Research Article

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Physico-chemical and sensory properties of marmalades made from mixtures of fruits and under-exploited Andean tubers

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Abstract

BACKGROUND: This work studies the added value to the Andean tuber crops through the production of jams. The objective were: (1) to study the sensory and instrumental characteristics of dietetic marmalades made with fruits and Andean tubers; (2) to research consumer's acceptability and emotional responses; (3) to assess the relationship between sensory and instrumental variables and (4) to determine sensory, instrumental and emotional variables that influence the acceptability.

RESULTS: Pearson's correlations showed that spreadability was the variable better predicted by sensory and instrumental ones. The analysis of variance showed that sourness increased with the increase of strawberry and the decrease of apple contents ($P < 0.05$). The acceptability increased when the strawberry proportion was higher. The sweetness–sourness balance drove the hedonic response and some emotions changed from one feeling to its corresponding opposite when the strawberry proportion reached 50 or 60. According to a partial least square 2 and a principal components analysis of sensory/acceptability/emotion data, 'typical', 'autochthonous', 'urban' and 'present' resulted in positive emotions which favored the consumer liking.

CONCLUSION: Formulating marmalades with mixtures of fruits and Andean tubers will allow giving value-added to these crops. The elaboration of products using innovative raw materials will be an incentive for farmers to cultivate them.

Keywords: Andean tubers; marmalade; acceptability; emotional response; sensory analysis

INTRODUCTION

Andean civilizations of the past had well-organized agriculture based on an appropriate use of the environment and the continuous improvement of food plants. The history of major civilizations should be approached from the point of view of the domestication of plants, the improvement of the main crops and the advances achieved in agriculture.[1] In the Andes, the domestication of the potato (*Solanum tuberosum andigenum*) stands out; it includes more than 400 varieties.[1] Some of these varieties are grown in small areas under traditional production systems and difficult conditions, but are essential to ensure food diversification[2] and play vital roles in the nutrition of the rural populace.[3] Andean potatoes are the most used ingredient in *Puna's* culinary preparations.[4]

Over the last 20 years, substantial work has been carried out concerning the conservation of Andean crops[1] based on the nutritional and medicinal properties, nowadays being rediscovered. Also, the utilization of the crops can lead to increased food safety for countries within and outside the Andean zone, for example two native potatoes in Spain,[5] *oca* and *papalisa* in Belgium,[6] and *oca* in New Zealand.[7] These tubers can be used to make by-products, such as marmalade, a value-added food, according to the United States Department of Agriculture (USDA).[8]

Marmalades are a highly consumed food worldwide. These are used mainly at breakfast (as a spread), but are also used in pie fillings, bakery products and confectionary.[9] In traditional jams, sucrose is a principal ingredient.[10] Excessive consumption of sucrose is considered to be a major contributor in the progression of dental caries,[11] metabolic diseases and hypertension.[12] However, sucrose replacement by low-calorie sweeteners could provide a feasible strategy for reduction of sugar intake.[13] Thus the development of sugar-reduced marmalades is an attractive alternative.

When dietetic products are prepared, the sensory attributes may be modified, suffering changes in flavor, color and texture characteristics.[14] The use of sensory analysis along with instrumental measurements is useful to study the functionality of a particular ingredient in the development of new products.[15,16] Correlations between sensory and instrumental methods are

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important because they allow understanding what is being sensed and perceived during the sensory assessment.[17]

Some researchers studied the changes of sensory and instrumental characteristics in confitures prepared with non-traditional ingredients. Vilela *et al.*[16] evaluated sensorial and rheological changes in dietetic jams; Markey *et al.*[13] studied the sensory profile of sugar-reduced products, and Basu *et al.*[18] analyzed the effect of substitution of sucrose by stevioside and sucralose on rheological, color and microstructural characteristics on mango jam.

On the other hand, the use of new ingredients such as the Andean tubers is growing. Amores Balseca[19] developed dairy desserts recipes prepared with *oca* flour, and Villacrés *et al.*[20] formulated chips using *oca* and *mashua* potatoes. Cruz *et al.*[21] studied the physico-chemical and rheological characteristics of Andean tuber starches. Additionally, Goldner *et al.*[4] concluded that sensory and instrumental characteristics of Andean tubers offer an opportunity to develop new applications for the industry. The addition of this non-conventional ingredient in confitures has not been reported.

Nowadays, measurement of the acceptability alone is not a sufficient benchmark for product development and testing.[22] The product perception is mediated by the preferences of the subjects, their moods and attitudes, and by the emotions that are elicited by the product associated in the mind of consumers.[23] In consequence, the assessment of food-evoked emotions profiles adds value beyond hedonic evaluations in explaining and predicting actual food choice behavior,[24] especially if these are correlated with sensory aspects.[25] Emotion testing has been studied in breakfast drinks,[24] orange juices, dairy beverages and cheese,[26] herbs/spices, snacks, meat[27] and dairy products.[28]

This research is about considering adding value to the Andean tuber crops through the production of jams. Value-added products can help the farm become more viable, more visible to the public, open up new markets, and extend the marketing season.[8]

The objectives of this study were: (1) to study the sensory and instrumental characteristics of marmalades made from mixtures of fruits and Andean tubers; (2) to research consumer's acceptability and emotional responses; (3) to assess the relationship between sensory and instrumental variables, and (4) to determine sensory, instrumental and emotional variables that influence the acceptability.

Finally, we proved the hypothesis that it is possible to add value to the Andean tubers making jams which are accepted by the consumers according to the sensory and instrumental characteristics along with the emotional response.

MATERIALS AND METHODS

Raw materials

As examples of the fruits and tubers, strawberries, apples and Andean potatoes, *oca* (*Oxalis tuberosa*), and *collareja* (*Solanum tuberosum* L. subsp. *andigena* Hawkes)[29] were purchased from a local market. Citric acid, as an acidity agent, was purchased from Sigma-Aldrich (Buenos Aires, Argentina); sucralose, a non-nutritive sweetener, was Beneo Orafti®, (Buenos Aires, Argentina) and inulin, a prebiotic ingredient, (Beneo Orafti®) were added.

Marmalade elaboration

Fruits and potatoes (harvested in 2014) were cleaned and washed. Apples were peeled, cut with the strawberries and cooked in boiling water (15 min) in order to inactivate enzymes. Cooked ingredients were processed and sifted until a smooth fruit puree formed.

Andean tubers were boiled with the skin (20 min), peeled and mashed to obtain *oca* and *collareja* purees. For the formulation, both purees were mixed separately with the fruit puree in different proportions (Table 1). Other ingredients were added and each mix was heated to 85 ± 5 °C and 28.2–36.0° Brix. All samples were stored in sterilized glass jars and kept in a refrigerator (4 ± 1 °C).

A study of traditional jams will be carried out in future research.

