Research Article

Textural, pasting, and rheological behavior of starch-pectin-sucrose gels. Relation with sensory perception†

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Abbreviations: ANOVA, analysis of variance; **APS**, Andean potato starch; **BD**, breakdown; **BET**, back extrusion test; **CPS**, commercial potato starch; **FV**, final viscosity; **G´**, storage modulus (Pa); **G´´**, loss modulus (Pa); **LVR**, linear viscoelastic region; **PCA**, principal component analysis; **PLSR**, partial least square regression; **PT**, peak temperature; **PV**, peak viscosity; **RVA**, rapid visco analyzer; **TPA**, texture profile analysis; **SB**, setback; **tan δ**, loss tangent.

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Abstract

The aims of this research were: (1) to analyze textural, pasting and rheological characteristics of gels made with Andean potato starch (APS) compared with commercial potato starch (CPS); (2) to assess the sensory texture features; and (3) to relate instrumental behavior to human perception. Ten starch-pectin-sucrose systems were elaborated: five with CPS and five with APS (at 2.5-3.5-4.5-5.5-6.5% starch concentrations), and characterized by textural profile analysis (TPA), back extrusion test (BET), rapid-visco analyzer (RVA), oscillatory tests and sensory analysis. The systems had a weak gel behavior. The samples having the lowest concentrations of both starches were associated with springiness, while those with the highest concentrations were associated with sensory firmness, gumminess, chewiness, consistency, PV and G´. From 5.5%, effect of starch type was more important on gels behavior. Spreadability was the variable mostly affected by starch type and concentration.

Key words: Andean potato starch; starch gels; sensory perception; textural, pasting and rheological behavior

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1. Introduction

Starch is an essential ingredient for imparting favorable textural characteristics to many different types of food products [1]. The sources of starch used for industrial food production depend both on the local availability of applicable crops as well as prevailing environmental conditions such as altitude and climate. While the most prevalent starches used are that of corn (Zea mays) and potatoes (Solanum tuberosum), there are inherent benefits to studying starches from new sources [2]. For example, in the Northwest Argentina region there are many unique types of grains and a great variety of native tubers.

The Andean civilizations domesticated more than 400 potato varieties [3] which are essential to ensure both food diversity [4] as well as satisfying the nutritional requirements of the rural population [5].

Currently, Andean potatoes are the main ingredients in the Puna's (high altitude desert) local culinary preparations [6] and have also been succesfully incorporated into sophisticated gastronomical dishes all over the world [7]. Moreover, there are other ways to take advantage of Andean potatoes that have not yet been well explored. Their starch could provide different and unique functionalities [8].

Starch is widely used in the food industry [9, 10], and is usually combined with hydrocolloid or sugar to improve its techno-functional properties [9-13]. Varying the proportion of these ingredients has a direct affect on mouthfeel properties, hence it is important to delve into the study of gelation, retrogradation, textural and rheological properties [14] as well as any potential esthetic issues. The relation between sensory and instrumental features was studied by different researchers [6, 15], and allows us to understand what makes certain textural characteristics more desirable than others in a given food [16].

The study of different concentrations of starch used as thickening agent can be both expensive and time consuming. Consequently, this investigation focuses on ten different model systems which were selected to simulate the properties of a wide variety of foods and to determine how changes in starch concentration affect textural characteristics. The aims of this research were: (1) to analyze textural, pasting and rheological characteristics of gels made with APS as compared with CPS; (2) to assess the sensory texture features and (3) to relate instrumental behavior to human perception.

2. Materials and methods

2.1. Raw materials

Two starch varieties were used: "commercial" (*Solanum tuberosum*) (moisture content: 18.5% and proteín content: 0.2%), purchased in the local market, and "Andean" (moisture content: 14.3% and proteín content: 0.9%) isolated from "rosadita" (*Solanum tuberosum spp. Andigenum*) [17]. Amylose content was determined according to Juliano [18]. Sucrose (commercial grade), low methoxyl pectin (Gelfix S.A.) and calcium lactate (Merck-Nºcas 5743-47-5) were also used to prepare composite gels.

2.2. Sample preparation

Ten model systems (gels) were elaborated: five with CPS and five with APS, at 2.5; 3.5; 4.5; 5.5; 6.5% w/w. Sucrose (35.0% w/w) was mixed with pectin (0.50% w/w); water (60±1 ºC) was added and pH=3 was adjusted with citric acid (0.026% w/v). The blend was cooled to 40±1 ºC and stirred (10 min, 600 rpm, constant temperature). The starch was dissolved in cold water and added to the mix. Afterwards, the mix was placed in a water bath (Vicking, Dubnoff) for 30 min at 80±1 ºC, stirred at 90 rpm. The calcium lactate (0.055% w/w) was incorporated after 25 min of stirring and heating. The hot solution was placed in containers at room temperature (22±2 ºC) for 30 min. Finally, the gels were stored at 5±1 ºC for 24 h. Five different batches were produced.

