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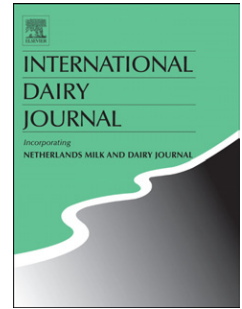
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1 **Whey protein concentrate gels with different sucrose content:**
2 **instrumental texture measurements and sensory perception**

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26

27 **Abstract**

28

29 Correlations between instrumental texture, sensory texture and sweetness perception
30 were studied in whey protein concentrate (WPC) gels at different pH (4 and 7), sucrose (0-
31 40%, w/w) and whey protein (10-20%, w/w) content. The presence of sucrose modified the
32 structure of WPC gels, mainly at pH 4, making the gel structure more homogeneous and
33 with smaller pores. Sucrose also increased the solid behaviour of gels, their water holding
34 capacity, hardness and adhesiveness. Sweetness perception decreased as protein
35 concentration increased, and was higher in gels at pH 4 than in gels at pH 7. A good
36 correlation was obtained between the instrumental and sensory attributes hardness,
37 cohesiveness and elasticity.

38

39 1. Introduction

40

41 Food texture is a major criterion of food quality, since it influences consumer
42 acceptance of foodstuffs (Szczeniak & Kahn, 1971). In many products, fats and sugars have
43 long played an important role in texture. However, new health trends among consumers
44 demand foods reduced in these components, but, needless to say, not reduced in taste or
45 texture. Thus, the development of foodstuffs with low sugar and fat content, but with the
46 same, or even better, sensory quality, has become a challenge for the food industry.

47 Whey protein concentrates (WPCs) contribute to enhance attributes such as
48 creaminess, texture or water binding in different food systems (Johnson, 2000; Ohmes,
49 Marshall, & Heymann, 1998). When whey protein (WP) gelation takes place under
50 conditions of electrostatic repulsion between protein molecules, fine-stranded structures are
51 obtained. On the other hand, at pH close to the isoelectric point, gels are opaque with a
52 coarse particulate structure (Clark, Judge, Richards, Stubbs, & Sugget, 1981; Stading,
53 Langton, & Hermansson, 1993). Moreover, the behaviour of WP is very different under acid
54 conditions or at neutral pH. Non-covalent interactions (van der Waals attractive forces,
55 hydrogen bonds and electrostatic and hydrophobic interactions) will determine the structure
56 of gels at acid pH, while at neutral pH intermolecular sulphhydryl-disulphide interchange
57 reactions are favoured (Lupano, Dumay, & Cheftel, 1992; Shimada & Cheftel, 1988; Yamul
58 & Lupano, 2003).

59 Protein concentration also plays a key role in gel formation. Different textures are
60 obtained within the concentration range of 7% to 20% (w/w). At lower concentrations (<7%,
61 w/w) the gel is not formed (Huffman, 1996, Tang, McCarthy, & Munro, 1995), and at
62 concentrations above 20% (w/w) it is difficult to obtain a homogeneous dispersion suitable
63 for gelation.

64 The microstructure of a gel, whether it is stranded or particulate, will directly
65 influence its sensory perception. Stranded gels are springy and breakdown into large
66 particles with minimal release of fluid during mastication. On the other hand, particulate gels
67 release a detectable amount of fluid and break down into small particles that adhere to the
68 teeth during chewing (Gwartney, Larick, & Foegeding, 2004). In addition, textural
69 characteristics of food matrices influence the perception process by facilitating (or not) the
70 release of tastants, their mixing with saliva and their interaction with gustatory receptors. In
71 a fluid matrix, tastants are immediately mixed with saliva and reach the gustatory receptors
72 quickly (Bayarri, Rivas, Izquierdo, & Costell, 2007). In contrast, in semi-solid foods, such as
73 WP gels, they are released at different rates depending on the interactions with the gel and
74 the chewing process, i.e., the breakdown rate.

75 It is for this reason that several authors have attempted to correlate sweetness with
76 texture in liquid and solid foods. Lethuaut, Brossard, Rousseau, Bousseau, and Genot (2003)
77 studied the effect of sucrose on the sweetness-texture interactions in carrageenan gels.
78 DeMars and Ziegler (2001) and Moritaka and Natio (2002) found that sweetness in gelatin
79 gels decreased as gelatin content increased. Holm, Wendin, and Hermansson (2009)
80 investigated the hardness of pectin gels on the sweetness perception. Bayarri et al. (2007)
81 studied the sweetness perception in carrageenan and guar gum gels. All these studies agree
82 that the harder the gels, the lower the sweetness perception.

83 In addition, numerous authors have studied the combination of sucrose–WP gel
84 (Boye, Kalab, Alli, & Ma, 2000; Dierckx & Huyghebaert, 2002; Kulmyrzaev, Bryant, &
85 McClements, 2000a); however, the core of their research was focused on the
86 physicochemical properties without considering the sensory texture perception. The aim of
87 this work was to study the correlations between instrumental and sensory texture in WPC
88 gels at different pH levels, sucrose and WP content. Results could be useful in determining

89 the best condition to create a low sugar content product with an attractive texture having the
90 advantage of the nutritional and functional properties of WP.

