Preference mapping and rheological properties of four nopal (*Opuntia* spp.) cultivars

Ayne O. Calvo–Arriaga[1], Arturo Hernández–Montes[1*], Cecilia B. Peña–Valdivia[2], Joel Corrales–García[1] and Eleazar Aguirre–Mandujano[1]

[1]Universidad Autónoma Chapingo, km 38.5 carretera México–Texcoco, CP 56230, Estado de México. México
[2]Botánica, Colegio de Postgraduados, km 36.5 carretera México–Texcoco, CP 56230, Estado de México. México

*Corresponding author, e–mail: sensorial@prodigy.net.mx

Received 20th January, 2010; Accepted 7th December, 2010

Abstract

The aim of this study was to identify the sensory characteristics that drive the preference of nopalitos consumers. Nopalitos from the cultivars Milpa Alta, COPENA F1, COPENA V1 and Tovarito (*Opuntia ficus–indica*), which are commercially important in Mexico, were physical, chemical and sensory characterized to explain their acceptability by consumers. The rheological behavior of aqueous dispersions made from the mucilage of each one of the four nopal cultivars was evaluated. Color, firmness, moisture, titratable acidity and mucilage content were measured in fresh nopalitos. Frequency sweeps and flow curves of the mucilage dispersions were done. A descriptive analysis and an acceptability test were carried out with cooked nopalitos. The heterogeneity of the four nopal cultivars stood out. Significant differences were found among cultivars for seven physical and chemical characteristics (lightness, saturation index, hue angle, cuticle firmness, firmness within the tissue, moisture and titratable acidity), for their plastic viscosity, important variable of rheological behavior, and for 12 sensory attributes (lightness, moist appearance, visual sliminess, green odor, elasticity, firmness, sourness, saltiness, green flavor, leatheriness, chewiness and sliminess in mouth). Milpa Alta, COPENA F1 and Tovarito cultivars were similarly accepted by consumers, whereas COPENA V1 had less acceptability. It was concluded that nopalitos acceptance can be predicted based on their physical, chemical and sensory attributes; moreover, that textural and visual characteristics were the variables with major influence on acceptability.

Keywords: descriptive analysis, mucilage, acceptability, rheology.

Introduction

In Mexico, it is called nopal to the plants of the genus *Opuntia*, *Cactaceae* family. Such genus includes 11 subgenera (*Opuntia*, *Consolea*, *Austrocylindropuntia*, *Brasiliopuntia*, *Corynopuntia*, *Cylindropuntia*, *Grusonia*, *Marenopuntia*, *Nopalea*, *Stenopuntia* and *Tephrocactus*), 300 species and their variants (Scheinvar, 1995). The species most utilized as vegetable are: *O. ficus–indica*, *O. robusta*, *O. leucotricha* and *N. cochenillifera*. The part of the cactus consumed as vegetable is the young, soft and flattened stem, known as cladode, nopalito o nopal verdura (Sáenz–Hernández *et al*., 2002).

Mexico is one of the centers of origin and diversification of nopal, and counts with almost 300 cultivars, of which approximately 50 are consumed as nopalito (Gallegos–Vázquez *et al*., 2006). In this country, nopalito is the sixth vegetable of major consumption with 6.36 kg annual per capita (Silva–Vale, 2006). The consumption of nopalito in Mexico is traditional and it has been increased in the last years because of the functional properties attributed to it: hypoglucemiant effect (Frati–Munari *et al*., 1988; Bwititi *et al*., 2000; Yang *et al*., 2008), hypocholesterolemic, anti–inflammatory, antiulcer and healing activity (Trovato *et al*., 2005); besides improve digestion, and clean the colon, among others (Sáenz *et al*., 2004).

The nutritional value of nopalitos is comparable to that of lettuce and spinaches, but the former have the advantage of being produced in abundance by plants that grow up in climates with high temperatures and limited water, conditions generally unfavorable for vegetables (Cantwell, 1999). Among the components of nopalito, a functional food is mucilage, which can be associated with an unpleasant sensation of sliminess. Such polysaccharide, isolated, could be used as thickening in food and other products because of its rheological behavior in aqueous dispersions (Cárdenas *et al*., 1997).

Nopalito cultivars differ by both their morphology (Cervantes–Herrera *et al*., 2006; Gallegos–Vázquez *et al*., 2006) and their physicochemical attributes (Corrales–García *et al*., 2004; Peña–Valdivia and Sánchez–Urdaneta, 2006; Ramírez–Tobías *et al*., 2007). It is considered that good quality nopalitos should have fresh appearance, be thin, turgent, bright green, and have low acidity and mucilage content. Ruíz Pérez–Cacho *et al*. (2006) developed sensory descriptors for nopalitos of the cultivars Milpa Alta, Atlixco and COPENA V1. Nevertheless, the relationship between physicochemical and sensory characteristics of cultivars remains unknown, as well as their relation to acceptability by consumers.

External preference mapping is the most used method to relate acceptability data with sensory attributes or physicochemical characteristics (Caspia *et al*., 2006). This technique has been utilized for apple (Jaeger *et al*., 1998), cheese (Lawlor and Delahunty, 2000), tomato (Lé and Ledauphin, 2006) and other products (Gámbaro *et al*., 2007; Martins–Medeiros de Melo *et al*., 2009; Rødbotten *et al*., 2009). Another commonly used technique is the partial least square regression (PLS), both 1 and 2, which allow to generate models for the prediction of one or more response variables (Y) in function of another group of variables (X) (Guinard *et al*., 2001; Tenenhaus *et al*., 2005).

The aim of this study was to determine the physical, chemical, rheological and sensory characteristics with major influence on the acceptability of four nopalito cultivars of commercial importance in Mexico. The hypothesis is that nopalito acceptability can be determined by a small number of sensory or physical and chemical characteristics, and that acceptability is opposite to sourness and mucilage content, and directly dependent on lightness and firmness.

Material and methods

Plant material

The study was conducted during 2008. Nopalitos from four cultivars of *O. ficus–indica* were used: Milpa Alta, COPENA F1, COPENA V1 and Tovarito, harvested at 6:00 h, between march and june, from the experimental field “Facundo Barrientos P.” at Universidad Autónoma Chapingo, in the State of Mexico. Selected nopalitos had an approximate length of 20 cm. Previous to analysis, nopalitos were washed and spines were removed.