2.3 Instrumental test

2.3.1 Texture Profile Analysis

It is a test based on the imitation of the chewing process with a double compression (in two cycles) of a sample [19]. It was applied using a cylindrical aluminum accessory (12.7mm internal diameter, 35mm length) was used (QTS Texture Analyzer, Brookfield CNS Farrell) with the following conditions: speed 120mm/min; distance 10mm and 100g of load, at 25 ºC. Measurements of hardness (N), adhesiveness (J), springiness (dimensionless), cohesiveness (dimensionless), gumminess (N) and chewiness (J) were obtained. Five replicates were conducted.

2.3.2 BET

Back Extrution-Test (Universal Testing Machine model 3342, INSTRON, EUA) was conducted on gels at 25 ºC. The samples were contained in extrusion cells (50 mm internal diameter). A compression disc accessory (35 mm diameter) was introduced to 30 mm at 1 mm/s speed. The extrusion max force (N) was used as firmness index and the area under the curve was used as thickness index (N/s) [9, 20]. The analysis was done in quintuplicate.

2.3.3 Rheological measurements

Viscoelastic properties (Discovery HR 2 rheometer, TA Instruments Inc., USA) were evaluated using plate-plate geometry (40 mm diameter), with Peltier temperature control. The gels were placed in the measuring system and the upper plate was placed in position (1 mm gap). The sample excess was removed and rested for 10 min to allow for sample relaxation [21]. The oscillatory assays were carried out: (1) strain sweep (0.01-100%, 1 Hz, 25 ºC), in order to determine LVR; (2) frequency sweeps into LVR (strain: 0.2%), frequency range 0.1-10.0Hz and 25 ºC; and (3) temperature ramp from 25 to 80 ºC, heating rate 5 ºC/ min, 1 Hz, strain: 0.2%.

Storage modulus (G´) (Pa), loss modulus (G´´) (Pa) and loss tangent (tan δ = G´´/G´) were recorded. The assays were carried out in duplicate.

2.3.4 Pasting properties

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This test allowed obtaining the apparent viscosity profile of the slurries as a function of temperature and time. RVA Potato Starch Pasting Method (RVA Method 7.05/2010) (RVA 4500 (Perten Instrument AB, Hägersten, Sweden) was applied. A known amount of starch (14% moisture base), corresponding to each gel concentration, was dispersed in 25 mL of solution (sucrose, pectin, calcium lactate and distilled water) inside the aluminum canister, and placed in the RVA measuring system. Dispersions were then stirred (960 rpm, 10 s) and slowed down to 160 rpm (50 ºC, 10 s). The samples were heated to 95 ºC (4 min 42 s) and finally, cooled down (50 ºC-11 min). The end of the test was set at 13 min. Throughout all the experiment the samples were stirred at 160 rpm. The following parameters were registered (Thermocline software for Windows): PT (ºC), PV (cP), BD (cP) (PV minus trough viscosity), FV (cP) and SB (cP) (FV minus trough viscosity). Pasting profiles were done in duplicate.

2.4 Sensory analysis

2.4.1 Panel training

Nine volunteers (24-42 years) with previous sensory evaluation experience [13] were trained in the texture profile method (5 sessions-1.5 h). They were instructed about the common terms used in texture descriptions, definitions, and the use of the scale (ISO 13299:2016) [22]. The anchors selection were performed according to ISO 6658:2005 [23] and verified in a focus group session (1 hour), where some were replaced by products more related to Argentinean habits (Table 1).

2.4.2 Sensory profile

Texture Profile Method was conducted using a 10 cm-unstructured scale (4 sessions-2 h). Seven descriptors were analyzed: spreadability, consistency, adhesiveness, cohesiveness, firmness, springiness and extensibility. Each assessor evaluated five samples in duplicate according to a randomized complete block design. The gel systems were presented in a balanced way (first the CPS gels, then those with APS and vice versa) with an intermediate break. Water and crackers were provided.

2.5 Statistical analysis

Amylose content was compared with Student-t test. One-way ANOVA was conducted to analyze TPA, BET, frequency sweep (1 Hz) and RVA data. Outliers' analysis 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. Moreover, types of starch×starch level interactions were analyzed and partitioned ANOVA was conducted when significant (F-test).

A stepwise linear regression model was used to select the instrumental variables which best predicts the perception response. The relationship between sensory attributes (Y-variables) and instrumental data (X-variables) was investigated by PLSR. Finally, a hierarchical cluster analysis was carried out using Ward´s method and Euclidean distance. Comparison of multiple means were carried out by Tukey-test. All statistical analyses were performed using Infostat (2016) ($P<0.05$).

