

Use of natural low-methoxyl pectin from sunflower by-products for the formulation of low-sucrose strawberry jams

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Abstract

BACKGROUND: Due to the increasing incidence of obesity and cardiovascular diseases, consumers are demanding products with lower sugar content. In this sense, the reformulation of traditional foods with improved, safe and tasty ingredients is arousing a huge interest. Jams are conventionally produced with elevated amounts of sucrose, which increase the glycaemic index and must be avoided in certain kinds of consumers.

RESULTS: This paper describes for the first time the elaboration of strawberry jams using low-methoxyl pectins from sunflower by-products, which allowed the addition of low amounts of sucrose (10–30%). These jams were compared with best-selling commercial samples. An in-depth physicochemical, compositional, sensorial and rheological characterization was carried out. The obtained jams were safe considering a_w and pH values; samples presented enough acidity to avoid microorganism development and syneresis. The stabilizing role of sunflower pectin is noteworthy in terms of colour and other physicochemical characteristics. The organoleptic analysis showed that the taste and sweetness of laboratory samples were highly valued, although the presence of pieces of fruits was disliked some panellists. After knowing the content of added sugar used in each jam, the tasters preferred samples with 20% and 30% of sucrose over commercial samples.

CONCLUSIONS: The results show the usefulness of sunflower pectin for the elaboration of jams of low glycaemic index.

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Keywords: low-sugar-added jam; low-methoxyl sunflower pectin; rheological properties; sensory properties; consumer acceptability

INTRODUCTION

Strawberries are one of the most appreciated fruits, not only because of their high content of bioactive compounds but also for their desirable taste. However, because of their high respiration activity, strawberries are extremely perishable and are often subjected to rapid post-harvest losses (~40%), causing a serious challenge in marketing.¹ In this context, the production of jams is an interesting option to preserve perishable foods and obtain high-value-added products.² According to the European Union Council Directive 2004/84/EC, a minimum content of soluble solids in the finished product, ranging from 40% to 65%, is required in the case of jams produced with fruits different from citrus.³ In addition, the utilization of a gelling agent as pectin is also important to ensure that the jam has a suitable gelled thickness.⁴

Pectin is a complex heteropolysaccharide, composed mainly of a linear domain, homogalacturonan, of partly methyl esterified α -1–4-linked galacturonic acid and neutral sugar side chains composed mostly of rhamnose, galactose and arabinose, among others.⁵ Depending on the degree of methyl esterification

(DM) of its carboxyl groups, pectin is classified into two groups: high methoxyl pectin (HMP, DM > 50%) and low methoxyl pectin (LMP, DM < 50%).⁶ Over the past years, commercial HMP (citrus peel and apple pomace) has been widely used for jam manufacture. Nonetheless, this kind of pectin only forms gel in the presence of sucrose at concentrations above 55%, since the dehydrating effect of sugar enables closer contact between the pectin chains during the production process of jam.³

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Because of the increased incidence of obesity and cardiovascular diseases, consumers are demanding reduced- or no-sugar-added products, leading manufacturers to develop a variety of new healthy products.⁷ Partial or full removal of sucrose from jam formulations would not only negatively affect their sweetness and flavour, but also their viscosity, structure and browning. Strawberry jams containing non-caloric carbohydrates should have similar textural and rheological characteristics, as well as sensory properties to those of the traditional products.⁸ To overcome this problem, the use of LMP could be an interesting alternative because of its ability to form gels without using sucrose. However, some authors have reported that small amounts of sugar could improve the organoleptic properties. Currently, artificial LMP is obtained from HMP by chemical methods, involving the depolymerization of these polysaccharides. This, in turn, influences the gel strength, leading to the formation of a weaker gel.⁵ In this sense, sunflower heads are considered of special industrial interest because of their high content of natural LMP and the possibility of using the remains as a by-product and hence avoiding environmental problems.⁹ Recently, Muñoz-Almagro *et al.*¹⁰ studied the potential viscosity of pectin extracted from sunflower heads using sodium citrate. To the best of our knowledge, limited work has been done on the elaboration of fruit jams with LMP. Abid *et al.*⁴ obtained jams from pomegranate peel and evaluated the application of LMP extracted from the same source on the texture and sensory properties of these preserves. However, there are no available studies focused on the effect of the partial substitution of sucrose and the utilization of sunflower LMP in the production of strawberry jams. Therefore, the aim of this work was to analyse the influence of using sunflower LMP along with a lower amount of sucrose (10%, 20% and 30%) on rheological, textural and sensory properties of strawberry jams.

MATERIALS AND METHODS

Materials and chemicals

Fresh strawberries (*Fragaria × ananassa* Duch.) and commercial jams were purchased from a local market in Madrid (Spain). Sucrose used as sweetener and calcium chloride were supplied by Normapur (Rhône-Poulenc, France), whereas citric acid was supplied by Sigma Aldrich (Steinheim, Germany). Sunflower pectin (DM 36.8 ± 0.2%; galacturonic acid 85.4 ± 0.9%) with a purity of 97% was extracted with sodium citrate at 52 °C for 184 min, following the method reported in a previous work.¹¹

Strawberry jam formulation

Jam formulations followed for the production of each sample are described in Supporting Information Table S1. The amount of pectin from sunflower and CaCl₂ was established on the basis of previous research.¹¹ During the manufacturing process, strawberries were cleaned and subjected to a first pre-cooking at 85 °C for 10–15 min. Furthermore, pH was adjusted to 3.3 ± 0.1 using a proportion of 2 g citric acid kg⁻¹ fruit pulp. Then, 1% LM sunflower pectin, CaCl₂ and sucrose were added according to each formulation (10%, 20% and 30% w/w). After that, the mixture was brought to the boil for 20 min, while the Brix degrees were measured until they reached 40–60 °Brix. Once the cooking was completed, jams were cooled to 85 °C and bottled in sterilized glass jars. Finally, jams (J-10%S, J-20%S, J-30%S) were stored until further analysis at 4 °C.