91

92 **2. Materials and methods**

93

94 *2.1. Gel preparation*

95

96 WPC was a gift from Arla Foods Ingredients S.A. (Martinez, Buenos Aires,
97 Argentina). WPC contained 77.71% (w/w) protein ($N \times 6.38$), 5.74% (w/w) moisture, 2.77%
98 (w/w) ash, 3.83% (w/w) lipids and 9.95% (w/w) lactose (estimated by difference).

99 Commercial sucrose (Ledesma, Ingenio Ledesma SA, Jujuy, Argentina) was also used. All
100 chemicals employed were of analytical grade. Gels were prepared according to the technique
101 described in previous reports (Cassiani, Yamul, Conforti, Pérez, & Lupano, 2011; Yamul &
102 Lupano, 2003, 2005). A completely randomised factorial design was obtained using the
103 Statgraphics plus 5.1 software (StatPoint Inc., USA). The three factors were: pH, WP
104 concentration and sucrose concentration. The levels of the factors were incorporated into the
105 design and were analysed in 30 combinations. For gel composition and pH see Table 1.

106

107 *2.2. Instrumental evaluation*

108

109 Confocal laser scanning microscopy was carried out as described by Cassiani et al.
110 (2011). The following samples were assayed: sucrose content, 0%, 20% and 40% (w/w); pH
111 of gels, pH 4 and pH 7; protein content of all gels, 10% (w/w).

112

113 Large deformation measurements were carried out as described in previous works
(Cassiani et al., 2011; Yamul, & Lupano, 2003, 2005), except for the hardness and Young's

114 modulus that were obtained by compressing the sample down to 20% of the original height.
115 Sample hardness was defined as the height of the peak of the force versus time/deformation
116 curve and the Young's modulus was calculated from the initial slope (linear region) of the
117 same curve. The average (\pm standard deviation) of at least three determinations was
118 calculated for each type of sample.

119 Water holding capacity (WHC) was performed as described in previous works
120 (Cassiani et al., 2011; Yamul & Lupano, 2003, 2005). WHC was expressed as a percentage
121 of the initial water remaining in the gel after centrifugation. Values are the average (\pm
122 standard deviation) of at least two determinations.

123

124 2.3. *Sensory evaluation*

125

126 2.3.1. *Sorting task*

127 A panel of 16 assessors, namely female students from Facultad de Ciencias Agrarias,
128 Pontificia Universidad Católica, Argentina; 20–24 years old, analysed the samples in
129 duplicate in two sessions by applying sorting task with description (Lelievre, Chollet, Abdi,
130 & Valentin, 2008). Assessors were highly familiar with discrimination testing and were
131 trained in descriptive methods in the evaluated samples. Testing took place in individual
132 booths kept at 22 ± 2 °C, under daylight (6,500 K). Ten grams of sample were placed in
133 three digit coded cups and presented in random order. Mineral water was provided for oral
134 rinsing between samples. Assessors were allowed to taste as many samples as they wished
135 and in any order; they were free to make as many groups as they wanted. Finally, they were
136 asked to describe each group of samples by using the attribute definitions shown in Table 2
137 and/or any other concept they wanted.

138

139 2.3.2. *Sweetness intensity quantification*

140 A panel of 14 assessors, who participated in such sorting task, was trained to quantify
141 the sweetness intensity of the samples in duplicate. First, they ordered the samples for
142 sweetness intensity having two sucrose solutions (5 and 15%, w/w) as standards. Once the
143 samples were ordered, assessors measured sweetness levels on a 15 cm line scale.

144

145 2.3.3. *Texture profile*

146 The same panel of 14 assessors analysed the texture of the selected samples by
147 following Quantitative Descriptive Analysis (QDA) method (Stone & Sidel, 1993). They
148 received three training sessions (one-hour long each), during which, with the aid of
149 standards, they learnt how to measure the attributes listed in Table 2. The QDA was done in
150 duplicate during two other sessions, under the same conditions as used in the sorting task
151 (above).

152

153 2.4. *Data analysis*

154

155 Statistical analysis was carried out using PASW Statistics 18 software (SPSS Inc.
156 Chicago, IL, USA). To estimate the influence of the factors pH, sucrose and protein
157 concentration on the gel instrumental texture, an analysis of variance (ANOVA) of the data
158 was performed. Means comparison was carried out with the least significant differences
159 (LSD) calculated with the Fisher test at a level of 95%. Sorting task data were analysed by
160 applying multidimensional scaling method. Analysis of variance (ANOVA) was carried out
161 to assess sensory attributes significantly different among samples. The variability of each
162 descriptor was studied using a model where the assessor was considered a random factor and
163 sample and replication fixed factors. Multiple means comparisons were carried out by

164 Student Newman-Keuls (SNK) test at $P < 0.05$. Principal Component Analysis (PCA) was
165 conducted to examine the relationship among sensory attributes and samples, correlation
166 matrix was used and the minimum eigenvalue was set at 1. Clusters were performed by K-
167 Means command. Pearson's Correlation was used to explore relationships between sensory
168 and instrumental data.