3. Results and discussion

3.1 Texture profile analysis

Hardness, springiness, gumminess, and chewiness depended on the starch used [starch type×starch level interactions: $F_{(4,41)}=4.08$ ($P<0.01$), $F_{(4,41)}=8.09$ ($P<0.001$), $F_{(4,41)}=5.30$ ($P<0.01$), and $F_{(4,41)}=8.91$ ($P<0.001$), respectively]. In general, for CPS gels, these variables remained constant up to 5.5% starch from which they increased ($P<0.05$). Regarding APS systems, such trend was not so clear (Table 2). The adhesiveness and cohesiveness did not depend on starch variety. Gels with 2.5 and 6.5% starch were more adhesive, principally those with CPS, and less cohesive, which could be due to the sugar

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molecules-starch granules interaction: when the amount of water available in the system decreases due to an increase in the concentration of starch, sugar plastifying effect is reduced and its interaction with the molecules of starch is delayed [9], interfering in the formation of dispersion structure, leading to more adhesive and less cohesive gels [24]. It could also be due to the fact that 2.5% starch gels were more liquid and, therefore, more adhesive; and 6.5% starch samples were particularly adhesive. This issue should be further investigated.

3.2 Back extrusion test

The firmness index and consistency data for gelatinized samples showed significant interaction with the starch variety [$F_{(4,40)}$=1539.5 and $F_{(4,40)}$=8821.9, respectively]. Both variables increased with the starch increase until 5.5% (samples nº 4 and 9; Table 2), where they decreased gradually. It could also be due to the sugar molecules-starch granule interaction whereby: the increase in the concentration of starch decreases the amount of available water. The sugar plastifying effect is reduced and its interaction with the molecules of starch is delayed, resulting in less firmness and consistency [9, 24].

3.3 Rheological measurements

The LVR was determined at 0.2% strain. Into the LVR, G´ was greater than G´´, and both moduli were almost independent of strain (not shown). Similar results were reported by Sharma, et al. [25] about texture of pureed carrots with hydrocolloids and for Galkowska, et al. [10] in their starch-pectin-sucrose systems study.

G´ was greater than G´´ throughout the whole range of frequency tested (Figure 1), as commonly observed for normal starch gels. This indicates the dominance of the elastic behavior over the viscous, which is a typical characteristic of solid-like gels [13]. No crossover was noticed within the range of frequency accessed (0.1 to 10.0 Hz). In addition, it was observed that moduli G´ and G´´ showed a negligible frecuency dependence, which reinforces the weak gel-like character [25].

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G´ and G´´ depended on the starch origin [starch type×starch level interactions: $F_{(4,10)}$=156.2 and $F_{(4,10)}$=167.4, respectively]. G´ and G´´ were different (P<0.05) for the commercial starch-pectin-sucrose systems, sample n°5 showing the highest values. No difference was found in APS gels. Tan δ relates to the viscous and the elastic behavior (tan δ G´´/G´) [8] and provides information on the balance of the viscoelastic modulus of a material [25]. The tan δ range of 0.115 to 0.173, indicating a weak viscoelastic gel character [26, 27] and a stable structure [21]. This is in accordance with results reported by Galkowska et al.[10], who obtained gels with sucrose, pectin and starch with weak viscoelastic character, and Cruz [8] using starch suspensions. Moreover, interactions between pectin molecules and amylose interfere with network formation and result in weaker gels [28-30]. These results suggest an interaction between pectin and starch, favoring the formation of weak gels.

Concerning temperature sweep (results not shown), G´ was predominant over G´´, indicating that all systems had solid features [9]. Both moduli slowly increase as temperature was increased.

The differences were more marked in CPS systems than in those with APS; M5 with the highest starch level (6.5%), for the major thickness and heat-resistance properties [9]. APS gels followed a similar viscoelastic behavior.

3.4 Pasting properties

Figure 2 and Table 3 show the pasting properties. The PT ranged between 88.4 and 94.0ºC and the values were higher than those reported by Cruz [8] and Galkowska [10] (65.3-70.6°C). It could be attributed to starch-pectin interactions which restrict the swelling of starch granules [10]. Sucrose could reduce the water availability and act as an anti-plasticizing agent requiring higher energy to gelatinization thus retarding this process [10]. In addition, the starches with high amylose content [18], like those used in this research (28.9±1.58 % and 31.7±2.09 %, for CPS and APS, respectively, classified as “high

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amylose content"; Student-t test showed no significant differences between them [$t_{(4)} = -1.79$, $P > 0.05$]), had higher PT and FV than starches with low amylose content, probably due to greater hydrogen bonding interactions [31].

In both cases, in the warm-up stage, the viscosity up until a PV (Fig.2). As expected, the samples prepared with the highest starch concentration showed the maximum PV (measure of the swelling power of starch in terms of the resistance of swollen granules to shear; it is influenced by size, rigidity and amylose and amylopectin ratio) [32].

Swelling of granules, accompanied by leaching of amylose, increases viscosity, while granules may rupture during further heating, resulting in a decrease in viscosity. During the holding period at 95 ºC, the sample is subjected to mechanical shear stress, which usually leads to further disruption of starch granules and amylose leaching. Leached-out amylose molecules are more or less aligned in the direction of flow, contributing to the breakdown of viscosity [13].

We can also be observe (Fig. 2) an increase in viscosity during the cooling period (SB), probably due to the reorganization of the leached linear chains in the heating steps and the greatest number of union zones during paste formation, turning into a network that retains more water [33], related to the retrogradation of the amylose chains [13]. Additionally, the higher starch concentration, the greater FV. This proves advantageous as a thickening and texturizing agent for applications on fruit-based products [10].