In order to compare the obtained results, two extra quality commercial jams, widely consumed, were analysed in parallel. One of

them (J-Com-1) presented 47% added sugar including glucose–fructose syrup (GFS) and sucrose, 57 g fruit for 100 g of product and HMP as gelling agent. The other one (J-Com-2) contained 50% added sugar, 50 g fruit for 100 g of product and HMP from citrus by-products as gelling agent. Both jams (J-Com-1 and J-Com-2) contained citric acid as lemon juice.

Analysis of jams

Physicochemical properties of the strawberry jams

The determination of soluble solids (°Brix) was carried out at room temperature using a digital refractometer (Mettler Toledo Refracto 30P, Giessen, Germany). The determination of pH value was carried out using a digital pH meter (Mettler Toledo GmbH). Water activity (a_w , value) of jams after processing was determined using an AW Sprint TH500 instrument (Novasina, Lachen, Switzerland) with controlled temperature. The moisture content of jams was determined at 102 °C until constant weight.¹²

Determination of low-molecular-mass carbohydrates

Carbohydrates were extracted twice from 100 mg homogenized jam weighed with 80% ethanol (9 mL) and an ethanolic solution of phenyl-β-D-glucoside (10 mg mL⁻¹; Sigma-Aldrich, St Louis, MO, USA) used as internal standard. Samples were then centrifuged and supernatant was evaporated under vacuum at 40 °C and finally derivatized. Trimethylsilyl oximes of saccharides were prepared according to Muñoz-Almagro *et al.*¹⁰

Analyses were performed on an Agilent Technologies gas chromatograph (Mod 7890A) equipped with a flame ionization detector. Separation was carried out in a fused-silica capillary column (DB-5HT, 30 m × 0.32 mm × 0.10 μm; J&W Scientific, Folson, CA, USA). Nitrogen at a flow rate of 1 mL min⁻¹ was used as carrier gas. The oven temperature program was increased from 150 to 300 °C at a heating rate of 3 °C min⁻¹. Injections were made in split mode (1:30). For quantitation, standard solutions of glucose, fructose and sucrose were prepared over the expected concentration range in jam extracts and analysed in order to calculate the relative response factor to phenyl-β-D-glucoside.

Colour analysis

Colour measurements were performed using an integrating reflectance sphere (Specord 210 Plus Analytik Jena, Germany). Results were expressed using the CIE $L^*a^*b^*$ system: L^* value indicates lightness/darkness (0 = black, 100 = white), chromaticity a^* assesses greenness (+)/redness (–) and chromaticity b^* evaluates yellowness (+)/blueness (–). These parameters were used to determine colour saturation (chroma; $C^* = (a^2 + b^2)^{0.5}$) and hue angle ($h^\circ = (\arctan b^*/a^*)$). Data were analysed using WinAspect Plus software.

Texture analysis

Textural properties of the five strawberry jams were conducted at room temperature using a Brookfield texture analyser (Engineering Laboratories, Inc., USA). The texture profile analysis (TPA) test was performed with a cylindrical probe (TA3/100), compressing the sample to a 3 mm depth with a pre-treatment speed of 2 mm s⁻¹, a speed test of 1 mm s⁻¹, a post-treatment speed of 1 mm s⁻¹ and a trigger detection force of 1500 g.

Rheological properties

Storage modulus (G') and loss modulus (G'') were obtained with a Haake MARS rheometer (Thermo Scientific, Karlsruhe, Germany) to evaluate the viscoelastic behaviour of each sample. Small-

deformation measurements of G' and G'' were done using a PP35 plate with parallel geometry. Frequency sweeps were recorded over the range 0.1–10 Hz at a controlled stress of 5 Pa and at a temperature of 23 °C.

Sensory evaluation

Sensory evaluation was performed by 46 (18 males and 28 females) regular consumers of jams aged between 23 and 73 just 1 day after their production in a quiet meeting room and in groups of a maximum of eight participants at the same time. The samples were individually and randomly served in small transparent plastic glasses coded with a random three-digit number and following a balanced complete block experimental design. Among the five samples, three were strawberry jams prepared at a laboratory scale (J-10%S, J-20%S, J-30%S), the fourth was a well-known brand of strawberry jam (J-Com-2) and the last was another commercial strawberry jam but with low sugar content (J-Com-1).

Overall acceptance, taste, appearance and texture were scored using a nine-point hedonic scale (from 1 = dislike extremely to 9 = like extremely). In addition, the main attributes related to jams (adequacy of sweetness, texture and strawberry flavour) were evaluated using a bipolar scale such as the Just-About-Right (JAR) scale. The score was attributed in the following way: 1 = much too little, 3 = just about right and 5 = much too much. Finally, panellists were asked to rank the jams in order of preference twice: one, before being informed about the sugar content of the jams; and the other after providing this information to them. All data were recorded with RedJade software.

