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3 **Effect of addition of cryoprotectants on the mechanical properties,**
4 **colour and sensory attributes of fresh and frozen/thawed mashed**
5 **potatoes**

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Abstract Cryoprotectants such as hydrocolloids (amidated low-methoxyl (ALM) and high methoxyl (HM) pectins), kappa- and iota-carrageenans (*k*-C and *i*-C), xanthan gum (XG)) and dairy proteins (whey protein (WP), sodium caseinate (SC)) were added to mashed potatoes to investigate ways of improving the effects of freezing and thawing. It was found that each hydrocolloid and protein, depending on concentration, affected the mechanical properties (instrumental textural profile analysis (ITPA), cone penetration (CP) test), the total colour difference (ΔE^*) with respect to fresh control (FC) and the sensory attributes of fresh (F) and frozen/thawed (F/T) mashed potatoes in a different way. In the F/T samples, adding 5 and 8 g kg⁻¹ ALM, 3, 5 and 8 g kg⁻¹ *k*-C, 1.5, 3, 5 and 8 g kg⁻¹ *i*-C and 1.5, 5 and 15 g kg⁻¹ WP significantly increased ITPA consistency. Also, adding 2.5 and 5 g kg⁻¹ XG significantly increased ITPA consistency of the F/T product. In both F and F/T samples, *k*-C provided the highest ITPA consistency and also high CP average force evidencing a stronger synergistic effect in κ -C/denatured milk protein systems, although the excessive thickening and stickiness provided was judged undesirable by the panellists. Adding 8 g kg⁻¹ HM pectin had a disruptive effect in the mashed potatoes, and decreased both ITPA consistency and CP average force. In all cases, freezing and thawing reinforced the gel structure of the products as compared to F and FC counterparts. The ΔE^* values were higher in F samples containing ALM and HM pectins. Dairy proteins affected the taste and odour of the mashed potatoes and were judged unacceptable in the sensory analysis. Samples containing 0.5 and 1.5 g kg⁻¹ added XG were preferred organoleptically due to the creamy mouthfeel it produced. ITPA consistency correlated well with sensory texture attributes.

Keywords Mechanical properties · Mashed Potatoes · Cryoprotectants · Freezing · Thawing · Sensory analysis

1 Introduction

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3 Potato varieties differ from one another in the texture of the tuber after cooking. Previous studies had shown that,
4 among various potato varieties, Kennebec tubers were suitable for producing fresh mashed potatoes of consistent
5 quality [1]. Preferences of food manufacturers and individual consumers as regards the quality of the potato
6 depend on eating habits in different countries [2]. Frozen purees made from mixtures of vegetables are a
7 relatively new kind of high-quality product with a good potential market in Europe [3]. However, freezing and
8 thawing of foods can have a detrimental effect on their sensory and water-holding properties as a result of
9 physical disruption of cells or cell components or to changes in the structure of certain macromolecules [4].
10 Technological solutions adopted to minimize the effects of freezing include the use of rapid freezing methods.
11 When authors examined the effects of freezing temperature (-80 °C, -40 °C, -24 °C) and thawing mode
12 (microwave or overnight at 4 °C) on instrumental textural profile analysis (ITPA) and cone penetration (CP)
13 parameters of mashed potatoes, the differences from freshly prepared product were less when the samples were
14 frozen at -80 °C and thawed by microwaving [1]. On the other hand, no difference was found in sensory
15 acceptability between samples frozen at -80 and -40 °C **irrespective of whether thawing mode was used**, which
16 reflects the panellists' **did not find significant differences between** air thawed vs. microwave thawed samples [1].

17 Pretreatments can have a considerable effect, particularly on the texture of the final potato product. One
18 technique, a low-temperature blanching (LTB) process, has been reported by numerous authors, offering a
19 promising approach to improved retention of firmness which was the reason for studying the effect of LTB prior
20 to cooking on ITPA, CP parameters, colour and sensory attributes of fresh (F) and frozen/thawed (F/T) mashed
21 potatoes [5]. Results of the different instrumental parameters indicated that in F/T mashed potatoes, blanching at
22 < 65 °C produced a softening of the product with respect to the unblanched controls, while blanching at 65 °C
23 for 30 min had a thickening effect. In both F and F/T mashed potato the panellists scored the samples blanched at
24 65 °C, 30-min significantly lower for overall acceptability than the unblanched controls, possibly because of
25 excessive thickening.

26 Another strategy to minimize damage from freezing and thawing is to incorporate compounds that interact
27 with water and offer protection against the deleterious effects of thawing in particular i.e. cryoprotectants [6],
28 which have been reported to slow down the rate of ice crystal growth and alter crystal shapes [7]. Hydrocolloids
29 and proteins, the two kinds of biopolymer used by food technologists to control structure, texture and stability
30 [8], both possess cryoprotectant properties [4]. In addition, hydrocolloids are known specifically for their water-

holding characteristics and are used in starch-based products to influence the gelatinization and rheological properties of starches. The apparent viscosity of low-methoxyl (LM) pectin in solutions increased by 20% and 39% as the concentration increased from 2.3% to 2.5% and 2.7% [9]. High-methoxyl (HM) pectin is preferred in acidic milk beverages as a stabilizer [10]. Pectin has also been used for textural stabilization in stirred yoghurt [11, 12]. For commercial dairy products, kappa- and iota carrageenans (*k*-C and *i*-C) are generally considered to be the most suitable hydrocolloids [13]. Water-binding agents, including xanthan gum (XG) and guar gum, offer an alternative for improving bread quality both in frozen storage and in microwave thawing. Increased water-holding capacity is desirable in the microwave process in order to hinder rapid water loss and render the product less tough [14]. Proteins are known specifically for their emulsifying and foaming properties [8], and protein-polysaccharide interactions in food formulation [15, 16] are now considered important for purposes of designing products with a desired structure, texture and consumer acceptance.