Three RVA variables: PT, PV and BD depended on starch variety [starch type×starch level interactions: $F_{(4,10)}=7.43$ ($P<0.01$), $F_{(4,10)}=8.21$ ($P<0.01$) and $F_{(4,10)}=17.26$ ($P<0.01$), respectively]. For samples with CPS (n°1-n°5), no significant differences were found for PT and SB (Table 3). PV, BD and FV increased with the increase in starch concentration ($P<0.05$). Cruz [8] found BD more pronounced (higher BD values), indicating less stability, on starch suspension at 6.25% w/w. The BD of samples analyzed in the present study was not abrupt, suggesting that both, sucrose-pectin combination favored the stability and starches were more resistant to disruption by shear during gelatinization [8].

Regarding gels with APS (n°6-n°10), all parameters increased with increasing starch concentration. This was more remarkable in PV and FV, since significant differences were found for all concentrations (Table 3, P<0.05).

In summary, even though there was no statistical difference in the amylose content of starches, this slight difference was enough to affect pasting behavior.

3.5 Sensory profile

The results of ANOVAs of the mixed model of sensory data indicated that assessors were a significant (P<0.05) source of variation in some variables (results not shown). This is common for sensory data, showing that the evaluators did not use the scale in the same way [34]. The replication factor was not significant among gels, except for spreadability in samples with CPS, adhesiveness for gels with APS and consistency for both cases, reflecting a relatively good reproducibility. The assessor×sample interaction was only significant for consistency (P<0.01) and firmness (P<0.001) in gels with CPS, suggesting that, in general, judges did not change their use of scale among samples.

Spreadability, cohesiveness, firmness and springiness depended on starch origin [starch type×starch level interactions: $F_{(4,317)}=3.72$ (P<0,01), $F_{(4,315)}=3.68$ (P<0,01), $F_{(4,309)}=8.19$ (P<0,001) and $F_{(4,312)}=4.67$ (P<0,01) respectively]. Taking the samples with CPS into account, highly significant differences (P<0.001) were found for spreadability, cohesiveness, firmness, springiness and extensibility. In APS gels, spreadability (P<0.05), consistency (P<0.01) and adhesiveness (P<0.001) were different.

The gels with CPS from 2.5 to 5.5% were more spreadable than those prepared with 6.5% which showed the greatest firmness and the lowest springiness (Table 2). At the lowest starch concentration (2.5%), spreadability was lower, and then increased to an intermediate concentration (5.5%), to end up falling at the maximum concentration (6.5%).

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A similar behavior but less marked was observed in model systems with APS. It could also be observed that systems with APS showed an increase in consistency and adhesiveness when the starch concentration increased (Table 2).

Spreadability was the variable most differently perceived due to the effect of starch origin and level, being one of the most important features for the consumer [15].

3.6 Relation between instrumental and sensory data (PLSR)

Hardness, instrumental adhesiveness and firmness, G´´, SB and FV were omitted according to stepwise method, and PLSR explained the 60.6% of the overall variation with the two first factors (Figure 3). Sensory adhesiveness was predicted by BD, tan δ, PV and instrumental consistency (quadrant I), opposite to sensory springiness (quadrant III). Small angles among sensory cohesiveness, consistency and firmness, G´, instrumental cohesiveness, chewiness and gumminess showed positive correlations (quadrant II), contrary to spreadability and extensibility, which correlated with instrumental springiness and PT (quadrant IV). These results highlight the relationship between perceived variables and their instrumental equivalents, cohesiveness for these models being particularly important [35].

Moreover, PV is a measure of the swelling power of the starch in terms of the resistance of swollen granules to shear [32], and G´ is a measure of strength/overall resistance of gels against deformation. A positive correlation of these parameters with instrumental and sensory consistency, respectively, indicates that a firm sample will need more energy to be deformed [25]. Sharma [25] also found correlations between consistency and G´.

A PLSR plot (Figure 3), shows that the gels were separated from left to right along the Factor 1 by its springiness, spreadability and extensibility, on the one hand (samples with 2.5-3.5-4.5% starch levels, for both starches), and gumminess, chewiness and sensory consistency, cohesiveness and firmness, on the other (samples with 5.5-6.5% CPS concentrations). In addition, from up to down along Factor 2, samples were separated by

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sensory adhesiveness (samples with 5.5-6.5% APS levels) and instrumental cohesiveness on the other.

Cluster analysis (distance of 9.0) allowed identifying three groups of samples (Figure 4): cluster I, formed by samples nº4 and nº5 (highest concentrations of CPS-5.5 and 6.5%); cluster II, made up of gels nº9 and nº10 (with the largest concentrations of APS-5.5 and 6.5%) and cluster III, with systems nº1, nº 2 and nº 3, and nº6, nº7 and nº8, with the lowest concentrations of CPS and APS (2.5, 3.5 and 4.5%), respectively.