Statistical analysis

Analysis of variance (ANOVA, $P < 0.05$) and Tukey's test were performed in order to evaluate statistically significant difference in the results using SPSS Statistics (version 24, IBM, Tokyo, Japan). In addition, penalty analysis was employed to evaluate the impact of JAR attributes on the overall acceptance using XLStat.

RESULTS AND DISCUSSION

Characteristics of the strawberry jams produced with different formulations

Physicochemical properties and low-molecular-mass carbohydrate characterization

Table 1 shows the results regarding the chemical properties of manufactured jams as well as of commercial ones. Remarkably, J-10%S presented a significantly lower content of soluble solids in comparison with the rest of jam formulations. The a_w values of all jams ranged between 0.962 and 0.884 and were especially high for products whose sucrose content was considerably reduced. Sugar allows the capture of free water in food products, promoting hydrophobic interactions between methoxyl groups from pectin.^{13,14} In general terms, jams are considered safe from pathogenic bacterial growth when their a_w is lower than 0.86,¹⁵ whereas for moulds and yeasts an a_w above 0.80 is needed for their growth.¹⁶ Hence the results indicate that these formulations could have a shorter shelf life due to the faster colonization of acidophilus microorganisms. Data of dry matter of jams followed the same tendency as the results for °Brix and a_w with J-10%S, presenting the lowest value (19.6%). Rada-Mendoza *et al.*¹⁷ reported data of dry matter and a_w of commercial jams in the range of 34.7–67.7% and a_w 0.937–0.805, respectively.

Regarding pH values, three low-sucrose jams and J-Com-2 presented values in the range of 3.2–3.4. As a result, they could be considered microbiologically stable for more than 1 year if thermal treatments were correctly applied as specified by the FAO.¹⁸ A pH of around 3.5 is also favourable for LMP gelling, since at low pH values carboxyl groups in LMP are protonated and can form hydrogen bonds even in the absence of calcium ions.¹³ However, J-Com-1 was significantly more acid. Higher acidity could damage the gelling capacity, leading to a weaker and unstable product and even resulting in syneresis. Koppel *et al.*¹⁹ and Rada-Mendoza *et al.*¹⁷ reported pH ranges in commercial jams between 3.11 and 4.45.

Table 1 lists the results of low-molecular-mass carbohydrate analysis of the strawberry jams under study. As expected, sucrose was the main sugar found in all jams except for J-Com-1. Commercial jams stood out for their fructose and glucose content, especially in the case of the J-Com-1 sample, whose label indicated the presence of glucose–fructose syrup. On the other hand, high maltose and maltotriose content were quantified in this sample, indicating the possible use of starch for obtaining the invert sugar.

Colour properties

The appearance of the final product depends to a large extent on its colour, since it significantly affects consumer perception and provides information concerning its quality. Nonetheless, this preference is not associated with an increase in the nutritional value or in the sensory quality of the product.²⁰

The average L^* , a^* , b^* , C^* and h^* values of each jam formulation are shown in Table 2. Although lab-made jams tend to be brighter than commercial ones, no changes were observed in the lightness (L^*) between the samples, suggesting that an increase in the fruit proportion has no influence on this parameter. Unlike other formulations, significant differences were found in a^* (redness) and b^* (yellowness) of the strawberry jam made with only 10% sucrose. The higher redness (a^*) of the 10% sugar sample could be due to a higher presence of fruit (Supporting Information Table S1). Ciurzynska *et al.*²¹ reported that the redness (a^*) of each sample strongly depends on the anthocyanin content, especially on the pelargonidin 3-*O*-glucoside content under acidic conditions ($pH > 3$). In this context, Holzwarth *et al.*²² found that with the addition of pectin, stabilized anthocyanin molecules and hence a^* value was increased. The colour-stabilizing effect of pectin is due to electrostatic interactions between the flavylum cation of the pelargonidin and dissociated carboxyl groups of the pectin in a very similar way, as it is produced between the calcium ion and LMP pectin. This association would prevent the nucleophilic attack of water molecules and therefore colour deterioration.

Concerning secondary parameters, the chroma value (C^*), which measures the colour intensity that can be perceived by the human eye, is important in highlighting that the formulation with the lowest amount of sucrose presented the highest colouration. Conversely, no differences were found in the tone (h^*) of the samples.