It is generally accepted that each hydrocolloid affects the pasting and rheological properties of starch-based systems like the mashed potato presented here in a different way [17]. There are many possible factors involved in this, the most important being the molecular structure of the hydrocolloids and/or the ionic charges of both starches and hydrocolloids [18, 19]. Starch is also widely used in the food industry as a thickening, stabilizing, and gelling agent [20, 21], but uses of native starch are limited since pastes present problems including retrogradation, syneresis and slow resistance to shear treatment [22]. To improve the physical and chemical properties of these pastes, starches have been chemically modified, for example by acid hydrolysis, oxidation, etherification, and crosslinking; in this connection authors have investigated the influence of the addition of modified cornstarch on the quality of frozen/thawed mashed potatoes [23]. Starch addition enhanced the positive effect of fast freezing rates on the texture of mashed potatoes as measured in terms of ITPA consistency, but in terms of sensory acceptability starch addition followed by quick freezing was judged undesirable by the panellists due to excessive softening.

Downey [24] studied the effect of addition of hydrocolloids (xanthan gum, guar gum, pectin, carrageenan) and dairy proteins (sodium caseinate, whey protein concentrate) on centrifugal drip loss and maximum resistance to penetration force in frozen and thawed, cooked puréed vegetables. The author showed that depending on the vegetable, quality maintenance or improvement after thawing may be achieved through selection of an appropriate cryoprotectant. The textural and sensory properties of this group of products were strongly influenced by type and concentration of crioprotectant, and their crossed interactions.

The texture of cooked potato has been the subject of research for many years. However, the diversity of techniques available for instrumental evaluation of cooked potato texture and the diversity of varieties make synonymous characterisation of texture difficult [2]. It has been reported that instrumental objective tests used to measure the texture of solid food, such as instrumental textural profile analysis (ITPA) and cone penetration (CP) tests, may be perfectly valid for semisolid food products, with the advantage that they provide a rapid means of ascertaining and characterizing product texture [25]. Maximum force needed for squeezing a portion of 60 g of mashed potato to about 2 mm from the bottom of the attachment has been considered as a measurement of the consistency for the comparison of cooked mashed potatoes prepared from seven varieties of potatoes [2], whereas Downey [24] used maximum resistance to penetration force in frozen and thawed, cooked puréed vegetables as a measurement of consistency. Also, puncture tests and/or ITPA have been used for evaluation of texture in other semisolid food products, such as gels made from fish mince containing different hydrocolloids [26], and fresh and frozen stored microwave-reheated breads [14].

The objectives of the work reported in this paper were to evaluate the effect of different hydrocolloids cryoprotectants added to fresh and frozen/thawed mashed potatoes on their: (1) the instrumental textural characteristics, (2) the instrumental colour characteristics; and (3) the sensory textural characteristics, in comparison to those of a fresh control (FC) and frozen/thawed control (F/T C) without cryoprotectants.

Materials and methods

Test material

The potatoes used were fresh tubers (cv Kennebec) from Galicia Spain cultivated in 2006 and having weights (g) within the confidence interval ($95.69 \leq \mu \leq 111.81$) and specific weights (g cm^{-3}) within the interval ($1.0721 \leq \mu \leq 1.0787$); $P \leq 0.01$. Total-N (DUMAS), potassium and starch were analyzed according to standard methods [27] before storage. Average values of dry matter, starch, N and K in fresh tuber were 187 (g kg^{-1} fresh weight), 762 (g kg^{-1} dry weight), 11 (g kg^{-1} dry weight) and 21 (g kg^{-1} dry weight), respectively. The total soluble solids content of the fresh tubers was 13.30 g 100 g^{-1} (w/w) as measured by refractive index and their pH 6. The raw material was stored during four months in a chamber at 4 ± 1 °C and 85% relative humidity throughout the experiment [28].

Preparation of mashed potatoes

Tubers were manually washed, peeled and diced. Mashed potatoes were prepared in 650-g batches from 607.7 g kg⁻¹ of potatoes, 230.8 g kg⁻¹ of semi-skimmed in-bottle sterilized milk (fat content: 15.5 g kg⁻¹), 153.8 g kg⁻¹ of water and 7.7 g kg⁻¹ of salt (NaCl) using a Thermomix TM 21 apparatus (Vorwerk España, M.S.L., S.C., Madrid, Spain). Cryoprotectants (hydrocolloids or proteins) were added at this point; the appropriate amount of each ingredient was added to 384.6 g kg⁻¹ of water and milk in the form of a dry powder and diluted by blending under slight heating (60 °C) and magnetic stirring for different times until dilution was complete. All the ingredients were then cooked for 20 min at 100 °C (blade speed: 100 rpm), and the amount of liquid evaporated was determined by weighing the ingredients before and after boiling. The evaporated liquid was then replaced by an equal weight of boiling water and the ingredients were again cooked at 100 °C for 5 min. The mash was immediately ground for 40 s (blade speed: 2000 rpm) and homogenized through a stainless steel sieve (diameter 1.5 mm). The final pH of the fresh mashed potatoes without added cryoprotectants was 6.3 and was not modified by freezing and thawing processes. Following preparation, half of each fresh mashed potato sample was immediately analysed and the other half was packed in 300 × 200 mm rectangular polyethylene plastic bags, sealed under light vacuum (-0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and frozen and thawed according to the freezing and thawing procedures indicated below.

