a	ND	1.4b	ND	ND	ND	ND
Umami	ND	ND	ND	ND	ND	1.3a	ND	1.2a	ND	ND	ND	ND
Astringent mouthfeel	1.3cd	1.3cd	1.0d	1.4cd	2.4a	2.3ab	1.8bc	2.2ab	1.6cd	1.5cd	1.4cd	1.6cd

Means in a column not followed by a common letter are statistically different ($P < 0.05$). Intensities were generated on a 0- to 15-point scale using the Spectrum method. Visual and texture terms were scored using a product specific scale; aromas and flavors were scored using a universal intensity scale. Cultivar numbers refer to Table 1.

O, orange sweet potato; P, purple sweet potato; Y, yellow sweet potato; V, visual; A, aroma; F, flavor in mouth; T, texture in mouth.

Consumer Acceptability

Consumer overall liking, flavor liking and texture liking means for sweet potatoes evaluated under blindfolded and no blindfolded conditions are shown in Table 4. There were significant blindfold effects ($F = 4.44$, $P < 0.05$) treatment effects ($F = 65.57$, $P < 0.0001$) and (blindfold × treatment) interactions ($F = 1.96$, $P < 0.05$) for overall liking scores (Table 4). The significant interaction between blindfold or no blindfold that were significant in samples 3 and 12 ($P < 0.05$) suggests that consumers scored these treatment differently when they were allowed to see the samples compared with when they were not allowed to see the samples. When presented without blindfold, the overall liking score of these two samples increased ($P < 0.05$). For flavor liking, there were significant main effects for blindfold ($F = 11.22$, $P < 0.05$) and treatment ($F = 76.88$, $P < 0.0001$) but no significant interac-

tion ($P > 0.05$), which suggests that blindfolding did not impact flavor liking. Similarly, with texture liking, significant blindfold and treatment effects were observed ($F = 5.13$, $P < 0.05$; $F = 36.58$, $P < 0.0001$) but no interaction effect ($P > 0.05$). Color was evaluated only without a blindfold. There was a significant treatment effect for color ($F = 34.33$, $P < 0.05$). Orange sweet potatoes (the most common type encountered in the U.S.A.) received higher appearance liking scores compared with yellow or purple cultivars.

Blindfolding only impacted overall liking of cultivars 3 and 12. These samples received higher overall liking scores when no blindfold was present (Table 4). Sample 3 received a high score for color liking (orange cultivar) and the typical and liked color may have contributed to its higher overall liking scores when evaluated without a blindfold. Interestingly, the color of sample 12 was less liked by consumers compared with other sweet potatoes ($P < 0.05$), but when presented with no
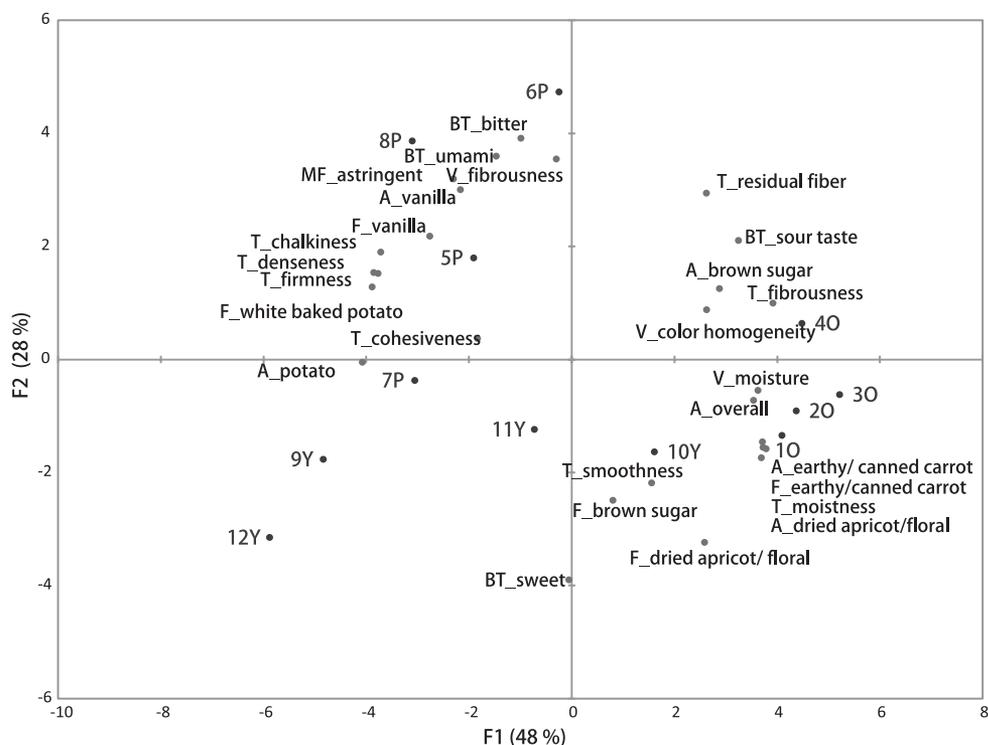
FIG. 1. PRINCIPLE COMPONENT ANALYSIS WITH A TOTAL OF 76% VARIABILITY OF ALL DESCRIPTIVE TERMS EXPLAINED WITH VARIMAX ROTATION (ON TWO FACTORS) FOR ALL SAMPLES