Texture

The texture profile analysis that was carried out could easily simulate the sensory attributes experienced by consumers after tasting jams.⁴ Primary texture parameters, especially the firmness, adhesiveness, cohesiveness and elasticity of strawberry jams, are shown in Table 2. In sensory analyses, firmness is the force required to compress a food product between the molars at the

Table 1. Chemical properties ($^{\circ}$ Brix, a_w , dry matter and pH) and low-molecular-mass carbohydrate content ($\text{g } 100 \text{ g}^{-1}$ jam) for the strawberry jams analysed (data shown as average \pm SD)

		J-10%S	J-20%S	J-30%S	J-Com-1	J-Com-2
Chemical properties	$^{\circ}$ Brix	35.6 \pm 3.2a	45.4 \pm 1.3b	54.7 \pm 1.3d	48.3 \pm 0.2bc	50.5 \pm 0.3c
	a_w	0.962 \pm 0.013a	0.924 \pm 0.003a	0.887 \pm 0.001a	0.884 \pm 0.280a	0.899 \pm 0.002a
	Dry matter	19.6 \pm 1.8a	24.4 \pm 0.8b	37.3 \pm 1.0c	43.6 \pm 1.9d	47.7 \pm 1.8e
	pH	3.24 \pm 0.09b	3.36 \pm 0.06b	3.27 \pm 0.02b	2.46 \pm 0.03a	3.26 \pm 0.02b
Carbohydrate content ($\text{g } 100 \text{ g}^{-1}$ jam)	Fructose	2.79 \pm 0.01a	3.34 \pm 0.27a	3.11 \pm 0.02a	14.58 \pm 0.09c	8.83 \pm 0.81b
	Glucose	1.83 \pm 0.00a	2.26 \pm 0.23a	2.12 \pm 0.02a	14.36 \pm 0.11c	6.35 \pm 0.67b
	Sucrose	8.32 \pm 0.13b	15.15 \pm 0.84c	30.08 \pm 1.93e	1.79 \pm 0.00a	27.06 \pm 1.03d
	Maltose				6.85 \pm 0.08	
	Maltotriose				1.69 \pm 0.01	
	Total	12.97	20.77	35.31	39.26	42.25

Averages with the same letter in the same row (a–e) indicate there is no significant difference between the samples ($P < 0.05$) in Tukey's test. a_w , water activity; J-10%S, J-20%S and J-30%S, strawberry jams produced in the lab with sunflower pectin and 10%, 20% and 30% sucrose. J-Com-1 and J-Com-2, the two extra quality commercial strawberry jams most consumed.

Table 2. Average values of texture and colour parameters (L^* , a^* , b^* , C^* and h^*) for the laboratory manufactured and commercial jams

		J-10%S	J-20%S	J-30%S	J-Com-1	J-Com-2
Colour parameters	L^*	28.61 \pm 1.11a	26.63 \pm 0.37a	28.17 \pm 0.52a	26.84 \pm 0.41a	27.63 \pm 1.39a
	a^*	14.30 \pm 1.53c	9.44 \pm 0.83b	9.16 \pm 1.05b	7.05 \pm 1.12ab	6.23 \pm 0.51a
	b^*	5.19 \pm 0.93c	3.63 \pm 0.85bc	2.95 \pm 0.89ab	1.71 \pm 0.04a	1.44 \pm 0.41a
	C^*	15.21 \pm 1.75d	10.12 \pm 1.08c	9.63 \pm 1.27bc	7.26 \pm 1.07ab	6.40 \pm 0.43a
	h^*	0.35 \pm 0.02a	0.36 \pm 0.05a	0.31 \pm 0.06a	0.24 \pm 0.04a	0.23 \pm 0.08a
Texture properties	Firmness (N)	3.98 \pm 0.25d	1.87 \pm 0.22b	3.51 \pm 0.02c	0.45 \pm 0.01a	0.66 \pm 0.01a
	Adhesiveness (mJ)	3.80 \pm 0.14d	0.99 \pm 0.02a	1.77 \pm 0.03c	1.41 \pm 0.01b	1.79 \pm 0.01c
	Cohesiveness	1.14 \pm 0.01b	0.71 \pm 0.01a	1.25 \pm 0.09c	1.04 \pm 0.02b	1.07 \pm 0.02b
	Elasticity (mm)	4.43 \pm 0.03d	3.05 \pm 0.21a	3.87 \pm 0.14c	3.48 \pm 0.02b	4.27 \pm 0.05d
	Chewiness (mJ)	21.25 \pm 0.10d	4.18 \pm 0.11c	4.08 \pm 0.30c	1.59 \pm 0.03c	3.03 \pm 0.07b
	Springiness (N)	4.77 \pm 0.02e	1.44 \pm 0.03d	1.05 \pm 0.08c	0.46 \pm 0.01a	0.71 \pm 0.02b

Averages with the same letter in the same row (a–e) indicate there is no significant difference between the samples ($p \leq 0.05$) in Tukey's test. L^* , lightness; a^* , redness; b^* , yellowness; C^* , chroma value; h^* , tone; J-10%S, J-20%S and J-30%S, strawberry jams produced in the lab with sunflower pectin and 10%, 20% and 30% sucrose. J-Com-1 and J-Com-2, the two extra quality commercial strawberry jams most consumed.

first bite.² As shown in Table 2, both commercial formulations presented a lower firmness value than low-sucrose jams, which could be ascribed to the type of pectin used for their production, as the junction zones in the LMP structure are more rigid than in HMP. Furthermore, a higher amount of strawberry pulp could also lead to an increase in the firmness values, probably due to the pectin that the fruit already contained, as can be seen in J-10%S⁴.