169

170 **3. Results and discussion**

171

172 *3.1. Microstructure of the gels.*

173

174 The confocal microscopy images of gels can be seen in Fig. 1. The clear areas
175 correspond to the fluorescence of rhodamine B, revealing the presence of a network of WP.
176 The dark areas correspond to water zones. The gels prepared at pH 7 (Fig. 1d,e,f) presented a
177 homogeneous distribution of fluorescence dots, whereas the gels prepared at pH 4 (Fig.
178 1a,b,c) exhibited a structure of WP aggregates with big pores. Yamul and Lupano (2003)
179 observed that when gelation took place at a pH close to the isoelectric point of WP a coarse
180 particulate structure was obtained due to the decrease of the electrostatic repulsion. The
181 isoelectric pH of β -lactoglobulin (the main WP) is 4.6, explaining the differences in the
182 structure between pH 7 and pH 4 gels (Fig. 1). Moreover, Boye et al. (2000) found that, in
183 general, the size of the protein clusters and the void spaces within the gel matrix tended to
184 decrease as the pH changed from acid to basic. At alkaline pH proteins are generally more
185 unfolded, exposing more reactive sites for crosslinking, and therefore enhances gel network
186 formation (Boye et al., 2000).

187 The concentration of sucrose modified the structure mainly of acid gels (Fig. 1). The
188 gel structure became more homogeneous and pores became smaller as sucrose content

189 increased. Similar results were obtained in other systems, such as micellar casein gels
190 (Schorsch, Jones, & Norton, 2002) and WPC gels with honey (Yamul & Lupano, 2003).
191 This could be explained by taking into account that sucrose increased the attraction between
192 WP molecules through hydrophobic interactions (Baier & McClements, 2001; Kim, Decker,
193 & McClements, 2003; Kulmyrzaev et al., 2000a; Kulmyrzaev, Cancelliere, & McClements,
194 2000b). Neutral gels already presented an homogenous structure before the addition of
195 sucrose; thus, only a slight change in the gel microstructure was observed (Fig. 1).

196

197 3.2. *Textural properties.*

198

199 Fig. 2 shows the texture properties of WPC gels with different content of sucrose and
200 WP prepared at pH 4 and pH 7. As WP content increased, an increase in the hardness,
201 Young modulus, elasticity and cohesiveness of the gels was observed. The increase in these
202 parameters can be explained by an increase in the level of cross-linking between the
203 molecules as WP content increases. Acid gels were more adhesive and less cohesive than pH
204 7 gels, especially at high sucrose content and at 10% (w/w) WP. Cohesiveness is a function
205 of the energy that holds molecules together in the gel structure. Sulphydryl-disulphide
206 interchange reactions are favoured in neutral gels, which could explain their higher
207 cohesiveness.

208 Sucrose slightly decreased the elasticity of gels at any conditions assayed (Fig. 2) but
209 increased hardness, Young's modulus, cohesiveness and adhesiveness of WPC gels. On the
210 other hand, sucrose increased the adhesiveness of gels due to its ability to form hydrogen
211 bonds, especially in acid gels. Neutral gels were more cohesive and, thus, would have less
212 ability to adhere to the metal of the probe.

213

214 3.3. *Water holding capacity.*

215

216 Fig. 3 depicts the WHC of WPC gels as a function of sucrose and WP content.
217 Significant differences ($P < 0.001$, Table 3) were observed in WHC at different sucrose
218 content at both pH values studied, reaching similar values at high sucrose concentration. On
219 the other hand, protein content did not modify significantly the WHC of gels ($P > 0.05$;
220 Table 3). Acid gels exhibited an aggregated structure with big pores (Fig. 1a,b,c); thus, the
221 flux of water in acid gels would be easier than in neutral gels, explaining their lower WHC.
222 Similar results were obtained by Verheul and Roefs (1998) with WP gels prepared with
223 different contents of NaCl. On the other hand, at pH 7, gels exhibit high WHC; thus, it is
224 expected that the energy dissipation in the viscous modulus due to the flow of liquid through
225 a matrix will be low, and gels would behave primarily elastic.

226 Hydrogen bonds between small molecules significantly increase the viscosity of a
227 liquid, and the bonds are weak enough to be temporarily extended, exchanged or broken
228 (Pomeranz, 1978). Sucrose has the possibility to form hydrogen bonds with water molecules
229 and, thus, increased the viscosity of the solution trapped within the gels pores. As sucrose
230 content increases the viscosity of the solution also increased and the liquid flux through the
231 matrix decreased, explaining the high water-holding capacity of gels containing sucrose
232 (Fig. 3).

233

234 3.4. *Sensory analysis*

235

236 3.4.1. *Sample selection.*

237 Samples for sensory analysis were selected based on the results of the instrumental
238 analysis, keeping only samples with a sucrose concentration of 10, 20 and 40% (w/w).

239 Samples without sucrose (0%, w/w) were not considered because they were not significantly
240 different ($P > 0.05$) from those with 10% (w/w) of sucrose in many of the conditions
241 assayed, and also due to the potential off-flavour of the WPC gels without sucrose that can
242 derive from the variable amounts of residual lactose and 3–7% (w/w) lipid materials that are
243 susceptible to chemical reactions (Morr & Ha, 1991).

244 All samples with 30% (w/w) sucrose and 15% (w/w) protein were also discarded
245 because they were not significantly different ($P > 0.05$) from the next corresponding
246 concentrations in almost all conditions assayed.

247

248 3.4.2. *Sorting task*

249 Sorting task results are presented in Fig. 4. According to this analysis, two major
250 groups of samples were formed, based mainly on protein concentration. On the one hand,
251 samples containing 10% (w/w) protein (samples 2, 3, 5, 17, 18 and 20) could be
252 characterised by the attributes creamy, wet surface, smooth, bright, humidity, soft and
253 cohesive. On the other side, samples containing 20% (w/w) protein (samples 12, 13, 15, 27,
254 28 and 30 were described as dry, fracturable, hard and rough.