Physicochemical analysis

Color

A Hunter Lab® colorimeter, model No. 45/O–L (HunterLab, Hunter Associates Laboratory, USA), with illuminant C, an observer angle of 10° and CIElab scale was used. Lightness, saturation index and hue angle were quantified. Four measurements were performed on each side of each nopalito.

Firmness

The firmness of the cladode on the cuticle and at a penetration distance of 3 mm was determined using a TA–Xt2i Texture Analyzer (Stable Micro Systems; Surrey, UK), with a 5 kg load cell, a P2N probe, pre–test and post–test speeds of 2 mm s^{-1} and a test speed of 1 mm s^{-1}. Three repeated measures were performed and firmness was reported in Newtons (N).

Moisture

Moisture was calculated from the difference in weight of 10 g of fresh tissue and its weight after complete dehydration by liofilization. A Labconco Freeze Dry System/ Lyph Lock® 4.5 (Labconco Corporation, Kansas City, Missouri, USA) liofilizer with the following parameters was used: –41°C; 1.8 X 10^{-2} mbar.

Titratable acidity

Acidity was determined by titration with 0.1 N NaOH of an aliquot prepared with 0.5 g of liofilized nopalito. Acidity was reported as g of malic acid per 100 g of fresh tissue.

Mucilage content

Mucilage content was determined with the methodology used by Peña–Valdivia and Sánchez–Urdaneta (2006) with the following modifications: two extractions were performed, the first represented the mucilage discarded by the consumer in cooking water, and the second, the mucilage that remains in the cooked cladodes and that therefore is ingested by the consumer.

Rheology

Dispersions of 2% mucilage, 45% sucrose, 0.1% calcium chloride and distilled water were elaborated according to the methodology of Löfgren and Hermansson (2007). pH was adjusted to 3. A citric pectin dispersion of low methoxil content was used (Droguería Cosmopolita, Distrito Federal, México) as control. A controlled Paar Physica MCR 301 stress rheometer (Anton Paar, Messtechnik, Stuttgart, Germany) was used, and adapted with a cone–plate geometry of 50 mm, a cone angle of 1° and a cone and plate gap of 5.1 X 10^{-5} m. Measurement temperature was 25 °C. Samples were left to set 30 min prior to measurement.

Flow curves

A shear rate of 0.01 a 100 s^{-1} was applied. Results were adjusted to the Carreau model, of which the following parameters were obtained: initial viscosity (η_0), infinite viscosity (η_{inf}), Carreau constant (k) and consistency index (m).

Low amplitude oscillatory tests

Storage module (G') and loss module (G'') were evaluated by running frequency sweeps at an interval of 0.1 to 300 s^{-1}, at a deformation rate of 0.1%, in the linear viscoelastic zone.

Sensory evaluation

Nopalitos cut into 2 x 1 cm slices were boiled for 10 min in a 2% sodium chloride solution (3:1, solution: nopalito). The four cultivars were presented to panelists, non–nomadically, in polyethylene cups, coded with three digit random numbers.

Descriptive analysis
Panelists were selected from an initial group of 48 people, based on their discriminative ability and reproducibility of results, by a sequential analysis (ISO, 2004) for triangular tests (α = 0.05, β = 0.05 and proportion of discriminants of 50%). The final panel consisted of seven individuals with ages from 18 to 53, with 22 h of training. A modified quantitative descriptive analysis (Murray *et al*., 2001), with a semistructured 15 cm scale, was used. 35 g samples were evaluated. Panel performance was monitored through principal component analysis (Zook and Wessman, 1977), and *panelist x treatment* interaction from the analysis of variance.

Acceptability test
One hundred consumers (51 men and 49 women) aged 10 to 56, assessed the global acceptability of 20 g of nopalitos, with a 9 point hedonic scale (Lawless and Heymann, 1999).

Statistical analysis
Physical, chemical and rheological variables were analyzed using a completely randomized design with five repetitions for physical and chemical variables, and two repetitions for rheological variables. Descriptive variables were evaluated using a completely randomized block design with a split plot arrangement, and three repetitions; and acceptability data were evaluated using a completely randomized block design ($P < 0.05$). Mean comparisons were performed using Fisher's least significant difference procedure.

Partial least squares regression (PLS1) was performed for the following variable pairs: physicochemical vs. acceptability, descriptive vs. acceptability and rheological vs. acceptability (Esbensen, 1994). External preference mapping (using descriptive and acceptability variables) was performed by principal component analysis. Statistical analyses were performed using SAS Version 8 (SAS Institute, NC, USA) and The Unscrambler version 9.2 (Camo Process AS, Oslo, Norway) statistical software.

Results

Physical and chemical characteristics
Significant differences were found among cultivars for all attributes, except mucilage content (Table 1). Greater values for lightness and saturation index were observed in COPENA F1, while COPENA V1 presented the lowest values for these variables. Greatest hue angle (greenest) was observed for COPENA V1, and the lowest (least green) for COPENA F1. Similar hue angle values were reported by López–Palacios *et al*. (2005) for different cultivars, which may indicate that this color parameter is common among different nopalito cultivars, and their variation evidences a wide green gamma among diverse nopalito cultivars.

Milpa Alta and COPENA F1 were the cultivars with greatest cuticle firmness. Greatest tissue firmness was present in Milpa Alta. Tovarito and COPENA V1 presented the lowest values for cuticle and tissue firmness, respectively. Cuticle firmness oscillated from 0.16 to 0.26 N, and tissue firmness from 0.55 to 0.85 N (Table 1). These results show that from the evaluated cultivars, Milpa Alta nopalitos, the cultivar with the greatest production area in Mexico, 7,500 ha (Cervantes *et al*., 2006), stood out for its internal and external firmness. Moisture varied from 89.93% in Milpa Alta to 94.35% in COPENA V1 (Table 1). Rodríguez–Félix and Cantwell (1988) reported a mean moisture content of 91.7% for three nopal species. This value is found within the interval limits obtained for this work.

Mucilage content varied from 0.117 to 0.230 g/100 g of fresh tissue, with no significant difference among cultivars (Table 1). This result indicates that variability among experimental units was such that although Milpa Alta nopalitos presented 32 to 96% more mucilage than the other cultivars, differences were not statistically significant.