Adhesiveness is an important parameter in food products since it can predict in a sensory way the degree of adherence of the product to the teeth. Indeed, it represents the work necessary to overcome the power of attraction between the jam and the surface of the material with which the food comes into contact.¹⁵ In general, the jams produced with 20% and 30% sucrose presented values of adhesiveness close to commercial ones. Conversely, the formulation with the lowest amount of sucrose (J-10%S) presented an adhesiveness twice as high as the others, probably due to excessive gel strength. Other useful texture parameters are cohesiveness, known as the deformation degree of the sample before being chewed with the molars, and elasticity, related to the height that the food recovers to at the beginning of the second bite.² The results for both parameters varied

within the same range in both manufactured and commercial jams, with the formulation J-20%S displaying the lowest values.

Some secondary parameters of texture are chewiness and springiness. The first is defined as the product of firmness, cohesiveness and elasticity; therefore, greater chewiness leads to a higher resistance of the mastication force.¹⁵ It can be observed that in J-10%S this parameter stood out considerably (21.25 mJ) because this sample presented a harder, more cohesive and less elastic texture. Regarding the results for springiness, or the required energy to disintegrate a semi-solid food ready for swallowing, it indicates a direct relationship with chewiness. Both values are considerably higher for manufactured jams in comparison with commercial ones. In short, J-10%S is the formulation that most differs from commercial jams, while J-20%S and J-30% S presented similar results. However, it is important to take into consideration that textural analyses should be complemented by sensory analyses; this will be discussed later.

Rheological properties

Figure 1 shows the rheological data of the dynamic assays. It represents the evolution of storage (G') and loss (G'') moduli of

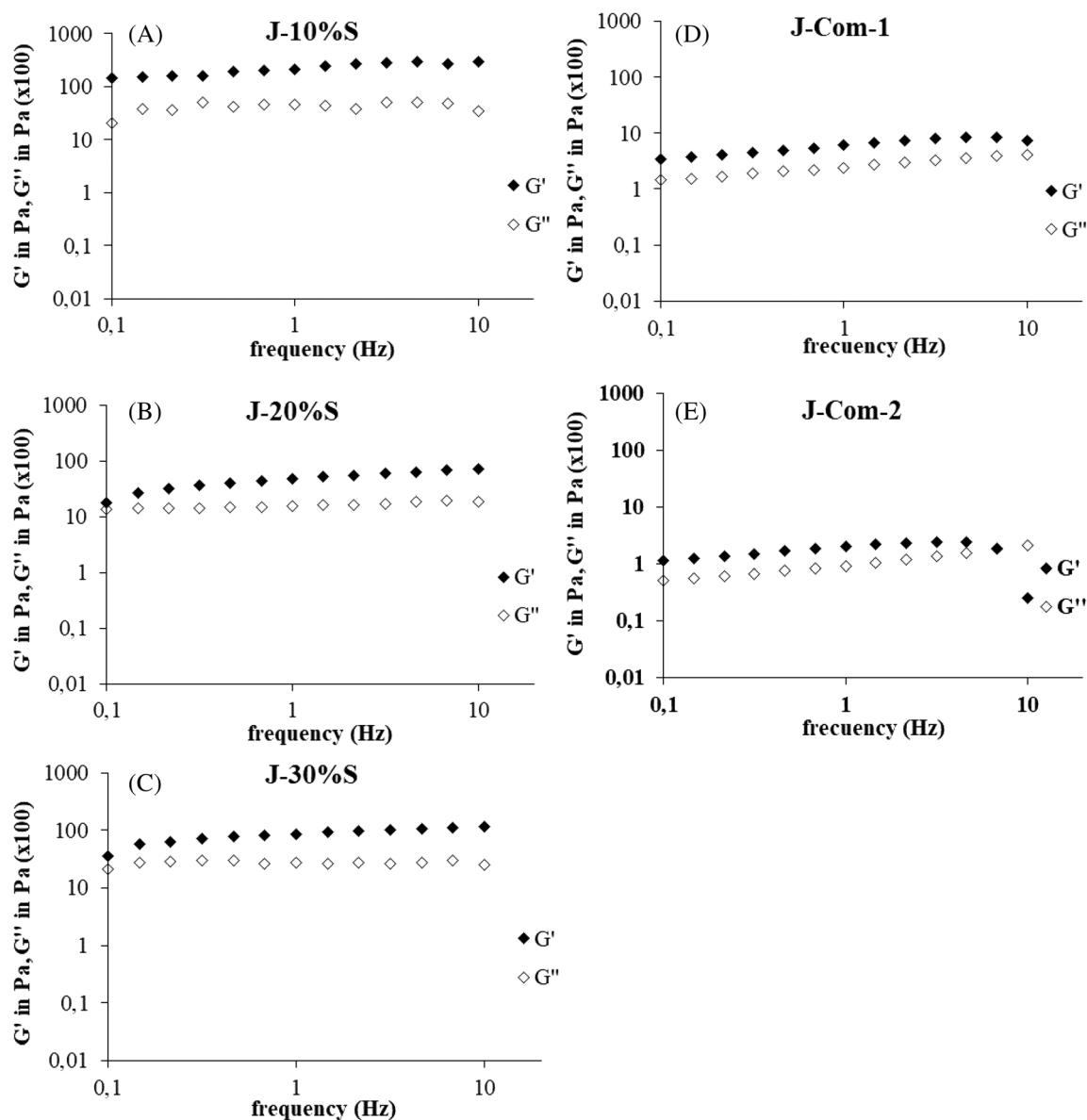


Figure 1. Study of gel strength of manufactured strawberry jams with reduced content of sugar using LMP pectin: (a) J-10%S; (b) J-20%S; (c) J-30%S; and commercial jams using HMP pectin: (d) J-Com-1; (e) J-Com-2.