Physico-chemical properties

The following physico-chemical analyses were determined: (1) soluble solids (°Brix) at 20 ± 2 °C (refractometer, Milwaukee MA871; Buenos Aires, Argentina); (2) pH (pH-meter, Adwa, AD12; Buenos Aires, Argentina); (3) water activity (a_w) (water activity meter, AQUA-Lab 3TE; Buenos Aires, Argentina); (4) moisture content (g 100 g^{-1}) by drying the sample to constant weight at 60 ± 2 °C in a vacuum oven.[30] Each analysis was conducted three times.

Sensory analysis

Panel training

Nine volunteer evaluators (aged 28–40 years) with previous sensory evaluation experience were trained in the descriptive analysis[31] (six sessions, 1.5 h). They were selected and instructed in accordance with the standards ISO 8586:2012[32] and ISO 6658:2005[33] (Table 2). The color attributes (redness and brownness) were selected during a focus session (2 h) taking into account the color observed in the samples.

Triangle test

Expanded triangular test[34] with forced choice (ISO 4120:2004)[35] was performed. This test consists of three samples being presented simultaneously. Two are the same, representing a single lot; the third represents another lot and may be different. The subject is required to pick the sample which he/she believes to be different. The objective was to determine differences among samples made with the same tuber. Twenty sample pairs (result of the combination of five marmalades for each type of potato) were evaluated 10–15 times (eight sessions, 1.5 h), in individual booths with red light. In addition, judges were asked to explain why the selected sample was different.

Sensory profile

The texture profile method[36] and descriptive analysis[37] (ISO 13299:2016)[38] of tastes and colors were conducted using a 10 cm unstructured scale (three sessions, 2 h). Some anchors for each attribute[39] were replaced with products more related to Argentineans' habits (Table 2). The samples were presented separately according to a randomized complete block design. The *oca* marmalades and then those with *collareja* were evaluated with an intermediate break, and vice versa.

Consumers and emotional test

The marmalades were tested by 203 consumers in which 103 (72 women/31 men, ages 17–52 years) evaluated those made with *oca*, and 100 (79 women/21 men, aged 18–43 years) those prepared with *collareja*. The consumers rated their liking using a 9-point hedonic scale (9 = 'like extremely' to 1 = 'dislike extremely'). The samples were evaluated separately by type of potato by each consumer according to a complete blocks design.

Table 1. Strawberry:apple proportions and physico-chemical properties of formulated marmalades*

Sample†	Type of potato‡	Strawberry:apple proportion	Soluble solids (°Brix)§	a_w §	pH§	Moisture (g kg^{-1})§
1	*Oca*	20:60	33.4 ± 0.12^{d}	0.98 ± 0.00^{b}	3.88 ± 0.01^{c}	642 ± 54.40^{ab}
2	*Oca*	30:50	36.0 ± 0.10^{e}	0.97 ± 0.00^{a}	3.50 ± 0.03^{a}	587 ± 4.20^{a}
3	*Oca*	40:40	28.2 ± 0.12^{a}	0.97 ± 0.00^{a}	3.63 ± 0.01^{b}	673 ± 4.20^{ab}
4	*Oca*	50:30	31.4 ± 0.06^{b}	0.97 ± 0.00^{a}	3.62 ± 0.02^{b}	717 ± 5.70^{b}
5	*Oca*	60:20	32.4 ± 0.08^{c}	0.97 ± 0.00^{a}	3.89 ± 0.01^{c}	684 ± 2.10^{ab}
6	*Collareja*	20:60	32.2 ± 0.19^{b}	0.98 ± 0.00^{b}	3.76 ± 0.01^{b}	776 ± 19.80^{b}
7	*Collareja*	30:50	29.6 ± 0.46^{a}	0.98 ± 0.00^{b}	3.81 ± 0.005^{c}	722 ± 14.80^{ab}
8	*Collareja*	50:30	32.3 ± 0.03^{b}	0.96 ± 0.00^{a}	3.88 ± 0.01^{d}	672 ± 15.60^{a}
9	*Collareja*	60:20	29.3 ± 0.03^{a}	0.98 ± 0.00^{b}	3.71 ± 0.02^{a}	672 ± 5.20^{a}
10	*Collareja*	40:40	34.3 ± 0.29^{c}	0.98 ± 0.00^{b}	3.74 ± 0.02^{b}	722 ± 1.40^{ab}

*The results are expressed as means ± standard deviation.
†All samples were prepared using water (177.0 mL kg^{-1}), sugar (71.0 g kg^{-1}), inulin (degree of polymerization >10) (35.0 g kg^{-1}), citric acid (3.5 g kg^{-1}), potassium sorbate (1.0 g kg^{-1}) and non-nutritive sweetener sucralose (0.2 g kg^{-1}).
‡*Oca* and *collareja* potato were used in a proportion of 20:80.
§Three measurements were taken of each sample.
Means within columns followed by different letters, for each kind of potato, denote those attributes where marmalades differed significantly at $P < 0.05$ according to Tukey's test.

Table 2. Color, texture and taste standards compositions

Attribute	Standard
Color	
Redness	Low: 10YR 25/284
	High: 00YR 08/409 standard color (Martel S.A.)
Brownness	Low: 10YR 17/184 standard color (Martel S.A.)
Texture	
Spreadability	Low: gelatin
	High: spreadable cheese
Gumminess	Low: scones
	High: gummy candy
Hardness	Low: spreadable cheese
	High: gelatin
Graininess	Low: powdered sugar
	High: corn flour
Consistency	Low: water
	High: firm yogurt
Taste	
Sweetness	Low: water
	High: sucrose 60.0 g L^{-1}
Sourness	Low: water
	High: citric acid 2.0 g L^{-1}

Moreover, in the same fashion as the acceptability test, testers were asked to state the marmalade-evoked emotions.

For the emotional test, 540 consumers evaluated the concepts immediately after exposure to the stimulus[40] in a 9-point semantic differential scale (from −4.0 to 4.0) anchored with each pair of emotions.[41] Two samples were tested by each assessor as recommended by King *et al.*[42] No information was given about the samples.

All sensory tests were performed in the Instituto de Investigaciones Sensoriales de Alimentos, designed under ISO standard 8589:2007.[43] The samples were served at room temperature[13] in plastic cups coded with 3-digit random numbers. Mineral water and unsalted crackers were provided.

Instrumental texture analysis

The TPA (Texture Profile Analysis, QTS Texture Analyzer, Brookfield CNS Farrell; MA, USA), was performed using a cylindrical aluminium accessory (12.7 mm internal diameter, 35 mm length). Conditions: speed 5 mm s^{-1}, 10 mm distance and 100 g of load and 25 °C. The parameters were: hardness, adhesiveness, springiness, cohesiveness, gumminess and chewiness. Five replicates were conducted.

Instrumental color analysis

The marmalade color was measured (CIELAB system, ColorTec-PCM colorimeter, standard illuminant D_{65}; Accuracy Microsensors Inc., Pittford, NY, USA). Samples were contained in optical glass cells (15 mm high, 55 mm diameter). Registered parameters were: L^* = lightness (0 = black, 100 = white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b^*$ = blueness, $+b^*$ = yellowness). Two measurements were taken of each sample.