Acidity was greater for Milpa Alta and COPENA V1 than for COPENA F1 and Tovarito (Table 1). Acidity values for the present study were found to be in the interval reported by Corrales–García *et al*. (2004) for 10 cultivars of *Opuntia* spp. (0.28 to 0.76 g/100 g of fresh tissue). It is convenient to remark that acidity of COPENA F1, Milpa Alta and Tovarito in the present study was, in general, similar (with a mean fluctuation of ± 0.09%) to that quantified by Corrales–García *et al*. (2004), with nopalitos harvested in previous years, from the same experimental field. However, acidity of COPENA V1 was highlighted for being the cultivar with the lowest acidity (0.28%) among the 10 cultivars evaluated, while in the present study it was one of the most acid cultivars (0.51%). The cause for this variation is unknown, however, the possibility of acidity being more affected for this cultivar than for other cultivars could be due to the interaction ambient x genotype or any other more complex interaction such as ambient x genotype x age of the plant.

Table 1. Means and standard deviations for the physicochemical properties of four nopalito (*Opuntia ficus–indica*) cultivars.

Color	COPENA F1	COPENA V1	Milpa Alta	Tovarito
Lightness (%)	49.17a± 4.03	40.21c ± 1.72	43.86b ± 1.18	45.01b ± 1.83
Saturation index	20.91a ± 0.36	16.71c ± 1.23	19.07b ± 0.86	20.42a ± 0.59
Hue angle (°)	115.77c ± 0.43	120.15a ± 1.12	117.83b ± 1.07	117.75b ± 0.35
Firmness (N)				
Cuticle	0.23ab ± 0.02	0.20b ± 0.02	0.26a ± 0.05	0.16c ± 0.02
Internal	0.75b ± 0.05	0.55c ± 0.05	0.85a ± 0.08	0.76b ± 0.05
Moisture (%)	91.47c ± 0.63	94.35a ± 0.51	89.93d ± 1.14	92.95b ± 0.55
Mucilage (%)[bh]	0.17a ± 0.07	0.156a ± 0.04	0.23a ± 0.11	0.12a ± 0.04
Acidity (%)[bh]	0.45b ± 0.04	0.51a ± 0.05	0.55a ± 0.04	0.41b ± 0.02

Different letters within rows indicate values with significant differences, according to least significant difference ($\alpha = 0.05$).
[hb] humid basis.

Rheology

Flow curves. Flow curves for aqueous mucilage dispersions (Figure 1) showed that at low shear rates (0.01 to 0.02 s^{-1}) viscosity increased, this could be due to a rearrangement of the dispersion structure, this was followed by a plateau known as "first Newtonian region", for which viscosity was constant (Barnes *et al*., 1989). An increase in the slope of flow curves was observed afterwards, indicative of the destruction of the dispersion structure. The nopalito mucilage and the citric pectin dispersions showed a pseudoplastic behavior, that is, their viscosity decreased at increasing shear rates.

Flow curves were adjusted to the Carreau model with a correlation coefficient of 0.98. The parameters for this model, for each cultivar, are shown in Table 2. Significant differences ($\alpha = 0.05$) among cultivars were found for initial viscosity (η_0), consistency index (m) and the difference in initial viscosity and infinite viscosity ($\eta_0 - \eta_{inf}$). All four cultivars presented a consistency index with a value lower than one, characteristic of a pseudoplastic behavior. COPENA V1 and Tovarito presented, respectively, the greatest and lowest initial viscosity, and Milpa Alta was distinguished for having the greatest consistency index among the four cultivars. The knowledge of this pseudoplastic property in nopalito mucilage may help to identify potential uses. Related to this, it must be pointed out that fruit and vegetable juices and purees commonly present a pseudoplastic behavior (Steffe, 1992; Vliet, 1999). Consistency of these products is an important quality parameter, and in general depends on the preparation method and the mechanical treatment of which food has been subject of, besides the cultivar or variant and maturity of the tissues (Ibarz and Barbosa–Cánovas, 2005).

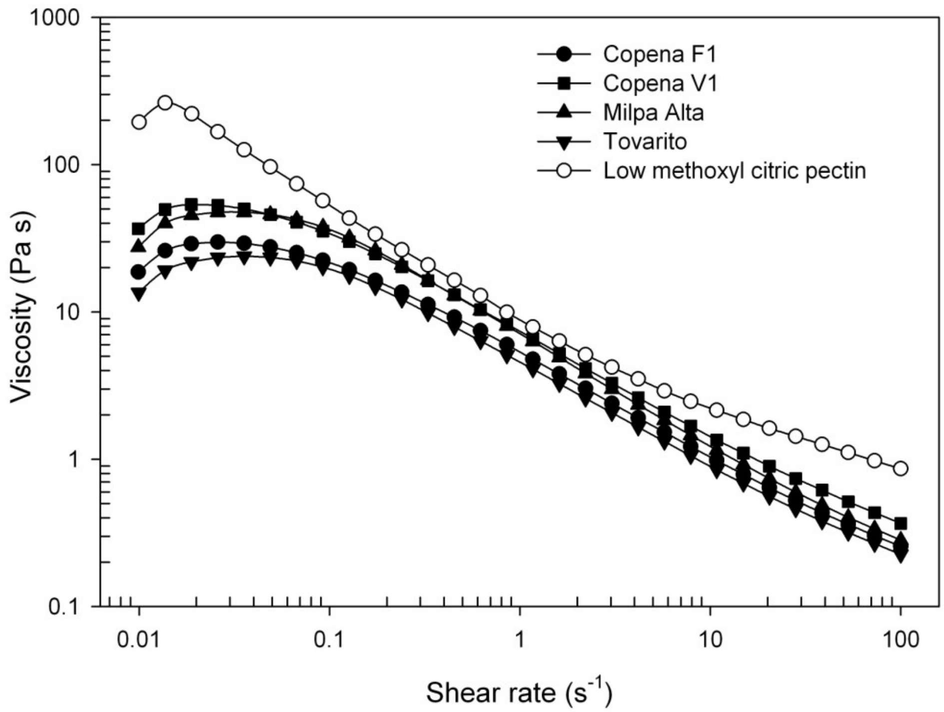

Figure 1. Flow curves for dispersions elaborated from mucilage of four nopalito (*Opuntia ficus–indica*) cultivars.

Table 2. Means and standard deviations of the rheological parameters of the Carreau model for mucilage dispersions of four nopalito (*Opuntia ficus–indica*) cultivars.