Color abbreviations O, P and Y next to sample numbers stand for orange, purple and yellow sweet potatoes, respectively. Abbreviations before attributes: V, visual; A, aroma; F, flavor; T, texture; BT, basic taste; MF, mouthfeel. Numbers are sample numbers (Table 1).

TABLE 4. CONSUMER LIKING SCORES FOR ALL SWEET POTATO CULTIVARS EVALUATED WITH AND WITHOUT A BLINDFOLD ($n = 90$)

Sample	Overall liking		Flavor liking		Texture liking		Color liking
	Blindfold	No blindfold	Blindfold	No blindfold	Blindfold	No blindfold	No blindfold
1O	6.1cde	6.4abc	6cdef	6.4bcd	6.2abcd	6bcd	7.1a
2O	6.2bcd	6.4abc	6.3bcd	6.4bcd	5.9cdef	6cde	7.1a
3O	**5.3ghi**	**5.9cdef**	5.1ij	5.7ef	5.3fghi	6bcd	7.0a
4O	6cde	6.1cde	5.9cdef	6.1bcde	5.9cde	6cde	7.0a
5P	5.1hij	4.8j	4.7j	4.6j	5.3fghi	5.4fefgh	5.8b
6P	3.7k	3.4kl	3.2k	3k	4.2kl	4.3jk	5.5b
7P	5.1hij	4.9ij	5.1hij	5.1ghij	5.1hi	5.3ghi	4.0d
8P	3.1l	3.5kl	2.9k	3.3k	3.2m	3.7lm	5.4b
9Y	5.3ghi	5.7efg	5.6efgh	6cdef	4.8ij	5hi	4.9c
10Y	6.7ab	6.9a	6.6ab	7ab	6.6ab	6.8a	4.8b
11Y	5.9cdef	5.8defg	5.5fghi	5.7efg	6.4abc	5.8cdefg	5.4bc
12Y	**5.5fgh**	**6.3bdc**	5.9def	6.6ab	4.9hi	5.8defg	4.4d
Blindfold	$F = 4.44$, $P < 0.05$		$F = 11.22$, $P < 0.05$		$F = 5.13$, $P < 0.05$		n/a
Treatment	$F = 65.57$, $P < 0.05$		$F = 76.88$, $P < 0.0001$		$F = 36.58$, $P < 0.0001$		$F = 34.33$, $P < 0.05$
Blindfold × treatment	$F = 1.96$, $P < 0.05$		$F = 1.07$, $P > 0.05$		$F = 1.69$, $P > 0.05$		n/a

Means in a row and a column for each liking attribute not followed by a common letter are significantly different ($P < 0.05$). Overall, flavor, texture and color liking were scored on a 9-point hedonic scale. Bolded means demonstrate treatments with significant (treatment × blindfold) interaction ($P < 0.05$). Cultivar numbers refer to Table 1.

O, orange sweet potato; P, purple sweet potato; Y, yellow sweet potato; n/a, not applicable (color liking was evaluated only without blindfold).

blindfold, this sample was more liked compared to with a blindfold. There were no (treatment × blindfold) interactions with other samples ($P > 0.05$). Yellow sweet potato 10 and orange sweet potato samples 1, 2, 4 received the highest overall liking, flavor and texture liking scores with and without blindfold followed by yellow sweet potato 11. Purple sweet potatoes 5, 7 and yellow sweet potato 9 were not as well liked; however, purple sweet potatoes 6 and 8 were least liked in all terms (overall, flavor and texture). For color liking, consumers liked orange sweet potatoes the most (samples 1–4), possibly because of the familiarity of orange color that is associated with sweet potatoes.