strawberry products as a function of applied frequency. This analysis determines the relative elastic/viscous nature of the jam formulations. When $G' > G''$ the food exhibits a semi-solid behaviour, which means that it is more elastic than viscous, which is a typical gel behaviour. When G' is equal to G'' , the food material behaves like a concentrated solution. Conversely, jam would be semi-liquid if $G'' > G'$, so the formulation behaves like a diluted solution. As is observed in Fig. 1, regardless of the amount of sucrose added to strawberry jams, G' was higher than G'' over the whole frequency range for every formulation, except for J-Com-1, which presented a sol-gel transition at higher frequencies. A plausible explanation for this fact could be related to the use of glucose and fructose syrup instead of sucrose. Grosso and Rao²³ reported that the addition of sucrose increased gel strength more than glucose, which had in turn a larger effect than fructose. It is important to highlight that low-sucrose strawberry jams produced with sunflower LMP were stronger than the commercial

ones made with HMP. The ionic crosslinking that occurs between calcium ions and carboxyl groups during the gelation of LMP is stronger than intermolecular hydrogen bonds and hydrophobic interactions between methyl esters involved in the formation of HMP gels. This rheological behaviour can be explained in terms of network formation. For HMP, initially, there is no network formed and each pectin molecule behaves very much like a single and dispersed molecule. As the HMP dispersion is sheared, the molecules relax quickly as a result of their high molecular mobility. Due to that, there is no extensive stress build-up at low oscillation frequencies. As time goes on, HMP molecules begin to associate with each other by the formation of hydrogen bonds and hydrophobic interactions. The resulting network restricts the freedom of molecules to react to the superimposed flow.^{5,13} On the other hand, Schuster *et al.*²⁴ reported for LMP that the entangled pectin solution starts to aggregate and forms crosslinks over time. In the early stages when the network is already built up, LMP molecules

present in the solution are separated. The polymers then cluster and the effective concentration of the solution decreases. As more clusters nucleate, grow and connect, a stronger network is slowly formed as a consequence of the increase in G' .

Among formulations that contained LMP, strawberry jams that had the lowest amount of sucrose presented the highest value of G' , suggesting the formation of stable and strong gels. However, the presence of sugar can promote inter-chain interactions, as in HMP gelation. Higher concentrations of sweeteners could adversely affect the gelling process of LMP, due to the dehydrating effect of sugars that enable the formation of hydrogen bonds, and decrease the strength of crosslinking bonding.²⁵

Sensory evaluation and consumer acceptability

As mentioned before, acceptability by consumers is a key factor that should be taken into account when it comes to developing a new food product. To confirm that sugar reduction did not compromise the sensory quality of our products, a consumer study was conducted. As shown in Table 3, the five samples subjected to evaluation presented good acceptance (5.78–7.47), with significant differences only between J-Com-1 (7.13 ± 1.62) and J-10%S (5.72 ± 1.82). Texture was the main differentiating element between the commercial jams and those made by us, with J-Com-1 and J-Com-2 receiving the highest scores. However, consumers rated highest the taste of J-30%S, without significant differences compared to J-Com-1 and J-20%S. Notwithstanding the low percentage of sucrose added, these results demonstrated that all strawberry jams were similarly appreciated.

In order to ensure a suitable proportion of sweeteners, consistency and strawberry flavour, five-point JAR scales were used (Fig. 2). To facilitate the analysis, the five categories were reduced to three ('too little', 'JAR' and 'too much'). Commercial jams were shown to be far too sweet for the majority of consumers, while J-30%S presented the most suitable proportion in terms of perception of sweetness. However, for the remaining percentage, panellists showed controversial opinions, since a percentage of them indicated that sweetness was too high (24%) and the other too low (33%). In the case of J-10%S, most consumers considered the sweetness to be low. Regarding strawberry flavour, similar behaviour was found in the samples J-30%S and J-20%S, showing the closest result to the optimal intensity. In contrast, the very-low-sugar strawberry jam (J-10%S) had an analogous behaviour to the commercial sample produced with sucrose and glucose-fructose syrup (J-Com-1). Regarding J-Com-2, an identical number of tasters recorded 'too little' and 'JAR' flavour. In terms of texture