Statistical analysis

The statistical analysis was conducted for each type of potato. Analysis of variance (ANOVA) was performed among physico-chemical data. The binomial distribution was used to calculate the significant level for the triangle test, based on a number of correct answers. Analysis of outliers on sensory data was carried out by box-plot and stem-and-leaf methods. The ANOVA of sensory data was performed according to a mixed model with assessors as a random factor, sample and replication as fixed, and the double interactions assessor × sample, sample × replication and replication × assessor. An ANOVA one-way was conducted to analyze instrumental texture and color measurements. Pearson's correlation coefficients were calculated between sensory and instrumental data. An ANOVA one-way was done on the acceptability and emotional response. A partial least square 2 (PLS2) was also studied between 19 pairs of emotions (*Y*-variables) and nine sensory descriptors (*X*-variables). Principal components analysis (PCA) was conducted to correlate the acceptability and sensory attributes, where a correlation matrix was used and the minimum eigenvalue was set at 1. Finally, the relationship between acceptability and emotions was investigated by a partial least square 1

Table 3. *P*-values of the ANOVA of mixed model for sensory data

	Marmalades with *oca* potato						Marmalades with *collareja* potato					
Attribute	Assessor	Sample	Replication	AxS[a]	SxR[a]	RxA[a]	Assessor	Sample	Replication	AxS[a]	SxR[a]	RxA[a]
Degrees of freedom (*df*)	8	4	2	32	8	16	8	3	2	24	6	16
Texture												
Spreadability	0.00**	0.03*	0.13	0.05	0.02*	0.08	0.00**	0.00***	0.13	0.06	0.20	0.11
Gumminess	0.00**	0.14	0.51	0.72	0.03*	0.08	0.11	0.00***	0.80	0.23	0.13	0.00***
Hardness	0.00***	0.06	0.59	0.01*	0.05	0.12	0.02*	0.00***	0.04*	0.03*	0.01**	0.23
Graininess	0.03*	0.01*	0.43	0.51	0.01**	0.29	0.00**	0.00***	0.72	0.07	0.00***	0.01**
Consistency	0.08	0.54	0.41	0.05	0.05	0.08	0.24	0.00***	0.85	0.06	0.00***	0.68
Color												
Redness	0.24	0.00***	0.00**	0.31	0.00***	0.83	0.11	0.00***	0.27	0.06	0.06	0.19
Brownness	0.77	0.06	1.00	0.02*	0.01*	0.01**	0.77	0.00***	0.07	0.01*	0.27	0.01**
Taste												
Sweetness	0.00**	0.44	0.09	0.02*	0.55	0.80	0.05	0.01**	0.13	0.03*	0.42	0.10
Sourness	0.02*	0.00***	0.22	0.45	0.16	0.08	0.10	0.00***	0.82	0.06	0.15	0.00**

$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. [a]A, assessor; S, sample; R, replication.

Table 4. Mean ± SEM (c) for the sensory data of different formulations

	Strawberry:apple proportion for marmalades with *oca* potato					Strawberry:apple proportion for marmalades with *collareja* potato			
Attribute	20:60	30:50	40:40	50:30	60:20	20:60	30:50	50:30	60:20
Sample number	1	2	3	4	5	6	7	8	9
Texture									
Spreadability	10.10 ± 0.13^{b}	9.35 ± 0.25^{ab}	8.92 ± 0.35^{a}	9.48 ± 0.21^{ab}	9.40 ± 0.27^{ab}	9.46 ± 0.19^{b}	6.70 ± 0.49^{a}	8.70 ± 0.32^{b}	8.31 ± 0.46^{b}
Gumminess	1.90 ± 0.20^{a}	2.10 ± 0.19^{a}	2.20 ± 0.20^{a}	1.88 ± 0.14^{a}	2.41 ± 0.20^{a}	2.16 ± 0.24^{a}	3.68 ± 0.36^{b}	2.26 ± 0.18^{a}	1.50 ± 0.10^{a}
Hardness	2.00 ± 0.20^{a}	2.37 ± 0.25^{a}	1.79 ± 0.15^{a}	1.69 ± 0.13^{a}	1.91 ± 0.18^{a}	1.81 ± 0.12^{a}	4.21 ± 0.39^{b}	2.04 ± 0.13^{a}	2.30 ± 0.32^{a}
Graininess	6.18 ± 0.42^{b}	5.30 ± 0.48^{ab}	5.05 ± 0.53^{ab}	4.01 ± 0.37^{a}	4.04 ± 0.32^{ab}	4.77 ± 0.46^{a}	6.73 ± 0.48^{b}	4.22 ± 0.49^{a}	3.82 ± 0.42^{a}
Consistency	6.49 ± 0.44^{a}	6.73 ± 0.37^{a}	6.88 ± 0.35^{a}	6.79 ± 0.32^{a}	7.36 ± 0.32^{a}	6.43 ± 0.36^{a}	9.09 ± 0.13^{b}	7.33 ± 0.34^{a}	6.64 ± 0.38^{a}
Color									
Redness	1.72 ± 0.70^{a}	3.45 ± 0.34^{b}	6.43 ± 0.58^{c}	9.91 ± 0.14^{d}	9.32 ± 0.25^{d}	1.49 ± 0.11^{a}	2.07 ± 0.14^{a}	5.27 ± 0.58^{b}	8.94 ± 0.21^{c}
Brownness	5.66 ± 0.57^{b}	5.38 ± 0.58^{ab}	4.77 ± 0.60^{ab}	3.50 ± 0.49^{a}	3.71 ± 0.53^{a}	7.01 ± 0.57^{b}	7.63 ± 0.47^{b}	6.09 ± 0.62^{b}	3.60 ± 0.41^{a}
Taste									
Sweetness	7.37 ± 0.38^{a}	7.61 ± 0.38^{a}	8.44 ± 0.31^{a}	8.07 ± 0.46^{a}	7.60 ± 0.44^{a}	9.33 ± 0.22^{b}	7.76 ± 0.31^{a}	6.70 ± 0.42^{a}	7.33 ± 0.48^{a}
Sourness	5.17 ± 0.49a	6.43 ± 0.45^{ab}	6.59 ± 0.41^{ab}	7.79 ± 0.33^{bc}	8.30 ± 0.28^{c}	3.93 ± 0.45^{a}	5.81 ± 0.43^{b}	7.38 ± 0.40^{bc}	8.30 ± 0.31^{bc}

(c) centimeters; SEM, standard error of means.
Means within rows followed by different letters, for each kind of potato, denote those attributes where marmalades differed significantly at $P < 0.05$ according to Tukey's test.
Each sample was evaluated three times by each of the nine panelists.

(PLS1) (*Y*-variable. hedonic response; and *X*-variables, 19 pairs of feelings).

Multiple means comparisons were carried out by the Tukey test. All statistical analyses were performed using Infostat[44] with $P < 0.05$.