Cryoprotectants

Amidated low-methoxyl pectin (GENU pectin type LM-104 A; pectin was methylated to a degree of 27% and in addition a further 20% of the residues was amidated (DA = 20%)), high-methoxyl pectin (GENU pectin 150 USA-SAG type A medium rapid set), kappa-carrageenan (GENULACTA carrageenan type LP-60), iota-carrageenan (GENUGEL carrageenan type CJ), xanthan gum (Keltrol F [E]), and microparticulated whey protein concentrate (53% protein, SIMPLESSE 100 [E]) were donated by Premium Ingredients, S.L. (Girona, Spain), and sodium caseinate EM-6 was supplied by Manuel Riesgo, S.A. (Madrid, Spain). All powders were stored at room temperature. Range finding experiments were performed at the outset of this work to ascertain the maximum acceptable amount of each biopolymer that could be added to the mashed potato. As the resulting product had to be acceptable to consumers, this assessment was done by trained testers on the basis of flavour

and viscosity, although colour was also a consideration. On this somewhat empirical basis, the following acceptable levels of hydrocolloid and protein use were established: amidated low- and high-methoxyl (ALM and HM) pectins and kappa- and iota-carrageenans (κ -C and *i*-C) were added at 0 (non-added), 1.5, 3, 5 and 8 g kg⁻¹; xanthan gum (XG) was added at 0 (non-added), 0.5, 1.5, 2.5 and 5 g kg⁻¹; whey protein (WP) was added at 0 (non-added), 1.5, 5, 15 and 25 g kg⁻¹ and sodium caseinate (SC) was added at 0 (non-added), 2.5, 5, 7.5 and 10 g kg⁻¹. Table 1 indicates the cryoprotectant contents of the F and F/T mashed tested, together with the notations used to refer to each of the samples.

Freezing and thawing procedures

Mashed potatoes were frozen by forced convection with liquid nitrogen vapour in an Instron programmable chamber (model 3119-05, -70 °C/+250 °C) at -60 °C until their thermal centres reached -24 °C [29]. The total duration of each freezing process was 75 min. Air and product temperatures were monitored by T-type thermocouples (NiCr/NiAl; -200 to +1000 °C) using the MMS3000™ Multi Measurement System™ (Mod. T4, Commtest Instruments, Christchurch, New Zealand). The software permitted real-time data gathering and storage and also calculation of the freezing rate (1 ± 0.10 °C min⁻¹). After freezing, samples were placed in a domestic freezer for storage at -24 °C and left there for at least 1 month before thawing. For microwave thawing, frozen mashed potato samples were unpacked, immediately placed on flat microwave trays and then thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain). In all cases the samples were placed in the same position and irradiated for a total of 20 min with output power ratings of 600 W. Thawing was conducted in two steps. Samples were first irradiated for 15 min, then removed from the microwave and stirred manual and gently with a spoon for 1 min to achieve a uniform sample temperature. Next, the samples were placed in the microwave again and irradiated for an additional 5 min under the same conditions. After this procedure, the temperature reached at the thermal centre of the product was measured in all cases ($+50 \pm 5$ °C) [1, 5].

Heating of samples

All the fresh and frozen/thawed samples were brought up to 55 °C by placing them in a Hetofrig CB60VS water-bath (Heto Lab Equipment A/S, Birkerød, Denmark), where again water and product temperatures were

monitored by T-type thermocouples using a hardware and software system developed with the LabWindows/CVI package (National Instruments Spain S.L., Madrid, Spain) for automation of thermal process control [30]. The selected sample testing temperature was 55 °C, as results from different analyses showed that this is the preferred temperature for consumption of mashed potato [1, 5].

Instrumental objective texture measurements

Instrumental texture profile analysis (ITPA) and cone penetration (CP) tests were carried out with a TA.HDi Texture Analyser (Stable Micro Systems Ltd, Godalming, UK) using a 25 N load cell and the application program supplied with the apparatus (Texture Expert for WindowsTM, version 2. 61). During the tests, the mashed potatoes were kept at 55 °C by means of a Temperature Controlled Peltier Cabinet (XT/PC) coupled to a separate heat exchanger and PID control unit. For ITPA tests, a flat 35 mm diameter aluminium plunger (SMS P/35) was used inside a 60 mm diameter stainless steel vessel containing 50 ± 1 g of sample. The Texture Analyser was programmed so that the downward movement began at a point 8 mm above the surface of the sample. The following experimental conditions were selected for each ITPA test: deformation rate (180 mm min^{-1}), compression level (33.3 %), with a rest period of 5 s between cycles [1, 5]. Measurements were performed in quadruplicate and results averaged. Textural parameters such as consistency (N), adhesiveness (N s), springiness (dimensionless) and cohesiveness (dimensionless) were automatically calculated by the software from the curve generated by these tests. Definitions of textural parameters are described elsewhere [1, 25]. For performing the cone penetration tests, a spreadability rig was used, consisting of a 45° conical perspex probe (P/45 C) that penetrated a conical sample holder containing 7 ± 0.1 g of mashed potatoes [25]. Tests were done at a deformation rate of 180 mm min^{-1} . Measurements were performed in quadruplicate and results averaged. The maximum resistance to penetration (N) and the average penetration force (N) were measured.