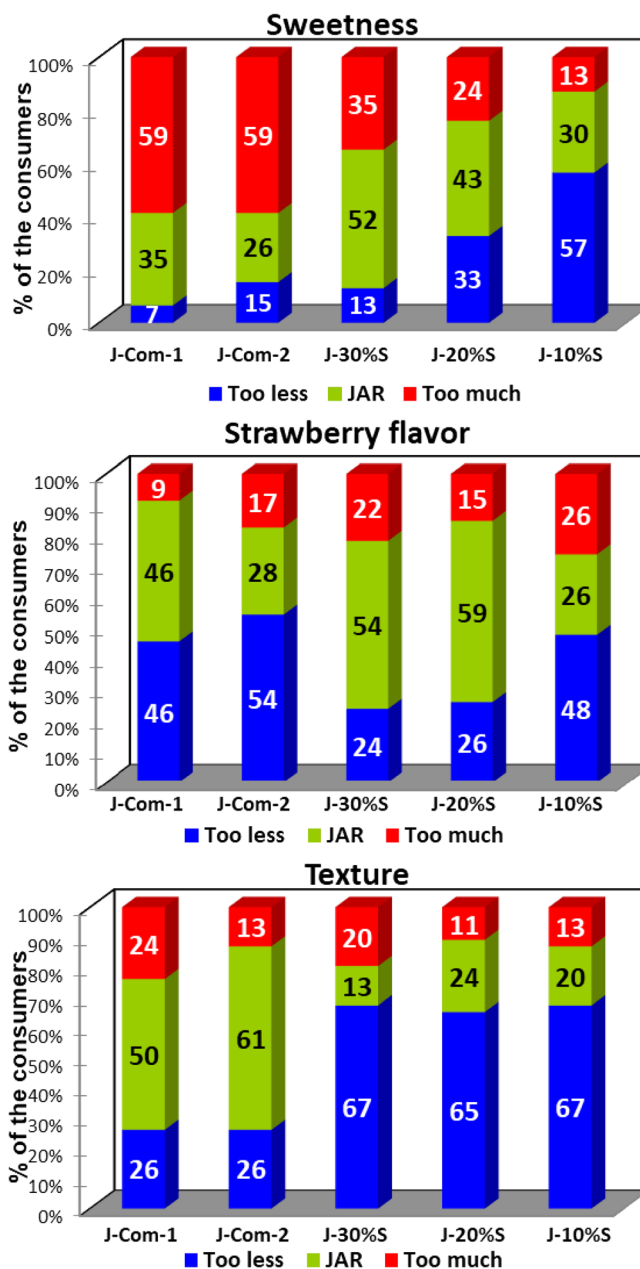


Figure 2. Sensory evaluation of strawberry jams analysed considering 'just-about right' (JAR) scale for each attribute.

Table 3. Sensory evaluation of strawberry jams analysed by 46 assessors considering a nine-point hedonic scale

	Taste	Appearance	Texture	Overall acceptance
J-10%S	5.67 ± 2.19c	5.76 ± 1.85c	5.48 ± 2.02b	5.72 ± 1.82b
J-20%S	6.59 ± 1.61abc	6.46 ± 1.68bc	5.91 ± 2.03b	6.37 ± 1.55ab
J-30%S	7.35 ± 1.55a	5.61 ± 2.02c	5.11 ± 2.01b	6.52 ± 1.44ab
J-Com-1	6.91 ± 1.90ab	7.47 ± 1.64a	7.26 ± 1.87a	7.13 ± 1.62a
J-Com-2	6.67 ± 1.92bc	6.49 ± 1.99ab	6.14 ± 2.09a	6.47 ± 1.63ab

Averages with the same letter in the same column (a–c) indicate there is no significant difference between the samples ($p \leq 0.05$) in Tukey's test. J-10%S, J-20%S and J-30%S, strawberry jams produced in the lab with sunflower pectin and 10%, 20% and 30% of sucrose. J-Com-1 and J-Com-2, the two extra quality commercial strawberry jams most consumed.

(Fig. 2), in general, commercial formulations were positively evaluated for their good consistency, whereas the others obtained a worse texture score, probably due to the existence of small pieces of strawberry according to assessors' comments at the end of the tasting, which were left on purpose in order to simulate a more natural appearance. These data revealed that most consumers preferred the consumption of strawberry jams with uniform texture.

In addition, the three JAR questions were evaluated by penalty analysis (see *P*-values in Supporting Information Table S2) in order to gain an understanding of the attributes that most affected liking ratings in the overall acceptance of each product. Figure 3 displays the significant penalties (drops in overall liking) by proportion of consumers. In general, the data revealed that the most penalizing attribute that deviated from the ideal 'right point'

in both commercial jams was 'too low' strawberry flavour, reducing overall acceptance around 2 points for at least 45% of the tasters. Conversely, consistency was the main factor reducing the acceptability of the low sucrose formulations, causing a decrease of 1.2 and 1.6 for the majority of the consumers of J-30%S and J-10%S, respectively. With respect to sweetness, the high perception reduced acceptance by 1 point in 60% of people in both commercial jams, and the low perception produced a strong reduction (2 points for 60% of tasters) in the acceptance of J-10%S.

Finally, the assessors ranked the jams in order of preference (Supporting Information Fig. S1); although J-Com-2 was chosen as the best one by most of the panellists (28.3%), the opinion changed considerably when they knew the amount of added sugars present in each formulation. Consequently, the score