Variable	COPENA F1	COPENA V1	Milpa Alta	Tovarito
η_0 (Pa s)	26.98bc ± 3.06	50.30a ± 21.46	43.11ab ± 0.51	21.37c ± 0.39
η_{inf} (Pa s)	0.08ab ± 0.004	0.14a ± 0.049	0.14a ± 0.045	0.09a ± 0.006
$\eta_0 - \eta_{inf}$ (Pa s)	26.90bc ± 3.05	50.16a ± 21.41	42.97ab ± 0.56	21.29c ± 0.40
k	9.18a ± 0.345	12.41a ± 4.18	11.10a ± 3.40	7.58a ± 0.22
m	0.37b ± 0.006	0.38b ± 0.001	0.40a ± 0.012	0.38b ± 0.001

Different letters within rows indicate values with significant differences, according to least significant difference ($\alpha = 0.05$).

η_0 – initial viscosity, with a shear rate tending to zero.

η_{inf} – infinite viscosity, with a shear rate tending to infinite.

k – Carreau constant, related to the time required by a macromolecule to recover from the elongation and deformation effect of shear.

m – consistency index.

Nopalito mucilage dispersions presented a notoriously lower viscosity than citric pectin of low methoxil content. This may be because of the presence of fewer interaction zones, weaker intramolecular cross–links, shorter polymer chains (Vliet, 1999) or a greater degree of esterification (DE) with respect to low methoxil citric pectin, a characteristic that allowed nopalito mucilage dispersions to form less calcium binding (Walter, 1991). If DE is considered as the determinant factor for dispersion viscosity, it may be inferred that COPENA V1 mucilage presented the least DE, preceded by citric pectin, and Tovarito mucilage the greatest DE among the four cultivars. Degree of esterification and chain length of the polysaccharides are very important characteristics because they define their functionality. At a greater degree of esterification, the polysaccharide presents a greater solubility in water and a faster rate of gelation. At greater chain length of the polysaccharide, greater is the jellifying power. It has also been proved that pectic substances have a hypocholesterolemic effect, and that it is greater for higher esterification (Judd and Truswell, 1982).

Frequency sweeps

Frequency sweeps for dispersions (Figure 2) showed that COPENA F1 and Tovarito mucilage presented a predominantly elastic behavior (G' > G'') for all the frequencies applied (0 to 300 s^{-1}). For COPENA V1 and Milpa Alta mucilage dispersions, a viscous character was predominant over the elastic character at high frequencies. The intersection between G' and G'' was registered at an approximate frequency of 70 s^{-1} and 150 s^{-1} for COPENA V1 and Milpa Alta, respectively.

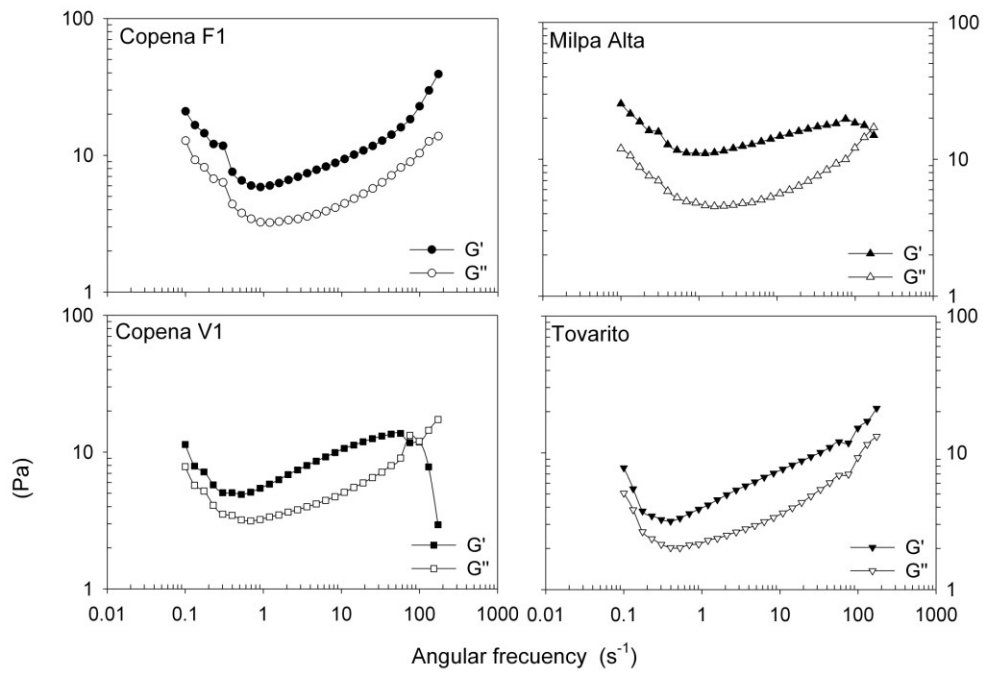

Figure 2. Storage modules (G') and loss modules (G'') from frequency sweeps for dispersions elaborated with mucilage from the four nopalito (*Opuntia ficus–indica*) cultivars.

In most solid foods, force distribution is not uniform and bonds are distorted producing a progressive deformation, only partially recoverable. The incidence of viscous behavior in its mechanical behavior should be considered for the rheological characterization, which implies the need to apply the theory for visco–elasticity (Ibarz and Barbosa–Cánovas, 2005). Mucilage is only one of the polysaccharides dispersed in the cellular walls of nopalitos, and is complemented by pectins, hemicelluloses and cellulose. The proportion of these compounds in the tissue and the interactions among them define, in part, the mechanical behavior of nopalitos, which present elastic, plastic and viscous characteristics.

Sensory evaluation

Descriptive analysis

The panel generated 13 descriptors for nopalitos and defined each one, the order of appearance, references and their score using a 15 cm linear scale, and how each sample and reference was to be evaluated (Table 3). Table 4 shows the mean comparisons for the sensory attributes of the four cultivars. All descriptors were significantly different among nopalitos, with the exception of acid aroma, which was eliminated for subsequent analyses.

Table 3. Definition, references and scores for nopalito attributes.