Measurement of colour

The colour of the mashed potato samples in the pots was measured instrumentally with a HunterLab model D25 colour difference meter (Reston, VA, USA) fitted with a 5 cm diameter aperture. Results were expressed in accordance with the CIELAB system with reference to illuminant D65 and a visual angle of 10°. The parameters

determined were L^* ($L^* = 0$ [black] and $L^* = 100$ [white]), a^* ($-a^*$ = greenness and $+a^*$ = redness), b^* ($-b^*$ = blueness and $+b^*$ = yellowness), C^* chroma (saturation) and H^* hue, as defined by the following equations:

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad H^* = \arctan(b^* / a^*)$$

The total colour difference (ΔE^*) between the fresh control made without cryoprotectant and other fresh and frozen/thawed mashed potatoes made with added biopolymers was calculated as follows:

$$\Delta E^* = \left[\left(\frac{L_n^* - L_1^*}{K_L S_L} \right)^2 + \left(\frac{C_n^* - C_1^*}{K_C S_C} \right)^2 + \left(\frac{H_n^* - H_1^*}{K_H S_H} \right)^2 \right]^{1/2}$$

where L_1^* , C_1^* and H_1^* are the reference (fresh sample) colour parameters values and

$S_L = 1.0$, $S_C = 1 + 0.045C_1^*$ and $S_H = 1 + 0.015C_1^*$.

The factors K_L , K_C , and K_H are parametric factors and vary with the experimental conditions. All were given a fixed unit value for the combination of our specific reference conditions [31, 32].

Sensory analysis

Sensory evaluation was conducted by a four-member panel with specific training in potato purees for six years [1, 23, 25]. Each sample was tested twice and average scores calculated, so that each sample was tested eight times in all. F and F/T mashed potatoes were subjected to texture profile analysis (TPA) modified to evaluate frozen vegetable purees according to UNE 87025 [33], which was used to select and define the sensory attributes included in the profile. Profile attributes were classified into four groups (Table 2). For each sample, panellists evaluated the perceived intensity of the 13 attributes on 9 cm descriptive linear scales labelled at each anchor (left anchor: 1 = “not detectable”; right anchor: 10 = “extremely intense”). Therefore each attribute “score or level of intensity” was measured in cm. Training sessions devoted to group discussion of the selected attributes and vocabulary alignment had been carried out previously. During these sessions, panellists were also trained to the use of linear scale, and for FC and F/T C mashed potatoes, they rated the perceived intensity of each of the 13 attributes over several sessions. Daily for 120 days at a fixed time (1 p.m.) panellists were given sequentially four samples (about 20 g each) with which to score the attributes of each group in the texture profile. The order

of scoring attributes was the same among sessions and among panellists (Table 2). FC or F/T C were used for reference together with the groups of four samples every time. All the samples were served at about 55 °C on Petri dishes. This sample temperature was reached and kept constant by placing the product in the Hetofrig CB60VS water bath prior to testing. Panellists sat in separate taste panel booths lit by tungsten filament lights and were provided with glasses of water. To reduce fatigue and sample cooling, a rest period of 5 min was taken after scoring each sample.

Statistical analysis

For analysis of the effect of cryoprotectant concentration and freezing and thawing processes on ITPA properties, CP parameters, ΔE^* and sensory TPA attributes of the mashed potatoes, results were subjected to multifactor analysis of variance (two-way ANOVA) and to one-way analysis of variance (one-way ANOVA) using STATGRAPHICS (version 5.0, STSC Inc., Rockville, MD, USA) on 10 hydrocolloid or protein concentrations (for both F and F/T mashed potatoes) $\times 2$ replicates with 19 degrees of freedom. Where significant differences were present, individual combinations were compared using least significant difference (LSD) tests. Confidence levels were 99% for instrumental parameters and 95% for sensory attributes. The software was also used to establish correlations between instrumental and sensory characteristics using the Spearman rank correlation coefficient (r). FC and F/T C mashed potatoes without added product were used as controls to study of the effect of each cryoprotectant on the quality of the mashed potatoes.

Results and discussion

Changes on instrumental textural profile analysis (ITPA)

Fig. 1 shows the effect of biopolymer concentration and freezing and thawing processes on ITPA consistency. With all the biopolymers selected, both concentration and processing significantly ($P < 0.01$) affected the sample consistency, and the interaction between effects was also significant. The addition of *k*-C at 5 and 8 g kg⁻¹ (Fig. 1c) and WP at 5, 15 and 25 g kg⁻¹ (Fig. 1f) to F mashed potatoes significantly ($P \leq 0.01$) increased consistency, i.e. had the

effect of thickening the mash. On the contrary, the addition of ALM pectin at 5 and 8 g kg⁻¹ (Fig. 1a) and XG at 1.5 and 2.5 g kg⁻¹ (Fig. 1e) to F product significantly ($p \leq 0.01$) reduced consistency, i.e. weakened the gel structure of the mashed potatoes. Mashed potatoes as made here are combined systems of native potato starch/denatured milk protein/water/salt plus the added biopolymer, and therefore complex interactions can influence the properties of these mixtures. Foods typically contain both kinds of biopolymers in the form of complex multicomponent mixtures, and so it is often difficult to disentangle the separate roles of the proteins and polysaccharides in terms of their functional properties [8]. In the F/T products, adding 5 and 8 g kg⁻¹ ALM, 3, 5 and 8 g kg⁻¹ *k*-C, 1.5, 3, 5 and 8 g kg⁻¹ *i*-C (Fig. 1d) and 1.5, 5 and 15 g kg⁻¹ WP, significantly increased the ITPA consistency of the samples, as compared to F/T C. Also, F/T samples with 2.5 and 5 g kg⁻¹ added XG had a stronger consistency than F/T C. In both F and F/T products, parameter values were highest in mashed potatoes with added *k*-C carrageenans (Fig. 1c).