255 Within each group certain samples were too close or even superimposed, showing
256 that no differences were found (Fig. 4). This was the case for samples 2, 3 and 5 (pH 4, 10%
257 protein, 10, 20 and 40% sucrose respectively) and sample 17 and 18 (pH 7, 10% protein, 10
258 and 20% sucrose respectively) in the first group and samples 13 and 15 (pH 4, 20% protein,
259 20 and 40% sucrose respectively) and samples 27 and 28 (pH 7, 20% protein, 10 and 20%
260 sucrose, respectively) in the second group. Therefore, to analyse by QDA only those samples
261 perceived as different, samples 3, 18, 13 and 28, which also had an intermediate sugar
262 concentration (20%, w/w), were discarded.

263

264 3.4.3. *Texture profile and sweetness quantification*

265 An ANOVA of the mixed model for all sensory quantified attribute scores was
266 performed to evaluate sensory panel performance and differences among samples (Table 3).
267 It was found that the sources of variation were samples ($P < 0.001$), and assessors only for
268 hardness and moistness ($P < 0.05$), indicating that the panel had a good performance for
269 quantifying attributes, replicating responses and discriminating among samples. Moreover,
270 the effect of protein content, pH and sucrose was studied on both sensory perception and
271 instrumental measurements; this is also shown in Table 3.

272 pH and protein were the main factors that affected sensory and instrumental texture
273 measurements ($P < 0.001$), except for WHC, for which it was sucrose content that was the
274 factor that most influenced WHC of gels. Although sucrose had a strong effect ($P < 0.001$)
275 on instrumental hardness, it was not reflected on sensory hardness; probably, the measured
276 differences were within the differential threshold so they were not perceived by the
277 assessors.

278 Mean values of all evaluated attributes for each sample are presented in Table 4. In
279 terms of sweetness no significant differences were perceived between two couples of
280 samples: samples 15 and 20 (both 40% sucrose; pH 4 + 20% protein and pH 7 + 10% protein,
281 respectively) and 17 with 28 (both pH 7; 10% protein + 10% sucrose and 20% protein + 20%
282 sucrose, respectively).

283 In all cases, as sucrose concentration increased, sweetness perception also increased.
284 However, at a same sucrose concentration, sweetness perception was smaller as protein
285 concentration increased and this reduction was more important at pH 7. This is probably
286 related to the fact that gels with a higher amount of protein prepared at neutral pH had a
287 harder texture (Fig. 2b), which might decrease mass transfer, reducing the sucrose access to

288 taste receptors. Moreover, as said before, sucrose favours interactions between protein
289 molecules reducing the contact with the surrounding solution.

290 Literature shows that in gels derived from carrageenan, gellan, pectin and/or gelatin
291 (Bayarri, Duran, & Costell, 2003; Boland, Delahunty, & van Ruth, 2006; Costell, Peyrolon,
292 & Duran, 2000; Guichard, Issanchou, Descourvieres, & Etievant, 1999; Lundgren et al.,
293 1986) perception of sweetness decreased with increasing hardness. Moreover, as a general
294 rule, it is known that the higher the hydrocolloid concentration, the lower the perceived
295 sweetness intensity (Bayarri et al. 2007).

296 To better interpret the data obtained from the textural profile, a PCA was carried out
297 with the mean values obtained for each sample; the biplot of Principal Component 1 (PC1)
298 versus Principal Component 2 (PC2) is presented in Fig. 5. This analysis explained 94% of
299 the variance among samples with the first two components. The main attributes composing
300 PC1 were hardness, roughness and cohesiveness, together with moistness and creaminess,
301 which were opposite to the aforementioned. PC2 was positively defined by adhesiveness of
302 mass, adhesiveness to teeth and thickness.

303 It can be seen that samples 27 and 30 (both pH 7 and 20 %, w/w, protein, 10 and
304 40%, w/w, sucrose, respectively) were grouped and described mostly by the attributes
305 hardness, roughness, elasticity and cohesiveness (Fig. 5); samples 17 and 20 (both pH 7 and
306 10% protein, 10 and 40% sucrose, respectively) were mainly characterised according to
307 moistness; samples 12 and 15 (both pH 4 and 20% protein; 10 and 40% sucrose,
308 respectively) according to adhesiveness of mass and to teeth together with thickness and
309 finally samples 2 and 5 (both pH 4 and 10% protein; 10 and 40% sucrose, respectively) were
310 the creamiest. This confirmed results showed in Table 3, that sucrose was the least important
311 factor influencing perceived texture in comparison to pH and protein concentration.

312

313 3.4.4. Instrumental and sensory correlation

314 To compare instrumental and sensory information, a Pearson's Correlation was done;
315 the results are shown in Table 5. A high positive correlation was found between the
316 instrumental and sensory attributes hardness ($P < 0.01$), cohesiveness ($P < 0.01$) and elasticity
317 ($P < 0.001$), showing that the measured property was the same by both techniques.
318 Instrumental hardness also correlated with the sensory attributes roughness ($P < 0.01$),
319 cohesiveness ($P < 0.01$) and in a lower proportion with elasticity ($P < 0.05$). Probably, surface
320 tactile information such as roughness (see Table 2 for definition) could also contribute to
321 hardness perception. Even if sensory adhesiveness (adhesiveness of mass and adhesiveness
322 to teeth) did not significantly correlate with the instrumental measurement of adhesiveness,
323 the instrumental measurement of adhesiveness correlated with perceived creaminess and
324 sweetness ($P < 0.05$). It must be taken into account that sucrose increased the adhesiveness
325 and the sweetness of samples; thus, the correlation between the instrumental measurement of
326 adhesiveness and the perceived sweetness could be due to the fact that all these attributes
327 increased with sucrose content. Creaminess can be associated with the low elasticity of the
328 samples, which decreased when sucrose content increased.