Attribute	Definition	Reference	Value
Lightness	Degree to which the green color of nopalitos varies from dark to light	Buffalo™ olives	13
Moist appearance	Quantity of liquid visually perceived on the surface of nopal	Saladet tomato	15
Visual sliminess	Length of the thread formed by mucilage	Egg white	7
Acid aroma	Aroma associated to a tingling sensation in the nose, produced by a solution of acetic acid	Acetic acid solution (1% v/v)	5
Green odor	Aroma associated to that produced by pea peel	Peas	10
Elasticity	Capacity of nopalitos for recovering their original shape once a force has been applied and removed	Seedless green grapes	12
Firmness	Force necessary to break sample	Seedless green grapes	12
Sournes	Basic taste sensation manifested as an increase in salivation, produced by an acid	Citric acid solution (0.05% w/v)	7
Saltiness	Basic taste sensation produced by a saline solution	NaCl solution (0.3% w/v)	10
Green flavor	Taste associated to green raw vegetables	Peas	12
Leatheriness	Permanence of epidermis that is easily folded and extended without breaking in mouth	Plums	13
Chewiness	Number of chews required to prepare sample for swallow	Duby™ mortadela	3
Sliminess in mouth	Sensation of a slippery covering in mouth	Pectin solution (1% w/v)	5

COPENA V1 cultivar was distinguished for having the highest values for moist appearance, elasticity and saltiness, and the lowest scores for lightness, firmness and chewiness (Figure 3); Milpa Alta was characterized by having high scores for visual sliminess, green odor, firmness and a low value for sourness; COPENA F1 presented the greatest values for lightness, firmness and green flavor, and the lowest values for visual and in mouth sliminess. Tovarito presented intermediate values for most of the attributes.

Table 4. Means and standard deviations of the sensory attributes of four nopalito (*Opuntia ficus–indica*) cultivars.

Attribute	COPENA F1	COPENA V1	Milpa Alta	Tovarito
Lightness	10.61a ± 1.32	6.63d ± 1.57	8.57c ± 1.97	9.31b ± 1.15
Moist appearance	9.33c ± 2.13	12.20a ± 1.54	10.66b ± 2.02	9.70c ± 1.93
Visual sliminess	7.03c ± 2.24	11.06a ± 2.33	10.56a ± 1.69	8.09b ± 2.34
Acid aroma	2.85a ± 1.10	2.80a ± 1.11	3.39a ± 1.42	3.46a ± 1.14
Green odor	5.21b ± 2.21	6.02ab ± 2.51	6.51a ± 2.96	5.34b ± 2.55
Elasticity	8.72b ± 2.71	9.97a ± 2.26	8.36b ± 1.73	8.87b ± 2.33
Firmness	11.22a ± 1.93	7.80c ± 2.00	10.67a ± 1.95	9.77b ± 1.89
Sourness	7.88a ± 1.63	5.50b ± 1.55	5.14b ± 1.39	7.42a ± 1.92
Saltiness	6.78b ± 1.89	9.08a ± 1.63	6.96b ± 1.53	6.81b ± 1.72
Green flavor	8.50a ± 2.99	6.71b ± 3.19	7.00b ± 2.86	7.46b ± 3.33
Leatheriness	9.37a ± 3.07	7.43c ± 2.58	8.25bc ± 3.00	8.94ab ± 2.17
Chewiness	6.57a ± 2.75	4.83b ± 2.63	6.13a ± 2.81	5.92a ± 2.61
Sliminess in mouth	3.97c ± 2.67	6.56a ± 2.47	5.53b ± 2.01	5.65b ± 3.06

Different letters within rows indicate values with significant differences, according to least significant difference (α = 0.05).

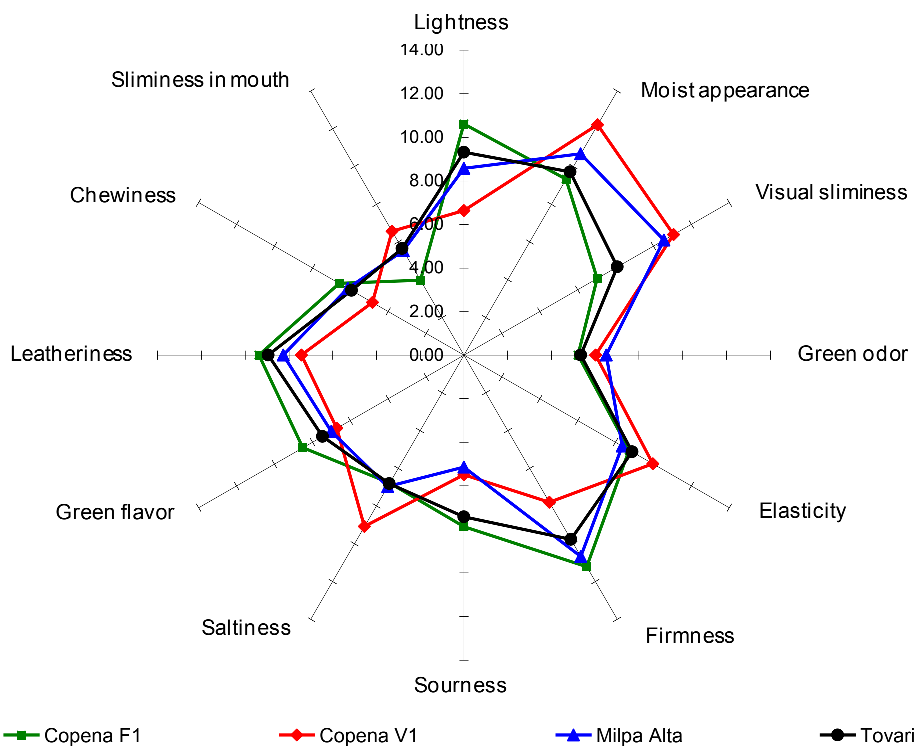

Figure 3. Radial graph for the sensory attributes of four nopalito cultivars (*Opuntia ficus–indica*).

Sensory evaluations, in general, did not correspond with the physical and chemical characteristics quantified. Lightness was the only attribute for which the order of perceived intensity (COPENA F1 > Tovarito > Milpa Alta > COPENA V1) by panel corresponded with instrumental measurements. Sensory and instrumental measures of firmness only corresponded for cultivar COPENA V1 which presented the least intensity for this attribute. Sensory perception of moist appearance could depend directly on moisture content, since both sensory and physical measurements show that cultivar COPENA V1 presented the greatest intensity for the mentioned attributes.

Opposed to what was expected, sensory perception of visual and in mouth sliminess did not correspond to instrumental quantification of mucilage content of nopalitos. Apparently, slimy sensation does not only depend on mucilage content of nopalitos, it also depends on the type of mucilage and, possibly on the presence of other polysaccharides not quantified in this work. It is convenient to point out that viscosity was significantly greater for cultivar COPENA V1 in comparison with other nopalito cultivars, and that panelists scored this cultivar as of greater visual and in mouth sliminess.