For commercial dairy products, *k*- and *i*-C are considered the most suitable hydrocolloids because they are able to combine into double helices and can interact with casein to form network structures [13]. However, the formation of a carrageenan-casein network cannot be expected in the mashed potatoes presented here, which contain denatured milk protein. The fact that the increase of consistency was greatest in the samples with added κ -C and *i*-C could be due to the ability of both carrageenans to immobilize water combined with their ability to combine into double helices. In an earlier work we found that of the biopolymers added to the mashed potatoes, ALM, *k*-C and *i*-C, XG and SC had high water holding capability, whereas HM and WP exhibited no ability to immobilize water [data unpublished]. Also, Tecante and Doublier [34] demonstrated that elasticity depends strongly on the κ -C concentration in mixtures with amylase: therefore, the increase in the structural strength of samples with added with κ -C could also be ascribed to interactions between the anionic sulphated polysaccharide

1 and the denatured milk protein present in the mashed potatoes. A stronger synergistic effect
2 was observed in κ -C/denatured soy protein systems associated with greater incompatibility
3 due to thermal denaturation of the protein [35]. Stronger synergistic effects of thermally
4 denatured whey protein isolates have also been observed on 5 g L⁻¹ κ -C gels [36]. The fact
5 that protein denaturation enhanced the synergistic effect of the gelling behaviour of κ -C could
6 reflect both an increase in thermodynamic incompatibility due to the excluded volume effect
7 and the formation of an electrostatic complex as more charged groups on the surfaces of the
8 biopolymers became exposed. On the contrary, in both fresh and processed samples, ITPA
9 consistency of mashed potatoes was not improved by adding HM (Fig. 1b), showing that HM
10 pectin, added to mashed potatoes at the concentrations used, had no beneficial effect on ITPA
11 consistency of either the F or the F/T product, but had an incompatible effect. Also, HM
12 pectins have shown low compatibility with surimi gels [37, 38]. Increased water loss resulting
13 from the addition of HM pectin may be caused by its displacement from inter-chain spaces in
14 the starch matrix as the hydrocolloid occupies these spaces [39]. The detrimental effect of the
15 combined mashed potatoes HM pectin system could be associated with interferences by water
16 loss in formation of the three-dimensional structures of the gel.

17 In turn, a disruptive effect was observed in the F/T mashed potatoes with added SC (Fig.
18 1g). Adding 10 g kg⁻¹ SC to F/T samples significantly debilitated the consistency of the
19 product, possibly due to phase separation. Several authors have recently studied phase
20 separation in milk protein (colloidal casein) and polysaccharide mixtures [40-43]. The time
21 evolution of phase separation in milk protein-amylopectin mixtures at pH 6.3 has been studied
22 by confocal scanning laser microscopy, revealing the formation of aggregate-like structures
23 by protein particles [44]. Certainly, visual and perceived granularity and fibrousness was
24 detected by the panellists in the samples with added WP and SC, probably as a consequence
25 of phase separation.

Note that ITPA consistency values were much higher in all the processed samples than in the fresh ones, except in the mashed potatoes with 0.5 g kg⁻¹ added XG and with 2.5 g kg⁻¹ added SC. This result suggests that in all cases, freezing and thawing processes reinforced the gel structure of the products as compared to F counterparts. Even processing of FC without added biopolymers significantly strengthened the consistency (from 2.14 to 2.64 N). This result does not concord with an earlier study [24], whose authors found that in mashed potatoes, all ITPA parameters except cohesiveness were lower in the processed than in the fresh samples, suggesting that the product's structure was weakened by freezing and thawing. Another study also showed that increasing time in frozen storage led to a natural mash with a firmer texture [1]. In this study, frozen mashed potatoes were stored for at least 1 month before thawing, so that the highest ITPA consistency value of the F/T C as compared to its fresh counterpart could be ascribed to thickening effect caused by prolonged frozen storage.

Fig. 2 shows the results for ITPA adhesiveness. In the case of the two pectins (Fig. 2a, 2b) and carrageenans (Figs. 2c, 2d), xanthan gum (Fig. 2e) and whey protein (Fig. 2f), increased in concentrations and processing significantly ($P < 0.01$) affected the sample adhesiveness, although the interaction between effects was only significant in the mash with added ALM, *k*- and *i*-C. In mashed potatoes with added SC (Fig. 2g), only processing had a significant effect on adhesiveness, which in fact was much greater in processed than in the fresh samples with all the ingredients selected. In F samples, adhesiveness increased significantly as compared to FC in the samples with 5 g kg⁻¹ added *k*-C, although the effect of biopolymer concentration was more significant in the F/T products in all cases, except in the samples with added HM pectin (Fig. 2b). ITPA adhesiveness values were significantly higher in F/T samples with 8 g kg⁻¹ added ALM pectin (Fig. 2a), with up to 5 g kg⁻¹ added *k*-C (Fig. 2c), and with up to 8 g kg⁻¹ added *i*-C (Fig. 2d) than in F/T C. Moreover, in the F/T product with added *i*-C, the effect of the concentration was linear with values increasing at the four