It should be noted that samples with the highest starch levels (5.5-6.5%), n°4 and n°5, were opposite to samples n°9 and n°10, reinforcing the effect of starch variety on the textural, pasting, rheological and sensory behavior from 5.5% starch level. In short, some starch type×starch level interactions were found and from 5.5% starch is the effect of variety was more important than the concentration.

4. CONCLUSION

In the current research, instrumental and sensory analysis showed complementary data to better understand the relation between gel behavior and perception. Gumminess, hardness, chewiness and springiness of TPA, and firmness and consistency of BET, G´ and G´´, PV, BD and PT depended on the starch used. This was perceived in its spreadability, cohesiveness, firmness and springiness. Spreadability was the most important variable in this differentiation.

The gels formulated with the lowest starch concentrations (2.5-4.5%) were associated with instrumental and sensory springiness, while those with the highest concentrations (5.5-6.5%) were related to sensory firmness, gumminess, chewiness, consistency, PV and G´. When the starch level reached 5.5% the effect of the origin was more important than the concentration.

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Both starches resulted in high amylose content. The use of APS obtained gels with lower final viscosities but more stable at temperature changes than those made with CPS. In addition, the APS gave rise to instrumentally firmer and more consistent gels, which were perceived to be more spreadable. This is an advantage from a functional point of view with respect to CPS.

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Table 1. Terms and standards selected for sensory evaluations.

Descriptors	Standards	
	Low	**High**
Spreadability	jelly	spreadable cheese
Consistency	water	jelly
Adhesiveness	water	spreadable cheese
Cohesiveness		
Firmness	spreadable cheese	jelly
Springiness		
Extensibility	marshmallows	spreadable cheese

Table 2. Means±S.D. for the TPA, BET and sensory data for model systems

		Samples									
		Gels with CPS					Gels with APS				
Type of starch × starch level	Starch percentage	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**
	n° of sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	TPA data										
Significant	Gumminess (N)	16.9±1.73ab	15.3±1.73a	15.7±1.73a	27.4±1.93c	23.4±1.46bc	14.4±1.01a	15.4±1.01ab	11.6±1.01a	15.0±1.01ab	16.5±1.01b
	Hardness (N)	50.6±6.77ab	38.2±6.77a	39.2±6.77a	74.5±7.57b	78.4±5.72b	44.4±2.04b	48.6±2.04bc	33.0±2.04a	50.4±2.04bc	55.0±2.04c
	Chewiness (J)	77.5±13.0a	95.4±13.0a	97.9±12.9a	207±14.5b	155±10.9b	84.0±9.00ab	89.2±9.00ab	54.9±9.00a	89.4±9.00ab	99.2±9.00b
	Springiness	4.75±0.24a	6.22±0.24b	6.24±0.24b	7.53±0.26c	6.50±0.20b	5.72±0.29b	5.76±0.29b	4.72±0.29a	5.94±0.29b	5.95±0.29b
Not significant	Adhesiveness (J)	-14.2±2.18a	-4.13±2.18c	-5.78±2.18bc	-3.84±2.44c	-10.7±1.84ab	-7.42±1.31a	-7.83±1.31a	-6.10±1.31a	-7.03±1.31a	-9.13±1.31a
	Cohesiveness	0.34±0.01ab	0.40±0.01b	0.41±0.01b	0.37±0.02b	0.30±0.01a	0.33±0.02a	0.32±0.02a	0.35±0.02a	0.30±0.02a	0.30±0.02a
	BET data										
Significant	Firmness	0.44±0.00b	0.41±0.00a	0.53±0.01c	1.04±0.01e	0.82±0.02d	1.10±0.03a	1.56±0.01b	1.11±0.01a	2.35±0.01d	1.65±0.01c
	Consistency	4.67±0.00a	4.65±0.07a	5.86±0.01b	12.8±0.01d	9.97±0.00c	13.2±0.03b	15.6±0.01d	11.5±0.00a	21.1±0.08e	15.1±0.05c
	Sensory data										
Significant	Spreadability	6.07±0.44ab	7.40±0.44b	7.48±0.44b	6.75±0.44b	4.75±0.44a	6.09±0.43a	7.08±0.43ab	6.43±0.43ab	7.55±0.43b	6.80±0.43ab
	Cohesiveness	3.28±0.39ab	1.78±0.42a	2.76±0.39a	2.48±0.40a	4.81±0.39b	3.47±0.39a	2.11±0.40a	2.48±0.40a	2.55±0.39a	2.51±0.40a
	Firmness	2.37±0.40a	1.58±0.42a	2.72±0.40a	2.20±0.42a	5.37±0.40b	2.93±0.37a	1.95±0.37a	2.41±0.37a	2.23±0.36a	2.08±0.37a
	Springiness	7.67±0.35b	7.82±0.35b	8.22±0.37b	8.47±0.36b	5.70±0.36a	7.60±0.43a	7.80±0.41a	6.72±0.41a	7.50±0.41a	7.23±0.41a
Not significant	Consistency	6.73±0.34a	6.22±0.34ª	6.61±0.34a	6.79±0.34a	6.84±0.34a	5.54±0.39a	5.68±0.39a	6.38±0.39b	6.49±0.39b	6.48±0.40b
	Adhesiveness	5.74±0.39a	5.68±0.39a	6.23±0.39a	5.78±0.39a	6.27±0.39a	5.18±0.40a	5.90±0.40ab	6.35±0.40ab	6.15±0.40ab	6.92±0.41b
	Extensibility	6.99±0.41ab	7.11±0.41ab	7.93±0.43b	6.87±0.41ab	5.71±0.41a	7.29±0.34a	7.62±0.35a	7.33±0.35a	7.95±0.34a	7.34±0.34a

Means within rows followed by different letters, for each kind of starch, denote those attributes where gels differed significantly at *P* <0.05 (Tukey´s test).