Regarding the perception of sourness, it was expected to correspond with titratable acidity measurements, but the opposed was observed. Milpa Alta and COPENA V1 cultivars presented greater titratable acidity than COPENA F1 and Tovarito cultivars, but panelists perceived the latter as of greater sourness. It is important to point out that the measurement of titratable acidity was performed on raw nopalitos, and that sensory evaluation of sourness was performed on cooked nopalitos. Organic acids probably solubilized during cooking in a different proportion for each nopalito cultivar, due to some intrinsic tissue characteristics. Additionally, perception of sensory sourness could have been affected by viscosity (Smith and Noble, 1998). Walter and Prescott (2000) demonstrated, in apple juice, that at a greater viscosity, sensory sourness perception diminishes. COPENA V1 and Milpa Alta nopalito mucilage presented a greater initial viscosity (η_0) than mucilage from COPENA F1 and Tovarito. This probably influenced the perception by panelists as less sour.

Global acceptability

All four cultivars obtained mean scores, using a hedonic scale, between 5 (I don't like or dislike it) and 7 (I like it moderately). COPENA V1 was the cultivar with the least global acceptability (5.46); Milpa Alta (6.16), COPENA F1 (6.09) and Tovarito (6.01) presented the greatest acceptability scores and no statistical differences were found among them.

Preference mapping and partial least squares regression (PLS1)

External preference mapping for physical and chemical variables, and global acceptability (Figure 4) shows that COPENA V1 was the least accepted cultivar, as is therefore found on the opposite vector for acceptability. The first and second principal components (PC1 and PC2) explained 58 and 36% of the total variability, respectively. Low acceptability for COPENA V1 was due to greater hue angle values (greener) and moisture, and the lower values of firmness in tissue, lightness and saturation index. Milpa Alta presented the greatest firmness value within tissue, which was the variable with greatest positive and direct correlation with global acceptability for consumers. COPENA F1 presented the greatest values for lightness and saturation index, which were positively correlated with acceptability.

The physical and chemical variables with greater influence (greater weighted regression coefficients) on acceptability were: tissue firmness, saturation index and lightness, with a positive correlation, and moisture and hue angle with a negative correlation.

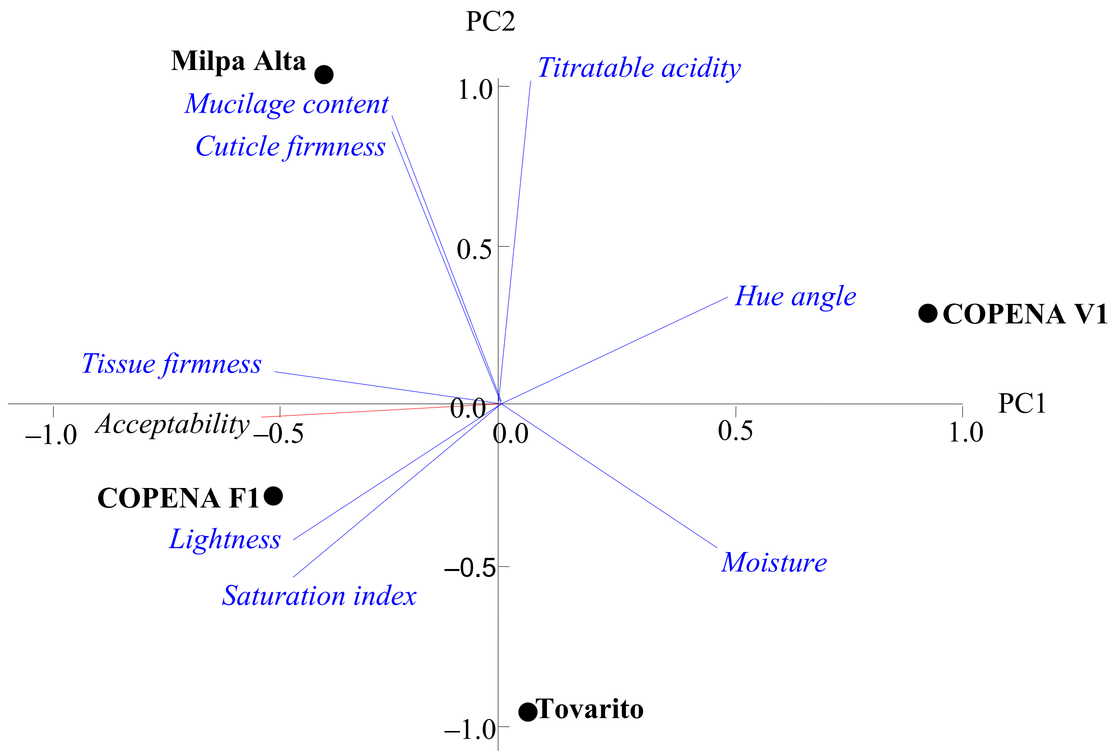

Figure 4. External preference map for the physicochemical properties of four nopalito (*Opuntia ficus–indica*) cultivars.

PLS1 of physicochemical variables and global acceptability showed a correlation coefficient of 0.96 between both data matrices. Raw regression coefficients were used to generate a model that allowed the prediction of acceptability for nopalito cultivars as a function of their physicochemical properties. The model obtained was the following:

$$Acceptability=11.348+0.598CF+0.588IF+0.015L+0.034SI-0.035H+0.035M+0.6MC-0.18A,$$

where:
CF = cuticle firmness (N); IF = internal tissue firmness (N); L = lightness (%); SI = saturation index; H = hue angle (°); M = moisture (% m/m humid basis); MC = mucilage content (% m/m humid base); and A = titratable acidity (% m/m humid basis).

External preference mapping for descriptive variables and global acceptability (Figure 5) showed that COPENA V1 was the least accepted cultivar. CP1 and CP2 explained 79 and 18% of total variability, respectively. The lower acceptability for nopalitos of cultivar COPENA V1 was due its greater intensity for saltiness, elasticity and moist appearance, and lower values for firmness, chewiness and lightness.