329

330 4. Conclusions

331

332 The presence of sucrose modified the structure of WPC gels mainly at acid pH,
333 making the gel structure more homogeneous and with smaller pores. Sucrose also increased
334 the solid behaviour of gels, their WHC, hardness and adhesiveness. An increase in the
335 sucrose content higher than 10 % (w/w) was needed to perceive changes in sweetness in
336 WPC gels at neutral or acidic pH. Sweetness perception decreased as protein concentration
337 increases. Also, sweetness of gels prepared at pH 4 was higher than sweetness of gels

338 prepared at neutral pH, indicating that texture is more important than the acid taste caused by
339 pH in the perception of the sweetness of these gels. The instrumental and sensory attributes
340 hardness, cohesiveness and elasticity showed a good correlation, indicating that the
341 measured property was the same by both techniques. This information could be useful for
342 the food industry since sensory evaluation by a trained panel is cost and time demanding.

343

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345

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Table 1

Composition of acid and neutral WPC gels as function of protein and sucrose content.

Samples	Protein (%, w/w)	Sucrose (%, w/w) ^a	pH
1, 2, 3, 4, 5	10	0, 10, 20, 30, 40	4
6, 7, 8, 9, 10	15	0, 10, 20, 30, 40	4
11, 12, 13, 14, 15	20	0, 10, 20, 30, 40	4
16, 17, 18, 19, 20	10	0, 10, 20, 30, 40	7
21, 22, 23, 24, 25	15	0, 10, 20, 30, 40	7
26, 27, 28, 29, 30	20	0, 10, 20, 30, 40	7

^a Values are respective to the sample number.

Table 2

Sensory attribute definitions, sample manipulation procedures and references chosen.

Attribute	Definition	References
Sweetness	Taste associated to a sucrose solution.	Sucrose solutions at 5 and 15%
Hardness	Force required to cut completely through the sample when placed between incisive teeth	(-) extreme: cream cheese Middle scale: olives, hotdogs (+) extreme: hard candy
Roughness	Degree of abrasion given by the surface of the product perceived on the lips and tongue.	(-) extreme: gelatin (+) extreme: cereal bar.
Moistness	Perception of water content released by the surface of the product. It was measured with the sample in the mouth, over the tongue and lips	
Elasticity-springiness	Degree or rate at which the sample returns to its original size-shape after partial compression between the tongue and palate.	(+) extreme: marshmallow
Cohesiveness	Degree to which sample holds together as a mass.	(+) chewing gum
Firmness	Resistance of the sample to movement or flow. It was measured as the force required to move the sample along the palate using the tongue.	
Adhesiveness of mass	Degree to which mass sticks to the palate or teeth (not sticky – very sticky).	
Adhesiveness to teeth	Amount of product which sticks to the teeth after mastication.	
Creaminess	Soft texture, velvety, smooth feeling which disappears when the mouth is rinsed	

Table 3

Analysis of variance results showing sensory panel performance, differences among samples and effect of protein, pH and sucrose on evaluated sensory and instrumental attributes.

Attribute	F-values ^a					
	Sample	Assessor	Replication	pH	Protein	Sucrose
Sensory						
Sweetness	1072 ^{***}	0.6	0.16	1889 ^{***}	1264 ^{***}	9577 ^{***}
Hardness	794 ^{***}	2.2 [*]	2.50	365 ^{***}	5377 ^{***}	0.4 ^{ns}
Roughness	1137 ^{***}	0.8	0.22	118 ^{***}	5085 ^{***}	232 ^{***}
Moistness	2031 ^{***}	2.5 [*]	0.29	100 ^{***}	13374 ^{***}	10.3 ^{**}
Elasticity	502 ^{***}	1.2	0.14	2905 ^{***}	1203 ^{***}	4.8 [*]
Cohesiveness	1389 ^{***}	0.9	0.001	3092 ^{***}	1897 ^{***}	8.0 [*]
Firmness	302 ^{***}	0.9	0.32	449 ^{***}	2113 ^{***}	23.9 ^{***}
Adhesiveness mass	890 ^{***}	1.4	1.32	5482 ^{***}	162 ^{**}	356 ^{***}
Adhesiveness teeth	354 ^{***}	0.9	3.66	814 ^{***}	2135 ^{***}	185 ^{***}
Creaminess	790 ^{***}	1.4	0.28	3041 ^{***}	2572 ^{***}	41.7 ^{***}
Instrumental						
Hardness				65 ^{***}	187 ^{***}	122 ^{***}
Elasticity				143 ^{***}	22 ^{***}	2.5 ^{ns}
Young's modulus (<i>E</i>)				1228 ^{***}	414 ^{***}	304 ^{***}
Adhesiveness				46 ^{***}	134 ^{***}	46 ^{***}
Cohesiveness				138 ^{***}	35 ^{***}	8.3 [*]
WHC				3.5 ^{ns}	1 ^{ns}	57.4 ^{***}

^a Significance values are: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; ^{ns}, not significant.