RESULTS AND DISCUSSION

Physico-chemical data

The ANOVA showed differences among samples ($P < 0.001$) (Table 1). The pH ranged from 3.50 to 3.89, which is in line with values reported by other authors.[45,46] The soluble solids (28.2–36.0°Brix) and a_w, (>0.950) were a consequence of the low proportion of sucrose used.

Sensory analysis

Triangle test

A total of 268 triangles were performed. The number of correct identifications required for significance within 10 and 15 judgments ($P < 0.05$), was between seven and nine. All samples produced different results except n° 10 (Table 1). Consequently, it was eliminated for the following analysis.

The list of descriptive texture terms and basic tastes was selected with the criteria that they were mentioned at least once by assessors, when the triangles were correct. Thus, the following attributes were chosen for descriptive analysis: spreadability, gumminess, hardness, graininess, consistency, sweetness and sourness.

Sensory profile and influence of the ingredient in the perception

Table 3 shows the results of the ANOVAs of the mixed model for sensory attributes. The assessors were a significant ($P < 0.05$) source of variation in some variables indicating that they did not use the scale in the same way, since differences among assessors are typical for sensory data.[47] Replication factor was not significant among samples except for redness in marmalades with *oca* and hardness in samples with *collareja*. This means that

Table 5. Mean ± SEM for the instrumental data of different formulations

	Strawberry:apple proportion for marmalades with *oca* potato					Strawberry:apple proportion for marmalades with *collareja* potato			
Attribute	20:60	30:50	40:40	50:30	60:20	20:60	30:50	50:30	60:20
Sample number	1	2	3	4	5	6	7	8	9
Texture[†]									
Gumminess	9.52 ± 1.31^{a}	9.12 ± 0.31^{a}	7.70 ± 0.73^{a}	8.78 ± 0.47^{a}	9.40 ± 0.67^{a}	8.40 ± 1.18^{a}	17.80 ± 2.21^{b}	9.14 ± 2.43^{a}	8.54 ± 0.61^{a}
Hardness	13.40 ± 1.44^{a}	13.80 ± 1.11^{a}	12.00 ± 1.76^{a}	11.80 ± 0.37^{a}	13.80 ± 1.16^{a}	15.80 ± 4.80^{a}	34.40 ± 2.58^{b}	14.00 ± 3.38^{a}	13.20 ± 1.50^{a}
Chewiness	58.70 ± 13.70^{a}	44.20 ± 4.05^{a}	32.00 ± 8.54^{a}	39.60 ± 5.46^{a}	47.40 ± 4.84^{a}	34.80 ± 5.57^{a}	102.00 ± 20.1^{b}	44.80 ± 21.5^{ab}	$38.30 \pm 6.08a$
Springiness	5.80 ± 0.70^{a}	4.73 ± 0.32^{a}	3.92 ± 0.62^{a}	4.45 ± 0.41^{a}	5.02 ± 0.31^{a}	4.08 ± 0.15^{a}	7.03 ± 0.98^{b}	4.52 ± 0.64^{a}	4.40 ± 0.39^{a}
Adhesiveness	-47.70 ± 9.13^{a}	-53.20 ± 10.90^{a}	-11.50 ± 21.20^{b}	-27.30 ± 8.59^{ab}	-57.20 ± 10.1^{a}	-32.50 ± 7.12^{b}	-95.00 ± 5.27^{a}	-51.70 ± 23.6^{ab}	-38.10 ± 10.10^{b}
Cohesiveness	-0.70 ± 0.03^{a}	-0.69 ± 0.04^{a}	-0.68 ± 0.04^{a}	-0.74 ± 0.03^{a}	-0.69 ± 0.02^{a}	$-0.60 \pm 0.06a$	-0.62 ± 0.05^{a}	-0.65 ± 0.04^{a}	-0.66 ± 0.05^{a}
Color[‡]									
L^*	33.50 ± 0.16^{d}	24.70 ± 0.06^{b}	25.20 ± 0.12^{b}	23.60 ± 0.00^{a}	27.00 ± 0.06^{c}	32.70 ± 0.04^{c}	28.20 ± 0.49^{a}	31.10 ± 0.01^{b}	27.70 ± 0.05^{a}
a^*	25.10 ± 0.26^{a}	26.00 ± 0.06^{a}	$26.40 \pm 0.37a$	25.10 ± 0.05^{a}	25.90 ± 0.40^{a}	24.00 ± 0.22^{a}	26.70 ± 0.17^{bc}	25.00 ± 0.77^{ab}	29.10 ± 0.28^{c}
b^*	32.30 ± 0.78^{a}	60.90 ± 0.11^{c}	43.50 ± 2.86^{b}	59.00 ± 5.00^{c}	63.00 ± 2.00^{c}	22.90 ± 0.18^{a}	53.50 ± 12.50^{a}	36.60 ± 6.18^{a}	27.40 ± 0.88^{a}

SEM, standard error of means.
Means within rows followed by different letters, for each kind of potato, denote those instrumental variables where marmalades differed significantly at $P < 0.05$ according to Tukey's test.
[†]Five replicates were carried out.
[‡]Two measurements were taken on each sample.

the judges showed good reproducibility. The differences were significant for spreadability, gumminess and graininess ($P < 0.05$) and highly significant for redness and sourness ($P < 0.001$) in samples with *oca*. The marmalades with *collareja* showed more marked differences for sweetness ($P < 0.01$), colors, all texture attributes, and sourness ($P < 0.001$) (Table 3), probably for the composition of this tuber.[21]

The assessor × ample interaction was significant for brownness, hardness and sweetness ($P < 0.05$) showing some assessor differences, but it is common in sensory studies.[47]

The mean values of sensory analysis are shown in Table 4. Concerning the samples with *oca*, note that marmalades with a low proportion of strawberry and high apple (20:60) were more spreadable than those with equal proportions (40:40), and more grainy than samples with high strawberry proportion (50) ($P < 0.05$). No difference was found in gumminess, hardness and consistency. The marmalades with high strawberry content (50–60 proportions) highlighted by the redness ($P < 0.05$); and the intensity of color increased with the strawberry proportion, as was expected. A similar observation was reported by Koppel *et al.*[48] in their study regarding strawberry jam. Marmalades with the highest apple proportion (60) were browner. High content of strawberry had significantly contributed to greater intensity of sourness (Table 4).

Concerning the *collareja* samples and taking into account the attributes of texture, the formulation n° 7, with high apple proportion (50), was different ($P < 0.05$) standing out by the gumminess, hardness, graininess, consistency and low spreadability. The formulations also increased the intensity of redness when the proportion of strawberry increased ($P < 0.05$). In the same way, the sample n° 9, with the highest strawberry proportion, (60) was significantly less brown (Table 4). Finally, the marmalade n° 6 with the lowest strawberry proportion (20) was the sweetest with the lowest sourness.