test concentrations used. Also, F/T-XG2.5 and F/T-XG5 samples (Fig. 2e), like F/T-SC2.5, F/T-SC5, F/T-SC7.5 and F/T-SC10 samples (Fig. 2f), presented greater adhesiveness than frozen/thawed control, although there were non-significant differences between values. In fresh samples, adding 3, 5 and 8 g kg⁻¹ HM pectin significantly decreased sample adhesiveness (Fig. 2b).

In the F/T mashed potatoes, the highest values for sample adhesiveness were found when either carrageenan was added. Addition of *k*-C at 5 g kg⁻¹ caused almost three times as large an increase of the force needed for the first probe reversal (from 5.91 to 15.50 N), and about twice for the mashed potatoes with 5 and 8 g kg⁻¹ added *i*-C (from 5.91 to 11.99 N). However, authors should clarify that the adhesiveness values of the processed samples with more than 3 g kg⁻¹ added carrageenans should be interpreted with caution, since these samples were clearly very sticky preventing a clean separation at the probe/mashed potatoes interface and thus affecting the physical significance of adhesiveness, and probably also of springiness and cohesiveness as indicated below. This bears out the suggestion by Pons and Fiszman [45] that for some kinds of foods, ITPA might not to be the most suitable measurement method, and this should be taken into account.

Fig. 3 shows the effect of biopolymer concentration and freezing and thawing processes on ITPA springiness. Neither biopolymer addition nor processing significantly affected the springiness of the samples with added ALM pectin (Fig. 3a), XG (Fig. 3e) and SC (Fig. 3g), which remained practically constant in the F and F/T products. On the other hand, springiness was significantly ($P \leq 0.01$) affected by adding HM pectin, *k*- and *i*-C, as well as by processing (Figs. 3b, 3c, 3d), and the interaction between effects was also significant when HM pectin and both carrageenans were added. Only, WP concentration had a significant effect on springiness, which was much lower in the F product with 25 g kg⁻¹ and in the F/T samples with 15 and 25 g kg⁻¹ added whey protein (Fig. 3f). The reduction of sample

springiness with increasing concentration produced by HM addition was masked by processing except at the highest concentrations (Fig. 3b). Also, in the F/T samples with either carrageenan added springiness decreased with increasing concentration (Figs. 3c, 3d), and the addition of *k*- and *i*-C at 5 g kg⁻¹ produced the lowest ITPA springiness values. Therefore, in the samples with either carrageenan added at the highest concentrations, it would be fair to say that higher adhesiveness was associated with lower springiness. But again, we would note that this could have been caused by the stickiness of these samples, given that on the second compression cycle the sample was no longer complete as part of it was still adhering to the probe. As a result, the curve for the upstroke of the probe was much greater than the curve for the downstroke, which would affect springiness as defined by the ITPA method [46].

One of the ITPA parameters which has undergone most modifications is springiness, initially called elasticity [42]. Fiszman et al. [47] and Alvarez et al. [46] measured two different springiness-related parameters in the same test: “instantaneous recoverable springiness”, derived from the first compression cycle, and “retarded recoverable springiness”, which corresponds to the springiness parameter normally measured by ITPA, and here. For *k*-C/locust bean gum, gellan gels and potato and apple tissues [46, 47], the two springiness values were quite different, since instantaneous recoverable springiness is derived from the first compressive cycle; therefore, the viscous component does not intervene and what is considered is principally the elastic element. The proposed “instantaneous recoverable springiness” parameter could be more useful for differentiating the structural natures of such sticky products.

Fig. 4 shows ITPA cohesiveness of F and F/T mashed potatoes with added biopolymers. In the mashed potatoes with HM pectin (Fig. 4b), XG (Fig. 4e) and both dairy proteins added (Figs. 4f, 4g), both concentration and processing significantly ($P < 0.01$) affected the sample cohesiveness, and the interaction between effects was also significant except for the samples

1 with added SC. The cohesiveness increased adding 3, 5 and 8 g kg⁻¹ HM pectin in the F
2 samples (Fig. 4b), and decreased in the F/T product, although differences between samples
3 were not significant. Also, the cohesiveness decreased as the concentration of ALM, *k*-C, *i*-C
4 and WP increased in the frozen/thawed mashed potatoes, although in the samples with added
5 ALM (Fig. 4a) mainly processing significantly affected cohesiveness, which was greater in
6 the processed product with 1.5 g kg⁻¹ added ALM than in its fresh counterpart. On the
7 contrary, in mashed potatoes with either carrageenan added (Figs. 4c, 4d), both concentration
8 and processing significantly affected this ITPA parameter.