Descriptive analysis results documented that the yellow Puerto Rican sweet potato cultivar (sample 10) had similar sensory characteristics (other than color) to orange sweet potato cultivars 1–4 (Fig. 1). Sample 10 was similar in overall liking to samples 1, 2 and 4, which suggests that consumers liked this product based on its sensorial characteristics and that differences in color (yellow versus orange) did not impact liking even though the color was not as well liked as typical orange-colored cultivars. There were no significant differences in the overall liking, flavor liking or texture liking of sample 10 when evaluated with and without blindfolding. This suggests that if the gustatory and olfactory sensory characteristics were well liked, visual appearance did not play a large role or that appearance was within an accepted context or range for this product. However, if the flavor and texture were not liked (sample 3) by consumers, appearance liking improved the overall liking scores (overall, flavor and texture) of the product ($P < 0.05$).

A purple sweet potato (Okinawa cultivar sample 7) had similar flavor and texture characteristics to yellow cultivars 9 and 12 (Fig. 1 and Table 3), and these sweet potatoes received the same liking scores when evaluated with a blindfold (Table 4). However, without the blindfold, the overall liking and flavor liking of these samples were different ($P < 0.05$) (Table 4). Without blindfolding, sample 12 received the highest overall and flavor liking score of the three samples followed by sample 9 and sample 7. In this case, the vastly different and unexpected purple color of sample 7 may have contributed to its low liking score compared with the more familiar (but still unexpected) yellow color of the other two cultivars.

Cluster Analysis

Cluster analysis was performed on the overall liking scores derived from when consumers were allowed to visualize the samples (no blindfold) (Table 5). Three preference segments were found: cluster 1 no blindfold cluster (C1-NB) consisted of 58 consumers, cluster 2 (C2-NB) consists of 23 consumers and cluster 3 (C3-NB) consisted of 9 consumers. As the number of consumers in C3-NB was small, further investigation on individuals within this data set was conducted. Upon investiga-

TABLE 5. CONSUMER OVERALL LIKING MEANS FOR EACH CLUSTER DERIVED FROM LIKING EVALUATIONS WITH NO BLINDFOLD

Sample	C1 (*n* = 58)	C2 (*n* = 23)	C3* (*n* = 9)
1O	6.6bc	5.9cdef	6.1
2O	7.1ab	4.9gh	6.0
3O	6.3bcde	5.4fg	4.7
4O	6.5bcd	5.3fg	5.9
5P	4.8gh	5.8def	2.4
6P	2.8i	4.9gh	3.9
7P	4.4h	7.0ab	2.8
8P	2.8i	5.0fgh	4.2
9Y	4.9gh	7.0ab	7.3
10Y	7.1ab	7.1ab	5.2
11Y	5.8ef	5.6ef	6.6
12Y	5.5f	7.7a	7.7

Means in a row and a column not followed by a common letter are significantly different ($P < 0.05$).
* C3 represents only nine consumers; therefore, analysis of variance could not be performed on this small sample size.
O, orange sweet potato; P, purple sweet potato; Y, yellow sweet potato; C1, cluster 1 (*n* = 58); C2, cluster 2 (*n* = 23); C3, cluster 3 (*n* = 9).

tion, these individuals did not have similar characteristics to each other but also did not have the same characteristics as the C1-NB and C2-NB. Thus, this suggests that this cluster is composed of distinct consumers and these differences may be derived from their demographics or other factors that were not evaluated in this study. The means of this cluster are reported; however, further analysis was not performed on this cluster because of small number. The overall liking means of C1-NB consumers were higher for orange sweet potatoes (samples 1, 2, 3, 4) compared with C2-NB consumers. C2-NB had higher overall liking scores for purple sweet potatoes compared with C1-NB consumers although the liking scores in general were low compared with other sweet potato cultivars.