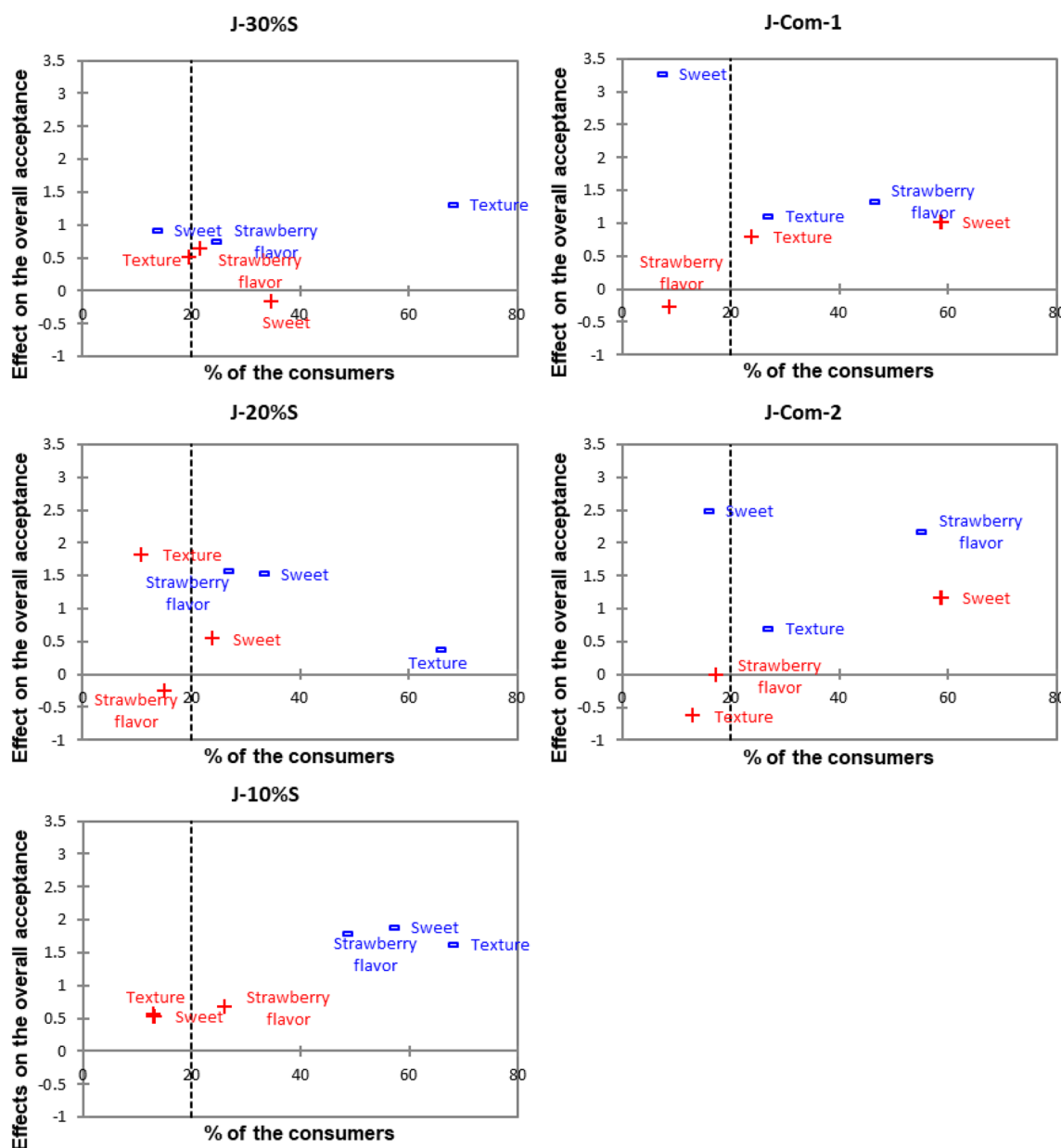


Figure 3. Penalty analysis. Representation of significant penalties (drops in liking) by proportion of panellists. The cut-off point was 20% of consumers stating that one attribute was 'not enough' (-) or 'too much' (+). Attributes scored as 'not enough' are shown in red and attributes scored as 'too much' are shown in blue.

corresponding to all low-sucrose strawberry jams increased significantly, J-30%S (28.3%) and J-20%S (26.1%) being preferred by the panellists.

CONCLUSIONS

The present study shows the quality attributes of three novel strawberry jam formulations manufactured using low-methoxyl pectin extracted from sunflower by-products and employing proportions of sucrose in the range of 10–30%. Their quality indicators have been compared with two commercial products considered as best sellers. Taking into account all parameters, the sample that differed the most was the one prepared with 10% sucrose. The physicochemical properties (pH, a_w , °Brix, dry matter) of low-sucrose strawberry jams were, in general, within the ranges reported in the literature for similar commercial products, and the total sugar content was lower as compared to the commercial jams analysed in the present study. In the case of colour, no significant differences were found in most of the attributes. However, low-sucrose jams produced with sunflower pectin were brighter, had a more intense colour and were also firmer and exhibited a good rheological behaviour in comparison to commercial strawberry jam samples. Regarding the sensory study, samples with 20% and 30% of sucrose presented good overall acceptance. Furthermore, panellist assessment of the sample containing 10% sucrose considerably improved in comparison with commercial samples when consumers were aware of the sugar content. More research is needed, mainly focused on modifying the texture in the case of the jam prepared with the lower amount of sucrose. Finally, it is possible to conclude that pectin from sunflower heads is a promising gelling agent for the production of new good-quality strawberry jams using low sucrose concentration. This is of huge importance in regard to the reduction of daily sugar consumption to prevent serious pathologies. Taking into account all the determinations carried out in this study, we can suggest that among the formulations we have produced the strawberry jam with 20% sucrose and sunflower pectin constitutes the most adequate option for consumers. To the best of our knowledge, this is the first time that jams have been manufactured with pectin from sunflower by-products. This opens up new ways to produce this kind of product and is in line with sustainable food systems.

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SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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