Table 3. Means±SD of RVA Parameters for model systems

		Samples									
		Gels with CPS					Gels with APS				
Type of starch × starch level	Starch percentage	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**
	n° of sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Significant	PT (ºC)	90.43±0.67a	91.83±1.10a	90.08±0.11a	89.23±2.23a	87.98±0.46a	90.88±0.11ab	91.20±1.70ab	88.35±0.07a	94.00±1.20b	92.83±0.60b
	PV (cP)	1200±187a	1774±21.9b	2866±78.5c	4049±200d	5703±265e	1379±89.8a	2021±120b	3190±129c	3756±226d	4958±83.4e
	BD (cP)	99.00±21.2a	217.5±40.3ab	375.5±34.6ab	743.5±227c	488.0±127bc	92.50±7.78a	290.5±88.4a	400.5±10.6a	1397±115b	1475±153b
No significant	SB (cP)	785.0±69.3a	952.5±99.4a	1024±109a	1259±526a	1734±317a	688.0±32.5a	1026±75.0ab	1349±94.1b	2477±0.71c	2686±160c
	FV (cP)	1887±236a	2509±37.5a	3515±3.54ab	4564±96.2b	6948±366c	1974±115a	2756±134b	4139±213c	4836±110d	6169±91.2e

Means within rows followed by different letters, for each kind of starch, denote these variables where gels differed significantly at *P* <0.05 according to Tukey´s test.

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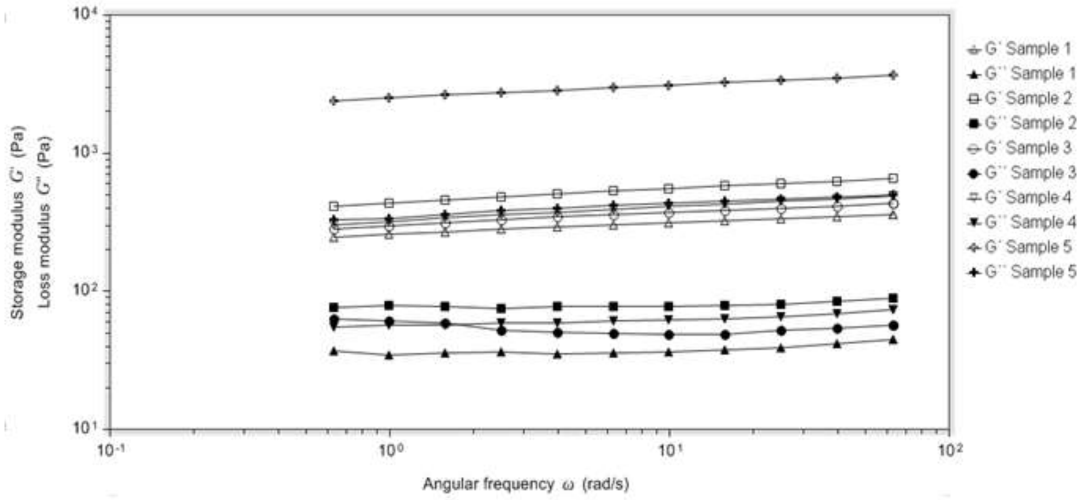
1a



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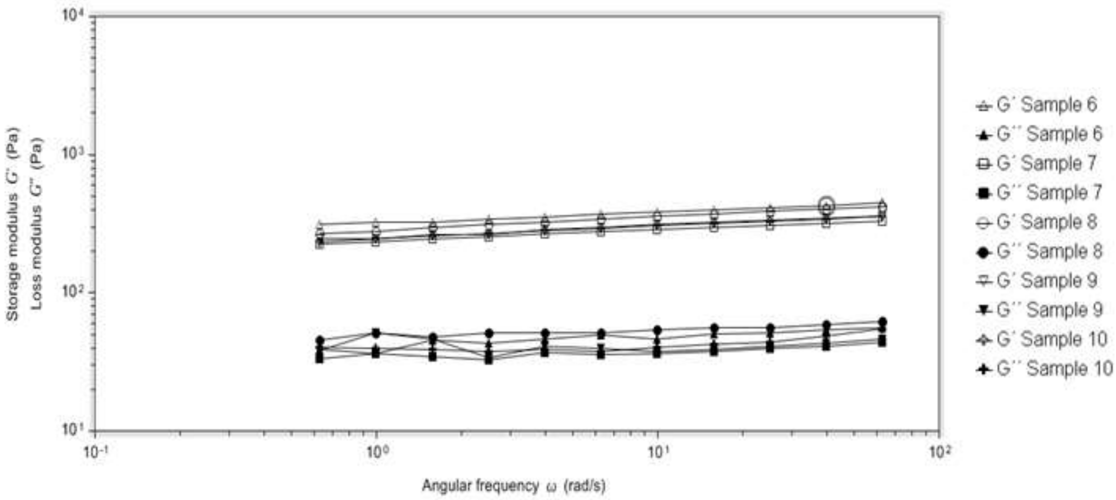