Cluster analysis was also performed on the consumer data under blindfolded conditions (Table 6). Consumer clusters found with blindfolding (when consumers could not visually perceive the products and only scored based on gustatory/ olfactory liking responses) were slightly different compared with the no blindfold clusters (when consumers were allowed to visualize and evaluate products using all the senses). Seven out of the nine consumers that were assigned to C3-NB because of discrete liking patterns in no blindfold data was assigned to cluster 3 in blindfolded data. This suggests that appearance greatly impacted the liking scores of those consumers. Cluster 1 blindfolded cluster (C1-B) consisted of 41 consumers, cluster 2 (C2-B) consisted of 19 consumers and cluster 3 (C3-B) consisted of 30 consumers. Similar to C1-NB, consumers in C1-B liked sample 1, 2, 3, 4 and 10. These samples were loaded close to each other on the PCA (Fig. 1), which suggests that both of these clusters (C1-NB and C1-B) were not influenced by the color of the potatoes and that other sensorial characteristic played a major role in overall liking (flavor,

TABLE 6. CONSUMER OVERALL LIKING MEANS FOR EACH CLUSTER DERIVED FROM LIKING EVALUATIONS WITH A BLINDFOLD

Sample	C1 (*n* = 41)	C2 (*n* = 19)	C3 (*n* = 30)
1O	6.9ab	6.4bcde	4.7hij
2O	6.8abc	7.2ab	4.8ghij
3O	6.4bcde	4.5ij	4.4j
4O	6.6abcd	5.7efg	5.3fghi
5P	4.4j	6.6abcde	5.3fghi
6P	3.1k	4.2j	4.1j
7P	4.3j	5.9def	5.8ef
8P	2.6k	3k	4.1j
9Y	4.7ij	4.4ij	6.7abcd
10Y	7.3a	4.7hij	6.5bcde
11Y	5.8ef	6.8abcd	5.6fgh
12Y	4.3j	6cdef	6.8abc

Means in a row and a column not followed by a common letter are significantly different (*P* < 0.05).
O, orange sweet potato; P, purple sweet potato; Y, yellow sweet potato; C1, Cluster 1 (*n* = 41); C2, cluster 2 (*n* = 19); C3, cluster 3 (*n* = 30).

texture, taste). However, the moisture and color homogeneity of these samples may be factors influencing C1-NB as these samples were characterized by high visual color homogeneity and visual moisture and were components of appearance that would be obscured when evaluated with no blindfold. Con-

sumers in C2-B liked samples 1, 2, 5, 11. These samples were projected on different spaces within the PCA (Fig. 1); however, examination of mean scores suggested that these samples were similar in high smoothness, low residual fiber, brown sugar flavor and sweet taste. These attributes may contribute to liking for this cluster. C3-B consumers liked samples 9 and 12 more than other clusters and disliked orange sweet potatoes 1–4 the most out of all clusters. Samples 9 and 12 were characterized by smoothness, brown sugar, dried apricot and sweet taste. This cluster liked firm, dense and chalky texture and white potato and vanilla flavor. Interestingly, when panelists were blindfolded, no clusters had obviously higher liking scores for purple potatoes (samples 5–8), whereas with no blindfold, C2 consumers did have higher liking scores for purple cultivars compared with C1 consumers. This result suggests that unique and uncommon color may positively impact overall liking for some consumers.

External PREFMAP

External PREFMAP were performed on the descriptive analysis map with varimax rotation (X configuration) and the overall liking means of clusters with (Fig. 2) and without
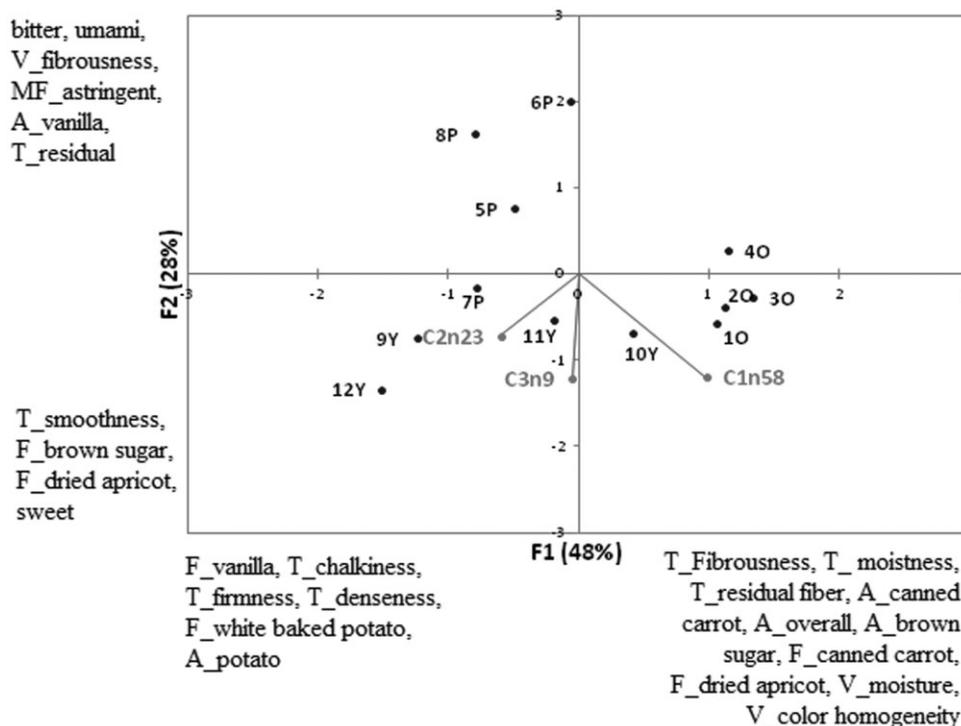