Table 4

Mean values for sensory attributes.

Attribute	Sample number ^a							
	2	5	12	15	17	20	27	30
Sweetness	48.2± 3.9 ^a	143.8± 10.5 ^c	42.4± 4.0 ^d	114.6± 10.3 ^f	26.9± 2.2 ^g	117.5± 9.7 ^f	6.8± 0.4 ⁱ	59.6± 4.4 ^j
Hardness	17.1± 2.2 ^a	19.7± 2.8 ^a	85.3± 5.0 ^b	66.9± 7.8 ^c	7.0± 0.3 ^d	28.9± 2.9 ^e	119.3± 15.8 ^f	115.9± 12.6 ^f
Roughness	17.8± 1.8 ^a	22.0± 2.9 ^b	95.4± 10.5 ^c	99.8± 11.9 ^d	21.9± 3.5 ^b	30.5± 3.4 ^e	89.7± 8.3 ^f	144.4± 10.3 ^g
Moistness	114.8± 8.7 ^a	100.7± 6.3 ^b	38.5± 2.8 ^c	57.6± 5.7 ^c	141.3± 4.4 ^d	109.7± 5.7 ^e	6.5± 0.7 ^f	24.1± 2.4 ^g
Elasticity	16.7± 2.8 ^a	22.7± 3.0 ^b	50.0± 5.8 ^c	46.8± 4.0 ^d	64.3± 4.3 ^e	63.9± 6.1 ^e	96.1± 10.6 ^f	86.9± 7.8 ^g
Cohesiveness	9.4± 2.2 ^a	10.3± 1.4 ^a	59.9± 6.0 ^b	37.4± 3.2 ^c	70.4± 6.3 ^d	57.1± 5.6 ^b	123.7± 12.4 ^e	144.5± 10.9 ^f
Firmness	37.8 ± 9.5 ^a	47.9± 8.0 ^b	118.8± 11.4 ^c	85.8± 5.0 ^d	7.5± 0.5 ^e	39.6± 7.1 ^a	65.4± 5.1 ^f	78.6± 8.6 ^g
Adhesiveness of mass	64.8 ± 5.0 ^a	73.2± 6.0 ^b	116.1± 6.6 ^c	118.1± 12.0 ^d	19.9± 3.2 ^e	60.0± 6.8 ^f	7.1± 0.3 ^g	21.8± 2.6 ^e
Adhesiveness to teeth	61.9± 5.2 ^a	65.6± 5.9 ^a	97.5± 8.4 ^b	120.4± 16.0 ^c	6.9± 0.3 ^d	31.2± 4.3 ^e	77.8± 6.9 ^f	92.3± 9.4 ^g
Creaminess	140.6± 14.1 ^a	129.1± 12.1 ^b	74.1± 6.8 ^c	74.0± 4.3 ^c	55.0± 3.7 ^d	83.4± 9.0 ^e	6.9± 0.3 ^f	19.6± 2.6 ^g

^a See Table 1 for sample composition. Different superscript letters within each row indicate significant differences among samples according to Student Newman-Keuls (SNK).

Table 5

Pearson's correlation between instrumental and sensory parameters

Instrumental parameter	Sensory parameter ^a									
	Hardness	Roughness	Moistness	Elasticity	Adhesiveness mass	Adhesiveness teeth	Cohesiveness	Firmness	Creaminess	Sweetness
Elasticity	0.539	0.476	-0.381	0.946***	-0.750*	-0.154	0.913**	-0.109	-0.891**	-0.356
Adhesiveness	-0.704	-0.659	0.614	-0.707*	0.185	-0.268	-0.717*	-0.451	0.760*	0.730*
Cohesiveness	0.647	0.595	-0.498	0.914**	-0.692	-0.014	0.944**	0.045	-0.851**	-0.312
WHC	0.218	0.306	-0.205	0.282	-0.038	0.207	0.223	0.069	-0.236	0.668
Hardness	0.836**	0.888**	-0.738*	0.790*	-0.333	0.458	0.862**	0.418	-0.826*	-0.183
Young's modulus	0.620	0.629	-0.486	0.897**	-0.501	0.066	0.866**	0.118	-0.848**	-0.107
Sweetness	-0.374	-0.213	0.290	-0.485	0.508	0.120	-0.540	-0.008	0.538	1.000

^a Significance values are: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

1 **Figure captions**

2

3 **Fig. 1.** Microstructure of WPC gels with different amounts of sucrose observed by confocal
4 laser scanning microscopy. Sucrose content: panels a and d, 0% (w/w); panels b and e, 20%
5 (w/w); panels c and f, 40% (w/w). pH of gels: panels a, b, and c, pH 4; panels d, e, and f, pH
6 7. Protein content of all gels was 10%, w/w.

7

8 **Fig. 2.** Hardness, Young's modulus, springiness, adhesiveness and cohesiveness of WPC
9 gels as a function of sucrose content. Protein content of gels: ■, 10% (w/w); ●, 15%
10 (w/w); ▲, 20% (w/w). Panels a, c, e, g, and i are pH 4; panels b, d, f, h, and j are pH 7; bars
11 show standard deviation. Values in the same graph with a letter in common are not
12 significantly different ($P > 0.05$).