In general, the sourness of samples increased with the increase of strawberry and the decrease of apple contents. This was not evident in the perception of sweetness which exercised a moderating effect in sourness perception (Table 4). This masking effect from the sweetness to the sourness perception was also reported by Koppel *et al.*[48] in strawberry jams.

Instrumental texture and color analysis

The ANOVA of instrumental texture measurements showed more differences in *collareja* marmalades. Chewiness and adhesiveness ($P < 0.05$), gumminess ($P < 0.01$), hardness and springiness ($P < 0.001$) were affected among *collareja* samples, while only the adhesiveness ($P < 0.01$) for *oca* confitures. This could be related to the major content of starch in *collareja*.[21]

Lightness (L^*) was highly significant ($P < 0.001$) in all samples as observed by Saron *et al.*[49] in passion fruit juice. Redness (a^*) was different ($P < 0.01$) for *collareja* marmalades, while yellowness (b^*) was different for those with *oca* ($P < 0.001$).

Means and standard errors of instrumental texture and color quantification are shown in Table 5. Samples n° 1 and n° 6 with 60 apple proportion were the lightest. Samples n° 2, n° 4 and n° 5 stood out for the yellowness (b^*). No differences were found in *collareja* samples indicating a significant contribution of the *oca* tuber to this variable. On the contrary, the redness of *oca* marmalades were no different, and samples n° 7 and n° 9 (*collareja*) were redder. These findings showed the influence of the used ingredients in the instrumental characteristics.

Relation between sensory and instrumental variables

The mainly Pearson's coefficients are mentioned (Table 6): spreadability was negatively correlated with four texture sensory variables ($P < 0.01$) and instrumental hardness and cohesiveness ($P < 0.01$). Moreover, it was correlated with sweetness and sourness ($P < 0.05$).

Concerning color measurements, the marmalades were observed redder as in less brown ($r^2 = -0.533$, $P < 0.01$), as reported by Koppel *et al.*[48] with more lightness ($r^2 = 0.594$, $P < 0.01$). Yellowness was negatively correlated with L^* ($r^2 = -0.708$, $P < 0.05$).

Table 6. Pearson's correlations between sensory descriptors and instrumental variables

Attributes/data	Sensory attributes							Instrumental data				
	Consistency	Graininess	Hardness	Gumminess	Spreadability	Sweetness	Sourness	Adhesiveness	Springiness	Chewiness	Hardness	Cohesiveness
Sensory attributes												
Graininess	0.23**	–	–	–	–	–	–	–	–	–	–	–
Hardness	0.34**	0.34**	–	–	–	–	–	–	–	–	–	–
Gumminess	0.28**	0.39**	0.68**	–	–	–	–	–	–	–	–	–
Spreadability	−0.31**	−0.23**	−0.69**	−0.52**	–	–	–	–	–	–	–	–
Sweetness	0.11	−0.16*	−0.18**	−0.16*	0.28**	–	–	–	–	–	–	–
Sourness	−0.08	−0.18**	−0.21**	−0.20**	0.19**	−0.09	–	–	–	–	–	–
Instrumental data												
Adhesiveness	−0.19	0.13	−0.13	0.18	0.25	0.12	−0.16	–	–	–	–	–
Springiness	0.16	0.15	0.15	0.07	−0.13	0.07	−0.08	−0.71**	–	–	–	–
Chewiness	0.23	0.06	0.02	0.04	−0.10	0.14	0.01	−0.69**	0.85**	–	–	–
Hardness	0.41**	0.16	0.30*	0.21	−0.39**	0.06	−0.04	−0.68**	0.68**	0.75**	–	–
Cohesiveness	0.16	0.01	0.23	−0.18	−0.39**	−0.01	−0.02	−0.32	−0.03	−0.02	0.39**	–
Gumminess	0.33*	0.09	0.12	0.14	−0.22	0.07	0.03	−0.70**	0.77**	0.91**	0.90**	0.06

* $P < 0.05$, ** $P < 0.01$.

To summarize, spreadability was the variable which correlated with more variables, suggesting that it should be considered an important sensory characteristic.

Vilela *et al.*[16] also found this type of correlations, confirming that they depend on the berry. Our formulations had two novelty ingredients – Andean tubers – which generated changes in texture, color and tastes. Moreover, it would be interesting to evaluate sensory aspects by dynamic methods which would allow a better understanding of perception behavior.[50]

Acceptability and emotional test

Means comparison for the acceptability is shown in Table 7. Marmalades made with *oca* ranged from 6.20 to 7.00 ('like slightly – like moderately'). Sample n° 4 with 50 strawberry proportion obtained the highest score. No differences were found among *collareja* samples. As a rule, the acceptability of marmalades increased when the strawberry proportion increased.

A total of 476 concepts were elicited by consumers, in which 320 were different. Some examples were: autumn afternoons, grandmother's marmalade, countryside, fruit candies, fruit compotes, baby food, good memories, and rainy days. Most of the evoked emotions had a positive connotation according to Gutjar *et al.*[24] Nineteen words were selected with the criteria that they were mentioned by at least five consumers. The antonyms of each word were found, in order to build 19 pairs of emotions with opposite meanings, listed in Table 7. As can be observed, these terms arise from the consumer himself/herself, therefore in compliance with the suggested result by Ares *et al.*[51,52]

Furthermore, 540 consumers performed the emotional test. Several studies have evaluated the emotional response of food products using different number of evaluators: Collinsworth *et al.*[26] evaluated commercial carbonated orange soda with 217 consumers; Spinelli *et al.*[23] studied commercial dairy beverages with 219 individuals, and chocolate and hazelnut spreads with 238 subjects; Seo *et al.*[28] analyzed commercial dairy products with 100 panelists; Piqueras-Fiszman and Jaeger[53] made three emotional studies on meals with between 400 and 500 consumers. But there is no consensus about the correct number of individuals for this type of test. According to the cited authors, we decided that the number of consumers was appropriate for the emotional test in our study. Further research on this matter is needed.

With respect to *oca* marmalades, 10 emotional responses were different among samples (Table 7). It can be seen that sample n° 1 with the least proportion of strawberry resulted in more 'happy', 'rare' and with 'smooth-taste'. Sample n° 2 stood out by 'holiday' and 'diet' sensations. Sample n° 3 was related to 'happiness', 'present', 'health' and a 'smooth-taste'. Sample n° 4 was related to 'past', 'holiday' and 'non-diet'. Sample n° 5 was highlighted by 'strong-taste', 'routine' and 'non-diet' emotions. All samples evoked memories of 'homemade', 'typical', 'autochthonous', 'childhood', 'family' and 'rural', with sensations of 'pleasure', 'freshness' and 'good-taste'.