Figure 1. G´ and G´´ vs. angular frequency (ω) for commercial (1a) and Andean (1b) systems

Figure 1

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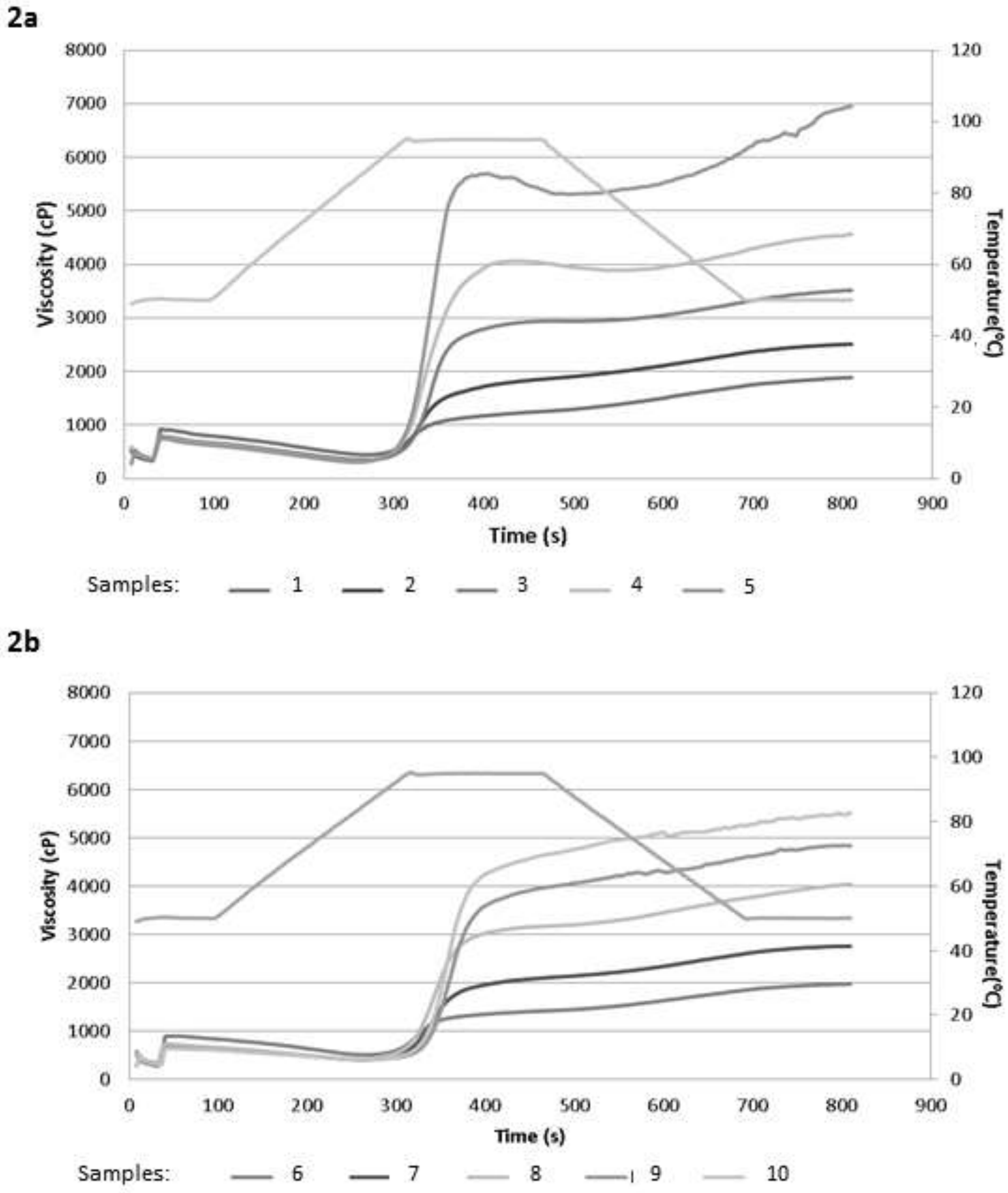

Figure 2. Pasting curves of commercial (2a)/Andean (2b) starch-pectin-sucrose systems