FIG. 2. EXTERNAL PREFERENCE MAPPING ON CLUSTERS DERIVED FROM EVALUATION OF SAMPLES WITH NO BLINDFOLD
Color abbreviations O, P and Y next to sample numbers stand for orange, purple and yellow sweet potatoes, respectively. C1n58 – cluster 1 (*n* = 58), C2n23 – cluster 2 (*n* = 23), C3n9 – cluster 3 (*n* = 9). Attributes on the plot are important attributes highly loaded on F1 and F2. Abbreviations before attributes: V, visual; A, aroma; F, flavor; T, texture; MF, mouthfeel. Numbers are sample numbers (Table 1).
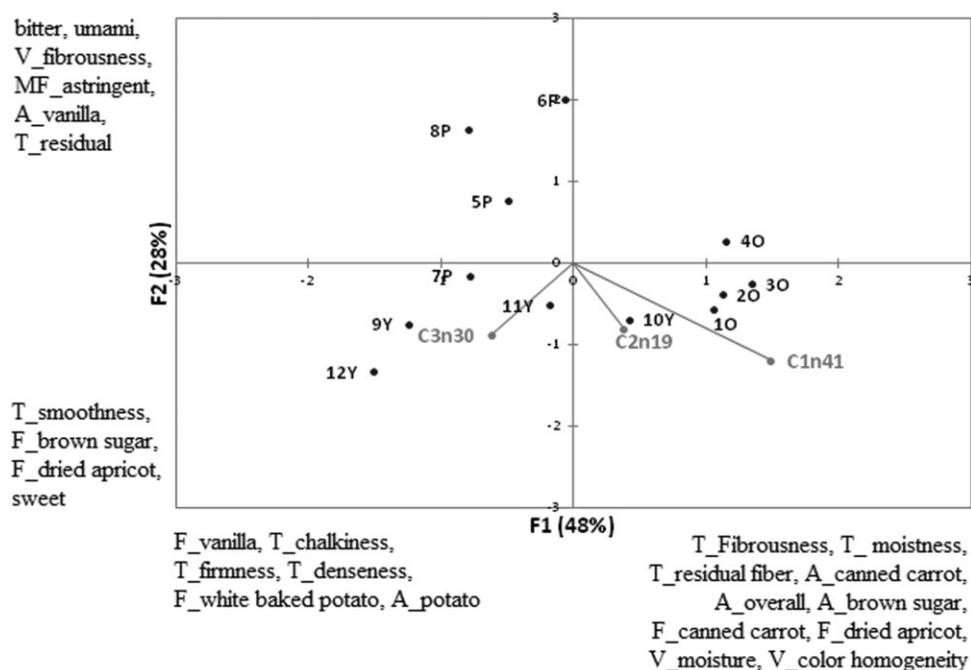
FIG. 3. EXTERNAL PREFERENCE MAPPING ON CLUSTERS DERIVED FROM EVALUATION OF SAMPLES WITH A BLINDFOLD
Color abbreviations O, P and Y next to sample numbers stand for orange, purple and yellow sweet potatoes, respectively. C1n41 – cluster 1 (n = 41),
C2n19 – cluster 2 (n = 19), C3n30 – cluster 3 (n = 30). Attributes on the plot are important attributes highly loaded on F1 and F2. Abbreviations before
attributes: V, visual; A, aroma; F, flavor; T, texture; MF, mouthfeel. Numbers are sample numbers (Table 1).