9 On the other hand, the cohesiveness of F/T mashed potatoes with added XG (Fig. 4e) did
10 not increase significantly as the concentration increased, while in the case of the F/T samples
11 with added SC (Fig. 4g), cohesiveness was only higher than in F/T C in the samples with 7.5
12 and 10 g kg⁻¹ added SC, although differences between samples were not significant. All the
13 frozen/thawed samples with added SC presented greater cohesiveness than the F products, but
14 with all other ingredients, freezing and thawing had no definite effect on the sample
15 cohesiveness as compared to F products. The lowest cohesiveness values were found in
16 samples with 5 and 8 g kg⁻¹ added *k*-C (Fig. 4c), although again it should be remembered that
17 because of the stickiness of these samples the upstroke curve of the probe was much greater
18 than the downstroke curve, which could mean that ITPA registered sample cohesiveness as
19 lower than it really was.

20 21 Changes in cone penetration (CP) parameters

22
23 The factors studied had similar effects on the two cone penetration (CP) test parameters, and
24 therefore results of maximum penetration strength have been omitted. Fig. 5 shows the effect
25 of biopolymer concentration and freezing and thawing processes on CP average penetration
26 force. Both concentration and processing of all the biopolymers selected significantly ($P <$

0.01) affected the sample average force, and the interaction between effects was also significant except for the samples with added HM. Adding 3, 5 and 8 g kg⁻¹ of either carrageenan (Figs. 5c, 5d) to F mashed potato significantly ($P \leq 0.01$) increased penetration force, i.e. had the effect of thickening the mash. Also, F samples with 5 g kg⁻¹ added WP (Fig. 5f) required greater penetration force than FC control. On the contrary, the addition of either ALM or HM pectin at 3 and 8 g kg⁻¹ respectively (Figs. 5a, 5b) to F product significantly ($p \leq 0.01$) reduced penetration force, i.e. weakened the gel structure of the mashed potatoes. In the F/T products, adding 1.5 and 8 g kg⁻¹ ALM, 3, 5 and 8 g kg⁻¹ *k*-C, and 1.5, 3, 5 and 8 g kg⁻¹ *i*-C (Figs. 5a, 5c, 5d) increased the penetration force of the samples as compared to F/T C. Also, F/T samples with 1.5, 5 and 15 g kg⁻¹ added WP (Fig. 5f), and 5 g kg⁻¹ added SC (Fig. 5g) presented greater penetration force than F/T C.

In F/T products, the highest average force values were recorded for the mashed potatoes with added *i*-C carrageenan (Fig. 5d), whereas values were lowest in the samples with added XG. For most of the concentrations used, average penetration forces were higher in processed than in fresh samples, also evidencing the utility of the biopolymers as texturizers for mashed potatoes subjected to freezing and thawing. Also, F/T C had a significantly higher force value than FC (from 1.53 to 1.90 N), corroborating ITPA sample consistency results. CP average force and ITPA consistency were positive and significantly correlated in the F samples with added HM, *k*- and *i*-C, XG and SC, whereas in the case of F/T products, correlations between both parameters were significant only when *i*-C and XG were added. We would further note that reproducibility of the instrumental tests was very high, but the coefficients of variation of ITPA consistency were lower.

Changes on colour of final mashed potatoes

1 In order to study the total colour differences between mashed potatoes the values of ΔE^* were
2 calculated. The reference taken in all cases was the colour of FC control. The increase in
3 biopolymer concentration and the processing and interaction were significant in all cases (Fig.
4 6), except for the samples with added SC, where the effect of processing was only significant
5 for controls and samples added at the highest concentration (Fig.6g). After processing, ΔE^* ,
6 was 1.37 (Fig. 6), and as a result F/T C was darker than FC, confirming previous findings [1].
7 Of course, this darkening is unlikely to be of major importance, since anyone preparing F/T
8 mashed potato is unlikely to have a F sample with which to compare it. As Figs. 6a and 6b
9 show, the value of ΔE^* increased when the concentration of both pectins increased, mainly in
10 F mashed potatoes. The values of ΔE^* with respect to FC were very much lower after freezing
11 and thawing processes. The trend of the results was similar when *k*-C and XG were added
12 (Figs. 6c and 6e), although the values of ΔE^* in the fresh product were lower than when the
13 pectins were added. As Fig. 6g shows, ΔE^* also increased when the concentration of SC
14 increased.

15 Processing had a highly significant effect on the samples with added WP (Fig. 6f), and
16 the differences in colour with respect to FC were greater in the processed products than in
17 their fresh counterparts, but only in this case. The presence of aggregate-like structures of
18 protein particles seems to be associated with interferences in uniform freezing of the product
19 and consequent modification of light reflectance. In contrast, F samples with added WP had
20 lower ΔE^* values than all other F samples. Finally, ΔE^* decreased as the concentration of *i*-C
21 increased, although after freezing and thawing the final colour of the product was similar to
22 that of the samples with added gums. Comparison of the results suggests that the addition of
23 ALM and HM pectins to F mashed potatoes affected the final colour more than any of the
24 other biopolymers, and it would be fair to say that freezing and thawing have a decisive effect
25 on the final colour of the mashed potatoes, so that the differences in colour between the F

product and the samples prepared with added hydrocolloids are reduced. F/T mashed potatoes containing WP presented higher ΔE^* values than any other F/T products or their F counterparts.

Changes in sensory texture attributes (TPA)

Tables 3-5 show results of the multiple range tests for the interaction between biopolymer concentration and freezing/thawing on the panellists' average scores for ITPA sensory attributes as compared to FC and F/T C controls. In general terms, either biopolymer concentration or processing significantly affected ($P < 0.05$) all the sensory attributes scored in the mashed potatoes with added cryoprotectants. The effect of concentration was not significantly only in the cases of granularity in samples with added ALM (Table 2) and either fibrousness (Tables 3 and 5) in samples with added *k*-C. For its part, the effect of processing was not significant in the cases of homogeneity in samples with added *i*-C (Table 3), granularity in samples with added XG (Table 4), or ease of swallowing in samples with added XG and WP (Table 5).