Figure 2

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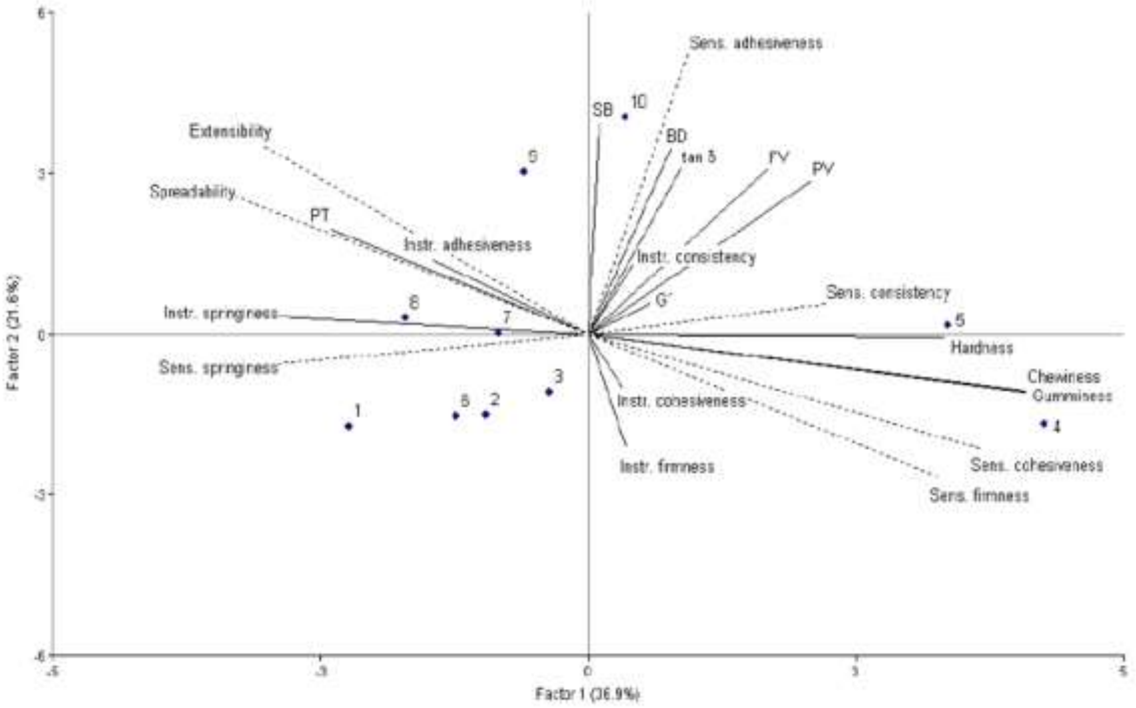

Figure 3. PLSR for sensory attributes and instrumental data

Figure 3

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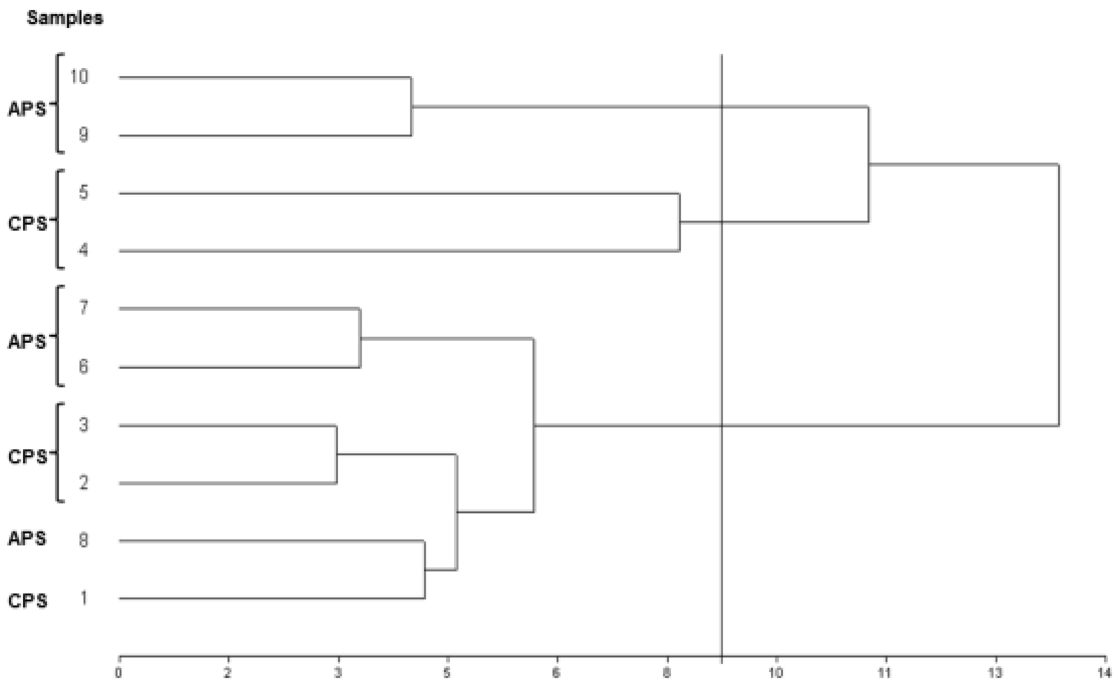

Figure 4. Dendogram of the cluster analysis

Figure 4