With respect to *collareja* products (Table 7), 11 evoked emotions were different. It can be seen that sample n° 6 with the least proportion of strawberry, was characterized as being 'atypical'. On the other hand, samples n° 7 and n° 8 stood out for evoking associations such us 'pleasure', 'childhood' and 'attractive', in addition to ''homemade', 'typical', 'health' and 'good-taste' for marmalade n° 7, and 'autochthonous' and 'happiness' for the confiture n° 8. The formulation n° 9 was considered less 'homemade'. In conclusion, it can be stated that samples with *collareja* produced sensations

Table 7. Mean ± SEM for the acceptability and emotional responses data of different formulations*

	Strawberry:apple proportion for marmalades with *oca* potato					Strawberry:apple proportion for marmalades with *collareja* potato			
Attribute	20:60	30:50	40:40	50:30	60:20	20:60	30:50	50:30	60:20
Sample number	1	2	3	4	5	6	7	8	9
Acceptability	6.20 ± 1.65^{a}	6.90 ± 1.27^{ab}	6.60 ± 1.70^{ab}	7.00 ± 1.69^{b}	6.40 ± 1.67^{ab}	6.40 ± 1.57^{a}	6.50 ± 1.51^{a}	6.30 ± 1.69^{a}	6.80 ± 1.66^{a}
Industrial/homemade	2.32 ± 0.26^{a}	1.88 ± 0.26^{a}	2.20 ± 0.26^{a}	1.97 ± 0.26^{a}	1.58 ± 0.26^{a}	1.30 ± 0.26^{ab}	2.27 ± 0.27^{b}	1.95 ± 0.27^{ab}	1.17 ± 0.26^{a}
Atypical/typical	1.28 ± 0.27^{a}	0.95 ± 0.27^{a}	1.45 ± 0.27^{a}	1.33 ± 0.27^{a}	0.97 ± 0.27^{a}	-0.45 ± 0.27^{a}	0.64 ± 0.28^{b}	0.37 ± 0.28^{ab}	0.47 ± 0.27^{ab}
Allochthonous/ autochthonous	1.88 ± 0.23^{a}	1.48 ± 0.23^{a}	1.65 ± 0.23^{a}	1.65 ± 0.23^{a}	1.53 ± 0.23^{a}	0.48 ± 0.23^{a}	1.39 ± 0.23^{bc}	1.68 ± 0.23^{c}	0.77 ± 0.23^{ab}
Sadness/happiness	2.18 ± 0.21^{b}	1.93 ± 0.21^{ab}	2.23 ± 0.21^{b}	1.82 ± 0.21^{ab}	1.35 ± 0.21^{a}	0.88 ± 0.21^{a}	1.73 ± 0.21^{bc}	2.03 ± 0.21^{c}	1.00 ± 0.21^{ab}
Past/present	-0.32 ± 0.28^{abc}	-0.43 ± 0.28^{ab}	0.72 ± 0.28^{c}	-0.62 ± 0.28^{a}	0.63 ± 0.28^{bc}	0.20 ± 0.28^{a}	0.08 ± 0.29^{a}	-0.37 ± 0.29^{a}	0.22 ± 0.28^{a}
Adulthood/ childhood	1.37 ± 0.28^{a}	0.65 ± 0.28^{a}	0.58 ± 0.28^{a}	0.73 ± 0.28^{a}	0.53 ± 0.28^{a}	-0.20 ± 0.28^{a}	1.17 ± 0.28^{b}	1.31 ± 0.28^{b}	0.20 ± 0.28^{a}
Artificial/natural	1.93 ± 0.26^{b}	1.70 ± 0.26^{b}	2.22 ± 0.26^{b}	1.75 ± 0.26^{b}	0.68 ± 0.26^{a}	0.67 ± 0.26^{a}	2.31 ± 0.27^{b}	2.14 ± 0.27^{b}	1.72 ± 0.26^{b}
Illness/health	1.75 ± 0.23^{ab}	1.15 ± 0.23^{a}	2.58 ± 0.23^{b}	1.52 ± 0.23^{a}	1.22 ± 0.23^{a}	1.58 ± 0.23^{a}	2.42 ± 0.23^{b}	1.97 ± 0.23^{ab}	1.48 ± 0.23^{a}
Non-attractive /Attractive	2.08 ± 0.25^{b}	2.27 ± 0.25^{b}	1.87 ± 0.25^{b}	1.83 ± 0.25^{b}	0.77 ± 0.25^{a}	0.23 ± 0.25^{a}	1.75 ± 0.25^{b}	1.47 ± 0.25^{b}	0.82 ± 0.25^{ab}
Common/rare	0.32 ± 0.26^{b}	-1.12 ± 0.26^{a}	-0.77 ± 0.26^{ab}	-0.38 ± 0.26^{ab}	-0.42 ± 0.26^{ab}	0.22 ± 0.26^{a}	0.31 ± 0.27^{a}	-0.64 ± 0.27^{a}	-0.40 ± 0.26^{a}
Traditional/exotic	-1.48 ± 0.27^{a}	-1.70 ± 0.27^{a}	-1.57 ± 0.27^{a}	-0.05 ± 0.27^{b}	-0.82 ± 0.27^{ab}	-0.23 ± 0.27^{a}	0.07 ± 0.27^{a}	-0.76 ± 0.27^{a}	-0.72 ± 0.27^{a}
Alone/family	1.48 ± 0.25^{a}	1.92 ± 0.25^{a}	1.20 ± 0.25^{a}	1.13 ± 0.25^{a}	1.60 ± 0.25^{a}	0.52 ± 0.25^{a}	1.59 ± 0.26^{b}	1.42 ± 0.26^{b}	1.08 ± 0.25^{ab}
Routine/holiday	-0.03 ± 0.28^{bc}	0.33 ± 0.28^{c}	-1.13 ± 0.28^{ab}	0.57 ± 0.28^{c}	-1.15 ± 0.28^{a}	-0.58 ± 0.28^{a}	0.19 ± 0.28^{a}	-0.07 ± 0.28^{a}	-0.03 ± 0.28^{a}
Rural/urban	-0.47 ± 0.30^{a}	-0.55 ± 0.30^{a}	-0.13 ± 0.30^{a}	-0.38 ± 0.30^{a}	0.27 ± 0.30^{a}	-1.08 ± 0.30^{a}	-0.90 ± 0.30^{a}	-0.76 ± 0.30^{a}	-0.25 ± 0.30^{a}
Non-diet/diet	-0.45 ± 0.30^{ab}	0.23 ± 0.30^{b}	-0.17 ± 0.30^{ab}	-0.07 ± 0.30^{b}	-1.30 ± 0.30^{a}	0.58 ± 0.30^{a}	0.49 ± 0.30^{a}	0.12 ± 0.30^{a}	-0.45 ± 0.30^{a}
Displeasure/pleasure	1.38 ± 0.22^{a}	1.73 ± 0.22^{a}	1.93 ± 0.22^{a}	1.32 ± 0.22^{a}	1.47 ± 0.22^{a}	0.63 ± 0.22^{a}	1.81 ± 0.23^{b}	1.97 ± 0.23^{b}	0.93 ± 0.22^{a}
Warmth/freshness	1.23 ± 0.29^{a}	1.02 ± 0.29^{a}	0.87 ± 0.29^{a}	1.15 ± 0.29^{a}	0.18 ± 0.29^{a}	0.25 ± 0.29^{a}	1.24 ± 0.29^{a}	0.93 ± 0.29^{a}	0.93 ± 0.29^{a}
Strong taste /smooth taste	0.87 ± 0.31^{b}	0.30 ± 0.31^{ab}	0.50 ± 0.31^{b}	0.08 ± 0.31^{ab}	-0.82 ± 0.31^{a}	0.98 ± 0.31^{a}	0.80 ± 0.32^{a}	0.88 ± 0.32^{a}	0.17 ± 0.31^{a}
Good taste/bad taste	-2.25 ± 0.22^{a}	-1.15 ± 0.22^{a}	-2.30 ± 0.22^{a}	-1.82 ± 0.22^{a}	-1.70 ± 0.22^{a}	-2.07 ± 0.22^{ab}	-2.64 ± 0.23^{b}	-2.29 ± 0.23^{ab}	-1.70 ± 0.22^{a}