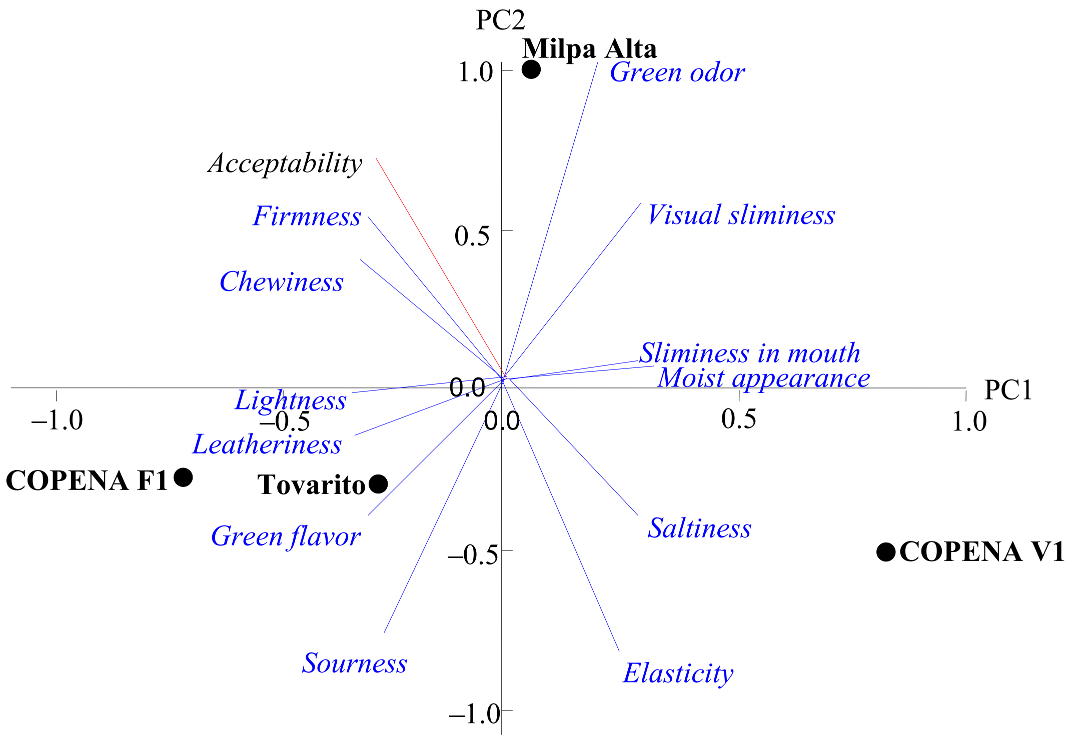

Figure 5. External preference map for sensory attributes of four nopalito (*Opuntia ficus–indica*) cultivars.

CP1 and CP2 explained 78 and 18% of the total variability, respectively. The descriptive variables of greater influence on global acceptability of the four nopalito cultivars were firmness and chewiness, with a positive correlation, and elasticity and saltiness with a negative correlation. Therefore, the cultivar perceived as most intense in the attributes salty and elastic, and least intense in the attributes firmness and chewiness was the least accepted by consumers.

The model that allows the prediction of acceptability of the nopalito cultivars as a function of their sensory attributes is the following:

Acceptability=6.333+0.0171L–0.026Ma+0.0042Vs+0.078Go–0.124E+0.041F–0.020So–0.059Sa–0,009Gf+0.025Le+=.073Ch–0.016Sm,

where:
L = lightness; Ma = moist appearance; Vs = visual sliminess; Go = green odor; E = elasticity; F=firmness; So = sourness; As = saltiness; Gf = green flavor; Le = leatheriness; Ch = chewiness; Sm = sliminess in mouth.

PLS1 for rheological variables and global acceptability generated an unsatisfactory model, probably due to the scarce relation among variables, which is explained by the great difference in the magnitude of the shear rates applied by consumers and by the rheometer, therefore, the corresponding preference map was not run.

Conclusions

The sensory descriptors and the physical and chemical characteristics of nopalito cultivars may help predict their acceptability by consumers. Sensory descriptors present greater correlation with acceptability. Texture and appearance characteristics are the variables of greater influence on nopalito acceptability. Sensory perception of firmness has a greater influence on acceptability in contrast with the attributes related to sliminess. Although no significant difference in the mucilage content of nopalito cultivars exists, differences in the rheological properties of mucilage dispersions are significant.

References

Barnes, H.A., Hutton, J.F., and Walters, K. 1989. An Introduction to Rheology. Elsevier. UK. 210 p.

Bwititi, P., Musabayane, C.T., and Nhachi, C.F.B. 2000. Effects of *Opuntia megacantha* on blood glucosa and kidney function in streptozotocin diabetic rats. Journal of Ethnopharmacology 69: 247–252.

Cantwell, M. 1999. Manejo Postcosecha de Tunas y Nopalitos. pp. 126–143. In: Barbera G, Inglese P. y Pimienta E. (eds.) Agroecología, Cultivo y Usos del Nopal. Estudio FAO Producción y Protección Vegetal, 132. Rome.

Cárdenas, A., Higuera–Ciapara, I. and Goycoolea, F.M. 1997. Rheology and aggregation of cactus (*Opuntia ficus–indica*) mucilage in solution. Journal of the Professional Association for Cactus Development 2: 152–159.

Caspia, E.L., Coggins, P.C., Schilling, M.W., Yoon, Y., and White, C.H. 2006. The relationship between consumer acceptability and descriptive sensory attributes in cheddar cheese. Journal of Sensory Studies 21: 112–127.

Cervantes–Herrera, J., Gallegos–Vázquez, C., Reyes–Agüero, J.A., Fernández–Montes, R., Mondragón–Jacobo, C., Martínez, J.C., and Luna–Vázquez, J. 2006. Mexican cultivars of *O. ficus indica* (L.) Mill. with economic importance. Acta Horticulturae 728: 29–33.

Corrales–García, J., Peña–Valdivia, C.B., Razo–Martínez, Y. and Sánchez–Hernández, M. 2004. Acidity changes and pH–buffering capacity of nopalitos (*Opuntia* spp.). Postharvest Biology and Technology 32: 169–174.

Esbensen, K. 1994. Multivariate data analysis in practice. An introduction to multivariate data analysis and experimental design. 5a ed. CAMO Process AS. USA. 598 p.

Frati–Munari, A.C., Gordillo, B.E., Altamirano, P., and Ariza, C.R. 1988. Hypoglycemic effect of *Opuntia streptacantha* Lemaire in NIDDM. Diabetes Care 11 (1): 63–66.

Gallegos–Vázquez, C., Cervantes–Herrera, J., Reyes–Agüero, J.A., Rodríguez, E., Fernández–Montes, R., Mondragón–Jacobo, C., Luna, J., and Martínez–González, J.C. 2006. Inventory of the main commercial cactus pear (*Opuntia* spp.) cultivars in Mexico. Acta Horticulturae 728: 17–27.