13

14 **Fig. 3.** Water holding capacity of WPC gels as a function of sucrose and WP content: ■,
15 10% (w/w) WP; ●, 15% (w/w) WP; ▲, 20% (w/w) WP; ■. Panel a, pH 4; panel b, pH 7. See
16 Table 1 for sample composition; bars show standard deviation.

17

18 **Fig. 4.** Sorting task representation of the evaluated samples; see Table 1 for sample
19 composition.

20

21 **Fig. 5.** Principal component analysis of the sensory texture profile; see Table 1 for sample
22 composition.

23

24

Figure 1

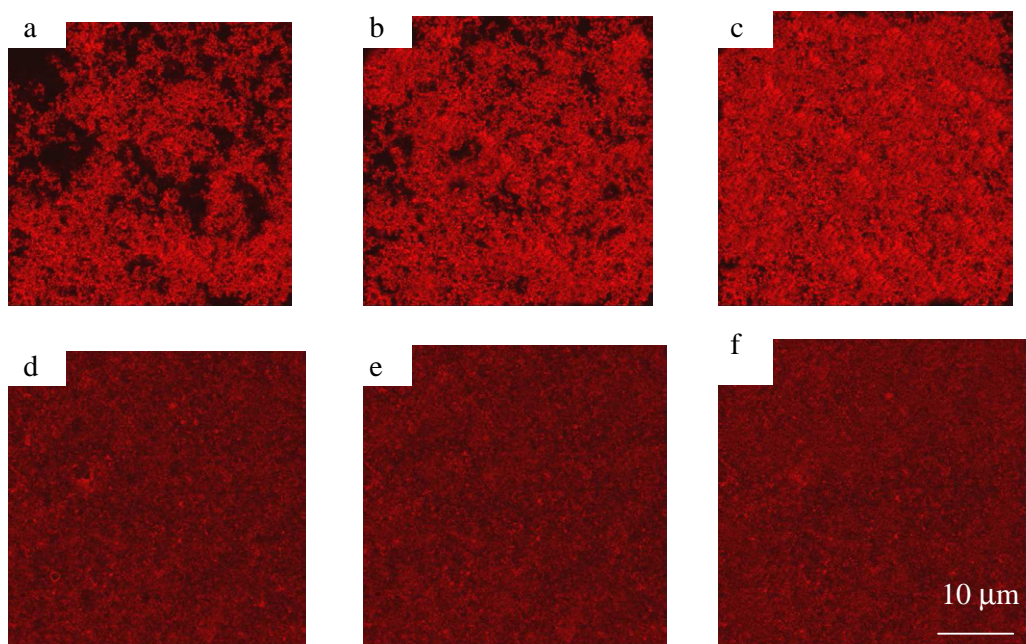


Figure 2

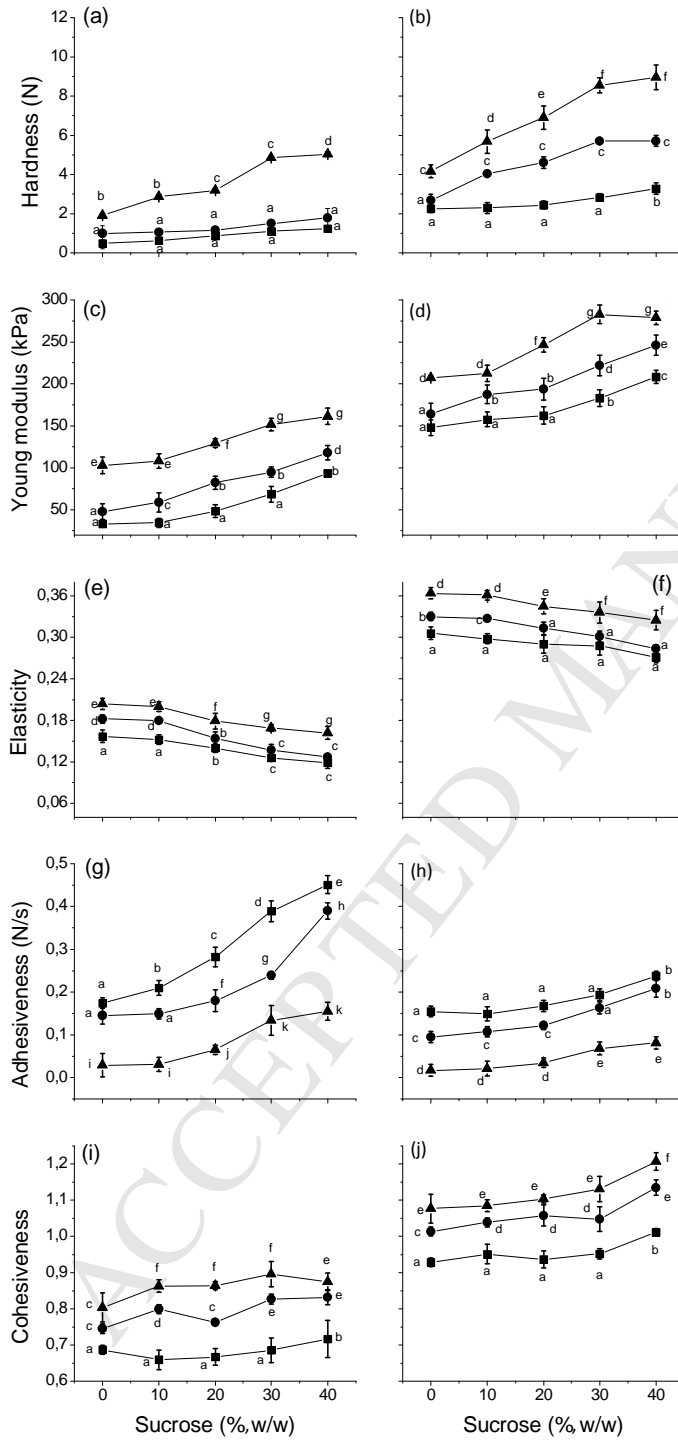


Figure 3

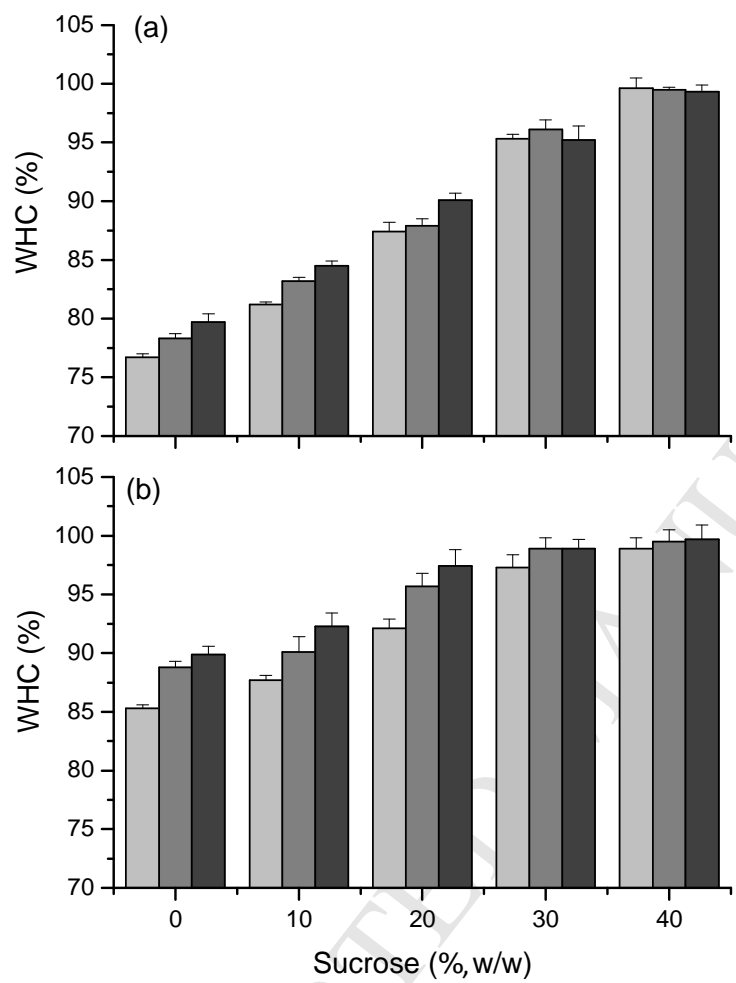


Figure 4

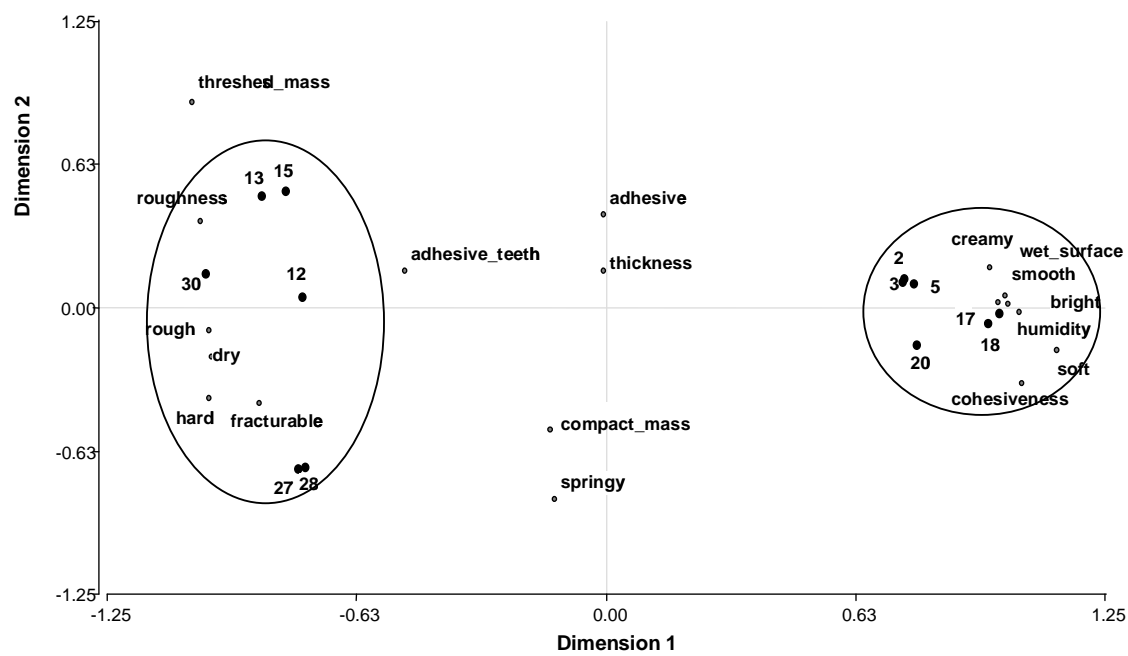


Figure 5