SEM, standard error of means.
Means within rows followed by different letters, for each kind of potato, denote those acceptability and emotions where marmalades differed significantly at $P < 0.05$ according to Tukey's test.
*Positive and negative values inform the direction of the rating in the semantic differential scale; 0 is the middle point.

such as 'present', 'rare', 'traditional', 'routine', 'rural' and 'diet', along with perceptions of 'freshness' and 'smooth-taste'.

In brief, a change in some evoked emotions was observed when the strawberry proportion reached 50–60, from 'holiday' to 'routine', 'smooth' to 'strong-taste', 'diet' to 'non-diet', 'atypical' to 'typical', and even more evident in *oca* than in *collareja* samples. It seems that with 50–60 strawberry proportion, the confitures resemble a traditional red marmalade. This result is consistent with our acceptability and sensory color results and with the classic consumers' expectations.[54]

Relation between sensory attributes, emotions and acceptability

Partial least square regression 2: emotions versus sensory attributes

Figure 1 shows the relationship between nine sensory and 19 pairs of emotional attributes. The first two components explained 60.1% of the variance. It was considered that one sensory attribute was related to the 'negative side of the scale' of the emotional pair in the opposite quadrant, and with the 'positive side' in the same quadrant, as was interpreted by Seo *et al.*[28] In the first quadrant, texture attributes such as consistency, graininess, gumminess and hardness were correlated with 'good-taste', 'homemade', 'holiday', 'freshness', 'happiness', 'natural' and 'childhood' associated with sample n° 7. In the second quadrant, brown was related with 'smooth-taste', 'diet', 'rare', 'rural', 'past', 'atypical' and 'allochthonous'. Along the *y*-axis sweetness was opposed to 'pleasure' and 'family' related to samples n° 1, n° 2 and n° 6. In the third and fourth quadrants, it can be seen that spreadability, redness and sourness were correlated with 'urban', 'present', 'typical' and 'autochthonous' opposed to 'health', 'rare', 'diet' and 'smooth-taste' associated to samples n°s 3, 4, 5, 8 and 9.

Principal component analysis: acceptability versus sensory attributes

The PCA of the correlation matrix for marmalades and sensory characteristics is shown in Fig. 2, where the first two components explained 77.9% of the variance and the cluster analysis determined three groups. As can be observed along the PC1 from left to right, the acceptability was clearly related to sourness, redness and spreadability associated with samples n° 3, n° 4, n° 5 and n° 9 (cluster I). Sample n° 7 (cluster II) was related to texture attributes – consistency, hardness and gumminess – contrary to the hedonic response. Finally, an intermediate group (samples n° 1, n° 2, n° 6 and n° 8, cluster III) (Fig. 2) were linked with sweetness, brownness, graininess, less sourness and acceptability. Koppel *et al.*[48] concluded that it was three principal groups of strawberry jams: (1) sweet, red and high in berry content jams; (2) with granular texture and artificial flavor; and (3) brown, sour, astringent, low in berry content; but the acceptability was not researched in this work.

Cadena *et al.*[55] evaluated the acceptability of mango nectar, in which a negative correlation with the sweet and sour tastes was

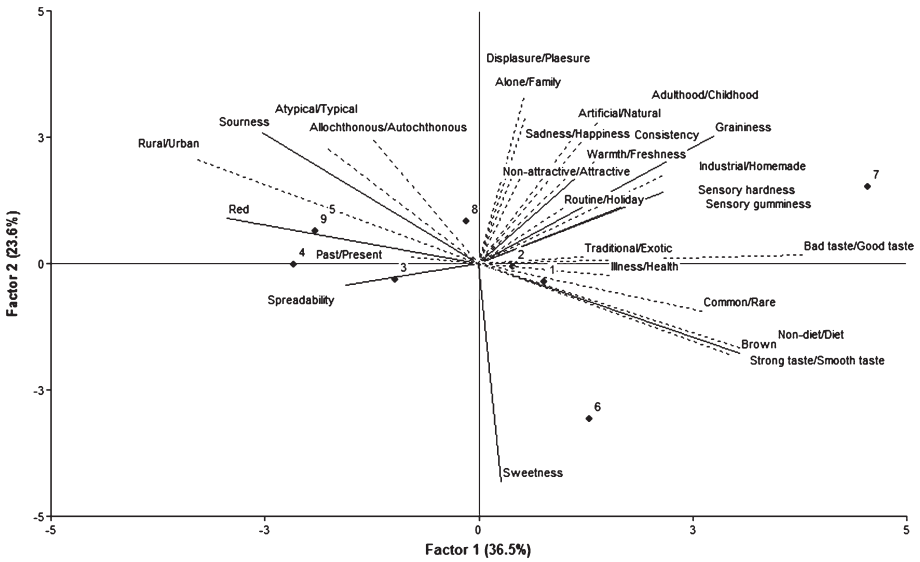

Figure 1. Partial least square regression (PLS2) for perceived attributes and 19 pairs of emotions (emotions are displayed in dotted line).

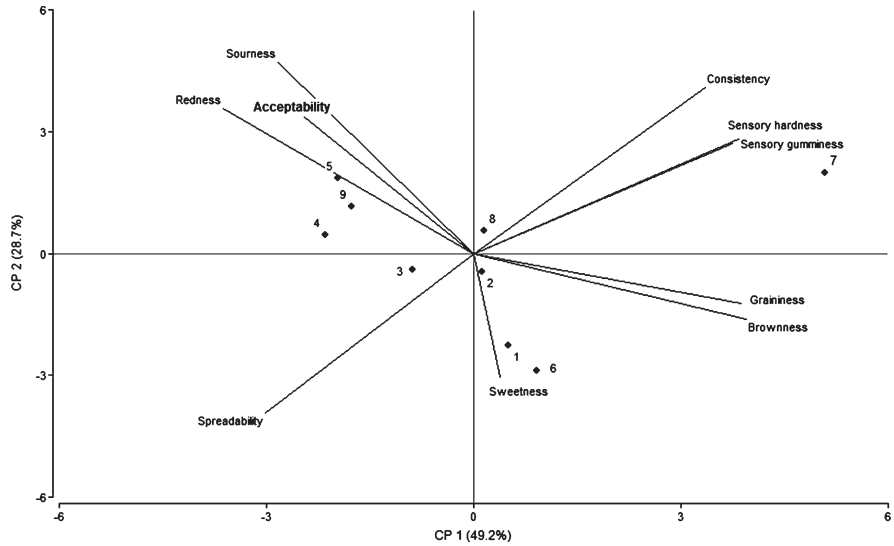

Figure 2. Principal component analysis (PCA) for sensory attributes and acceptability of nine marmalade samples.