(Fig. 3) blindfolding (Y). Both maps showed that the drivers of liking for all clusters were in the negative PC2 axis. This suggests that for all consumers and clusters, whether or not they were allowed to visually perceive the products, smooth texture, brown sugar and dried apricot flavor and sweet taste were the main drivers of liking for sweet potatoes, while bitter and umami tastes, astringent mouthfeel, vanilla aroma and residual fiber texture were negative attributes. In general, drivers of liking were similar for the different consumer clusters under blindfolded or no blindfold conditions. Drivers of liking for C1-NB and C1-B consumers were smooth, fibrous and moist texture, sweet flavors (brown sugar, dried apricot/floral, canned carrot) and sweet and sour taste. C2-NB and C3-B consumers were similar and liked smooth and firm texture, white potato flavor and other sweet flavors (vanilla, brown sugar, dried apricot). C2-B, a minor proportion of overall consumers (n = 19), were smooth texture, sweet flavors, sweet taste likers.

For both external maps, the clusters were differentiated on the PC1 axis. Figure 2 shows external PREFMAP of overall liking means of no blindfold consumer clusters. Overall liking of C1-NB (n = 58), the majority of consumers, was driven by fibrousness, moistness, residual fiber texture, earthy/canned carrot and dried apricot/floral flavor and aroma, brown sugar aroma, and moisture and color

homogeneity appearance. These panelists disliked chalky, firm and dense texture, white baked potato flavor/aroma and vanilla flavor. As previously stated, these consumers liked orange sweet potatoes (1–4) as well as sample 10 (yellow sweet potato). C2-NB (n = 23) consumers were driven by opposite attributes from C1-NB consumers. This cluster preferred chalky, firm, dense texture and liked the white potato flavor/aroma and vanilla flavor. This cluster liked yellow sweet potatoes 9 and 12 and purple sweet potato 7.

External PREFMAP of BF clusters showed similar results (Fig. 3). Again, the C1 group contained the highest percentage of consumers and similar drivers of liking to C1-NB consumers; however, the percentage of consumers in C1 decreased for the blindfolded group and rearrangement of cluster assignments were observed (results not shown) suggesting that visual perception had an impact on liking for many if not all consumers. C2-B (n = 19) was the smallest cluster out of the three blindfolded consumer clusters and liked similar attributes to C1-B consumers with altered sensorial intensity. C3-B (n = 30) consumers were similar to C2-NB (n = 23) consumers and were driven by attributes opposite to C1-NB consumers (chalky, firm, dense texture and white baked potato flavor/aroma and vanilla flavor).

CONCLUSIONS

The sensory characteristics of sweet potato cultivars with varying flesh colors were differentiated by descriptive analysis and consumer acceptance. Orange potatoes were characterized by fibrousness, moistness and residual fiber texture, earthy/canned carrot, dried apricot/floral flavor and aroma, brown sugar aroma and visually moist, high color homogeneity and sour taste. Purple sweet potatoes were characterized by chalky, dense and firm texture and also characterized by white baked potato flavor/aroma and vanilla aroma. All purple sweet potatoes appeared more fibrous visually compared with other samples. Yellow sweet potato cultivars were characterized by sweet taste, brown sugar and dried apricot flavor and smooth texture. However, some of these potatoes (yellow Puerto Rican cultivar) had similar characteristics to orange cultivars, and Japanese and DM02-180 yellow sweet potato cultivars were more similar in sensory characteristics to Okinawa purple potato sample 7.

The overall liking of sweet potatoes was driven by flavor liking followed by texture liking. The lack of blindfold positively impacted consumer acceptance for two samples that were distinct in color (orange and yellow) with high and low color liking scores, respectively. This suggests that color liking may not be a major driver of overall acceptance. Main drivers of liking of the two conditions where appearance was visible or not visible were similar, but the cluster assignments were different. For all clusters, whether or not they were allowed to perceive the products or not, smooth texture, brown sugar and dried apricot flavor and sweet taste were the main drivers of liking for sweet potatoes, while bitter, umami, astringent mouthfeel, vanilla aroma and residual fiber texture were negative attributes for all consumers. The general characteristics for purple sweet potatoes, visually, texturally and flavor-wise were not drivers of liking for consumers. This study demonstrated that sweet potatoes with unfamiliar colors were accepted by consumers as long as the other sensorial characteristics (flavor, texture, aroma and basic taste) were well liked. In an effort to increase the consumption of sweet potatoes, the sweet potato industry should advertise the health benefits of new flesh color sweet potatoes (purple or yellow) while maintaining desirable flavor and texture characteristics such as smooth texture, brown sugar, dried apricot and sweet taste and minimizing undesirable attributes bitter, umami, astringent mouthfeel and residual fiber texture.

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