Gámbaro, A., Ares, G., Giménez, A. and Pahor, S. 2007. Preference mapping of color of Uruguayan honeys. Journal of Sensory Studies 22: 507–519.

Guinard, J.X., Buotani, B. and Schlich, P. 2001. Internal and external mapping of preferences for commercial lager beers: comparison of hedonic ratings by consumers blind versus with knowledge of brand and price. Food Quality and Preference 12: 243–255.

Ibarz, R.A., and Barbosa–Cánovas, G.V. 2005. Operaciones Unitarias en la Ingeniería de Alimentos. Mundi–Prensa. España. 865 p.

ISO 16820. 2004. International Standard. Sensory analysis–Methodology–Sequential analysis.

Jaeger, S.R., Andani, Z., Wakeling, I.N., and Macfie, J.H. 1998. Consumer preferences for fresh and aged apples: a cross–cultural comparison. Food Quality and Preference 9 (5): 355–366.

Judd, P.A., and Truswell, A.S. 1982. Comparison of the effects of high– and low–methoxyl pectins on blood and faecal lipids in man. British Journal of Nutrition 48: 451–458.

Lawless, H.T., and Heymann, H. 1999. Sensory Evaluation of Food: Principles and Practices. Aspen Publishers. USA. 827 p.

Lawlor, J.B., and Delahunty, C.M. 2000. The sensory profile and consumer preference for ten specialty cheeses. International Journal of Dairy Technology 53 (1): 28–36.

Lé, S., and Ledauphin, S. 2006. You like tomato, I like tomato: Segmentation of consumers with missing values. Food quality and preference 17: 228–233.

Löfgren, C., and Hermansson, A.M. 2007. Synergistic rheological behavior of mixed HM/LM pectin gels. Food hydrocolloids 21: 480–486.

López–Palacios, C., Ramírez–Tobías, H.M., Reyes–Agüero, J.A. y Aguirre–Rivera, J.R. 2005. Atributos físicos y pH en nopalitos. Universitarios Potosinos. Órgano informativo y de divulgación de la Universidad Autónoma de San Luis Potosí 6: 22–25.

Martins–Medeiros–De–Melo, L.L., André–Bolini, A.M., and Efraim, P. 2009. Sensory profile, acceptability, and their relationship for diabetic/reduced calorie chocolates. Food Quality and Preference 20: 138–143.

Murray, J.M., Delahunty, C.M., and Baxter, I.A. 2001. Descriptive Sensory Analysis: Past, Present and Future. Food Research International 34: 461–471.

Peña–Valdivia, C.B., and Sánchez–Urdaneta, A.B. 2006. Nopalito and cactus pear (*Opuntia* spp.) polysaccharides: mucilage and pectin. Acta Horticulturae 728: 241–247.

Ramírez–Tobías, H.M., Reyes–Agüero, J.A., Pinos–Rodríguez, J.M. y Aguirre–Rivera, J.R. 2007. Efecto de la especie y madurez sobre el contenido de nutrientes de cladodios de nopal. Agrociencia 41: 619–626.

Rødbotten, M., Martinsen, B.K., Borge, G.I., Mortvedt, H.S., Knutsen, S.H., Lea, P., and Naes, T. 2009. A cross–cultural study of preference for apple juice with different sugar and acid contents. Food Quality and Preference 20: 277–284.

Rodríguez–Félix, A., and Cantwell, M. 1988. Developmental changes in composition and quality of prickly pear cactus cladodes (nopalitos). Plant Foods for Human Nutrition 38: 83–93.

Ruíz–Pérez–Cacho, M.P., Galán–Soldevilla, H., Corrales–García, J., and Hernández–Montes, A. 2006. Sensory characterization of nopalitos (*Opuntia* spp.). Food Research International 39: 285–293.

Sáenz, C., Sepúlveda, E., and Matsuhiro, B. 2004. *Opuntia* spp. Mucilage's: a functional component with perspectives. Journal of Arid Environments 57 (3): 275–290.

Sáenz–Hernández, C., Corrales–García, J., and Aquino–Pérez, G. 2002. Nopalitos, Mucilage, Fiber, and Cochineal. pp. 211–234. In: Nobel, P. S. (ed.). Cacti: Biology and Uses. University of California. Davis, CA, USA.

Scheinvar, L. 1995. Taxonomy of Utilized Opuntias. In: Barbera, G., Inglese, P. and Pimienta–Barrios. Agro–ecology, Cultivation and Uses of Cactus Pear. FAO Plant Production and Protection Paper 132. Roma, Italia.

Silva–Vale, M. 2006. El nopal, marca de fábrica de nuestra cultura. Revista Gente Sur 120. Versión electrónica. Fecha de consulta: 14 de diciembre de 2006. http://www.gentesur.com.mx/artículos.php?id_sec=&id_art=679&id_ejemplar=154.

Smith, A.K., and Noble, A.C. 1998. Effects of increased viscosity on the sourness and astringency of aluminum sulfate and citric acid. Food Quality and Preference 9 (3): 139–144.

Steffe, J.F. 1992. Rheological methods in food process engineering. Freeman Press. USA. 428 p.

Tenenhaus, M., Pages, J., Ambroisine, L., and Guinot, C. 2005. PLS methodology to study relationships between hedonic judgements and product characteristics. Food Quality and Preference 16: 315–325.

Trovato, A., Mondello, M.R., Monforte, M.T., Rossitto, A., and Galati, E.M. 2005. Biological activities of *Opuntia ficus–indica* (L.) Mill. (*Cactaceae*) cladodes. Acta Horticulturae 581: 291–293.

Vliet, T. 1999. Clasificación Reológica de Alimentos y Técnicas Instrumentales para su Estudio. In: Rosenthal, A. (ed.). Textura de los Alimentos: Medición y Percepción. Aspen publications. USA. 311 p.

Walter, R.H. 1991. The Chemistry and Technology of Pectin. USA: Academic Press Inc.

Walter, S., and Prescott, J. 2000. The influence of solution viscosity and different viscosifying agents on apple juice flavor. Journal of sensory studies 15 (3): 285–307.

Yang, N., Zhao, M., Zhu, B., Yang, B., Chen, C., Cui, C., and Jiang, Y. 2008. Anti–diabetic effects of polysaccharides from *Opuntia monacantha* cladode in normal and streptozotocin–induced diabetic rats. Innovative Food Science & Emerging Technologies 9: 570–574.

Zook, K., and Wessman, C. 1977. The selection and use of judges for descriptive panels. Food Technology 11: 56–61.