found. Additionally, Alves *et al.*[54] in their study of time-intensity profile of strawberry jams, asseverated that the least accepted samples were the ones with the lowest sweetness; higher sourness intensity had a negative influence on the acceptability and jam consumers desire the equilibrium of strawberry flavor, sourness and sweetness. Additionally, Garrido *et al.*[56] analyzed apple jellies and concluded that consumers preferred fruitier, sweeter, and less acidic confitures. By contrast, Culetu *et al.*[57] affirmed that consumers' preferences of sugar-free plum jams are in line with a moderate degree of sweetness and sourness, and a good balance of sweet and sour. Moreover, in the cited work, the sweetest sample had lower scores for taste and overall acceptability. In our study, the sourness positively contributed to the hedonic response. This discrepancy could be related not only to trying other formulations and applying different sensory methods, but also to the different consumer's eating habits which varies by region and culture.[58]

The aforementioned research combined with our results allows us to state that it is the sweetness–sourness balance, because of a masking effect, rather than the sweetness or sourness separately, which determines the hedonic response of confitures with respect to tastes.

Concerning the color, Alves *et al.*[54] found that consumers prefer strawberry jams that are lighter in color and red. Moreover, Ares *et al.*[59] established a sensory quality index for strawberries in which strawberry odor, red color, and gloss were the most important characteristics. These results match ours.

In contrast, Garrido *et al.*[56] discovered that overall acceptability was mainly determined by the taste, and possibly the color of apple jellies, but not by their texture and spreadability. Instead, spreadability is an important variable commonly measured in gels; for example, lemon marmalade,[60] berry marmalades,[16] black-plum jams[61] and fluted pumpkin jams[62] because the microstructure of mixed gels had an essential role in sensory perception.[63]

In general, the acceptability of studied marmalades was positively correlated with sourness, redness and spreadability contrary to sweetness, brownness and graininess.

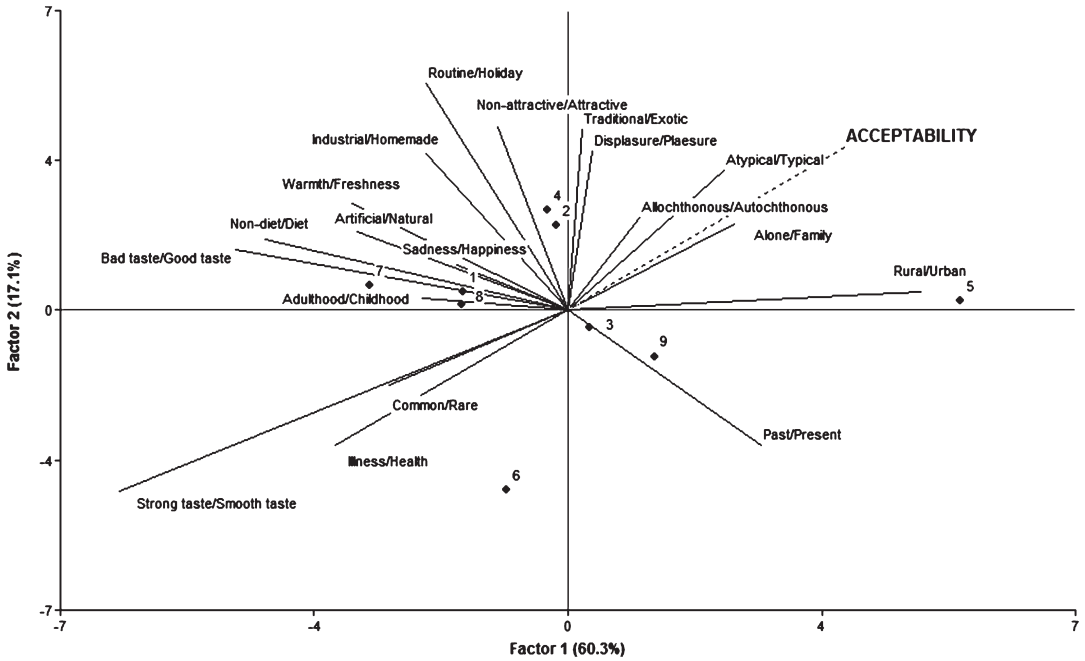

Figure 3. Partial least square regression (PLS1) for 19 pairs of emotions and acceptability of nine marmalade samples.

Partial least square regression: acceptability from emotions

PLS1 of the linking score and emotional response is presented in Fig. 3. The first and the second factors explained 77.4% of the variance. Along the first factor, it can be seen that acceptability is associated with 'typical', 'autochthonous', 'family', 'urban' and 'present' according to samples n° 5 and n° 9, contrary to 'bad-taste', 'diet', 'natural', 'freshness', 'smooth-taste', 'health' and 'rare' associated with the samples n° 1, n° 6, n° 7 and n° 8. Regarding the second factor, the acceptance was related to 'holiday', 'attractive', 'homemade', 'exotic' and 'pleasure' (samples n° 2 and n° 4). The relationship between emotions versus acceptability was also found by Leitch *et al.*[64] in teas with natural and artificial sweeteners; Gutjar *et al.*[24] in breakfast drinks; King *et al.*[27] in herbs and spices, carbonated and non-carbonated beverages, snacks and meat; and by Seo *et al.*[28] in dairy products, providing incremental information about consumers choice.

To summarize, what consumers liked most was related to spreadability, sourness and redness, because it evoked 'typical', 'autochthonous', 'urban' and 'present' emotions (Figs 1, 2 and 3) which showed that nowadays, urban consumers value regional confitures representative of the culture.

CONCLUSIONS

Spreadability was the variable which more correlated with other variables, suggesting that it should be considered an important sensory characteristic of marmalades.

The acceptability increased when the strawberry proportion was increased. In general, it was related to sourness, redness and spreadability, but it is the sweetness–sourness balance, because of a masking effect, which determines the hedonic response with respect to tastes.

A significant change in some emotional responses was observed when the strawberry proportion reached 50–60, from one feeling to its corresponding opposite. 'Typical', 'autochthonous', 'urban' and 'present' sensations favored the hedonic response revealing the important role of emotions in consumer liking.

Formulating marmalades with mixtures of fruits and non-traditional ingredients will allow giving value-added to Andean tubers. The elaboration of new products using innovative raw materials will be an incentive for farmers to cultivate them.

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