As Tables 3 and 4 show, granularity was significantly higher in F/T control than in its F counterpart; this indicated a negative effect of freezing and thawing causing more appreciable granularity, probably due to structural disruption. In F samples with added ALM, *k*-C or WP at any concentration, granularity increased significantly as compared to FC; the differences from fresh control were non-significant only in the cases of F-HM8, F-*i*-C1.5, F-XG0.5, F-XG1.5 and F-SC2.5. In F/T product, granularity decreased significantly with respect to control with the addition of ALM, *i*-C and XG at all the concentrations used (Tables 3, 4); in most cases it increased significantly with the addition of WP, which could be ascribed to phase separation rendering granularity more appreciable. Also, in the F/T samples with added

WP granularity increased with increasing concentration. Another point to note is that there were no significant differences in the scores for granularity between FC and any of the F/T samples with added XG (Table 4).

The scores for both moistures were lower in F/T C control than in the fresh one, indicating that processing dried the samples. In F/T samples with added ALM, *k*- or *i*-C, XG or SC, panellists detected less moisture in both situations with increasing biopolymer concentration, and the scores were lower than in FC, except in the case of moisture perceived before placing the sample in the mouth in F/T-ALM1.5, F/T-ALM3, F/TXG0.5 and F/TXG0.5, which were practically the same as that of the FC. In contrast, in F/T samples with added HM and WP, panellists detected more moisture in both situations with increasing biopolymer concentration; this confirms that neither ingredient exhibited an ability to immobilize water as cited above. In F/T C, scores for stickiness and adhesiveness were higher than in the F counterpart (Table 3). In both F and F/T samples, scores for adhesiveness perceived at the time of preparing the sample for swallowing were higher than those for stickiness perceived at the time of placing the sample in the mouth. In both fresh and processed products, scores for stickiness and adhesiveness increased significantly with increasing biopolymer concentration in the case of samples with added ALM, *k*- and *i*-C, XG and SC, and decreased linearly with increasing HM concentration. In the case of mashed potato with added WP, scores for stickiness and adhesiveness decreased significantly with increasing concentration in the F product. In the F/T samples, scores for stickiness presented no identifiable trend, while again those for the adhesiveness decreased with increasing WP concentration. The processed products generally scored higher than their F counterparts. Also, the highest scores were recorded for the F/T samples with either carrageenan added, especially *i*-C, confirming the results of the ITPA test.

In F/T mashed potato, denseness and firmness also increased significantly with increasing biopolymer concentration in the samples with added ALM, *k*-C, XG and SC, while again in

the F/T samples with added HM and WP scores for both sensory attributes decreased significantly with increasing concentration of these ingredients. In the F/T samples with added *i*-C, there were no significant differences between samples in the scores for denseness (Table 3), while in these samples firmness scores increased with increasing concentration up to 5 g kg⁻¹. In both controls and samples with added cryoprotectants, scores for denseness and firmness were lower in F products than in their F/T counterparts, again confirming ITPA results. Also, the processed control scored lower than the FC for homogeneity. Scores awarded to this attribute in F/T-ALM5, F/T-ALM8, F/T-HM1.5, F/T-HM3, F/T-HM5, F/T-HM8, F/T-*k*-C1.5, F/T-*k*-C3, F/T-*k*-C5, F/T-*i*-C1.5, F/T-*i*-C3, F/T-*i*-C5, F/T-*i*-C8, F/T-XG0.5, F/T-XG1.5, F/T-XG2.5 and F/T-XG5 samples were significantly equal to or higher than those awarded to FC, indicating that processing of the samples with added hydrocolloids rendered homogeneity more appreciable. The lowest scores for this attribute were recorded for products with added dairy proteins, while the highest scores were awarded to the samples with added xanthan gum (Table 4). Cohesiveness was scored higher in F/T C than in FC control. In both F and F/T samples with either carrageenan (Table 2) or XG (Table 4) added, there was a significant linear increase of this attribute with increasing concentration. In contrast, in both F and F/T samples, there was a significant linear decrease in cohesiveness with increasing concentration of either dairy protein (Table 4).

Also, scores for fibrousness perceived at the time of preparing the sample for swallowing were highest in the samples with added dairy proteins, especially when WP was added before processing of mashed potatoes; addition of WP or SC produced fibrous-like structures, which may have been a consequence of phase separation. TPA did not include any taste attribute, but panellists found that the addition of whey protein to the mashed potatoes produced an unpleasant taste. Panellists further found that the addition of 7.5 or 10 g kg⁻¹ SC gave the mashed potatoes an unfamiliar taste and odour. Certainly, binding of flavour compounds and

reduction of taste perception by casein and whey proteins have been reported [48]. Scores for fibrousness in the F/T samples with added XG were all significantly similar to that of FC, where as found elsewhere, fibrousness is not expected to be easily detectable [1, 25].

Finally, Table 5 shows the effect of biopolymer concentration and processing on the panellists' average scores for the three sensory attributes perceived during the final and residual phases of mastication. In F and F/T products, ease of swallowing decreased significantly with increasing concentration in the samples with either carrageenan, XG or either dairy protein added. The highest scores were awarded to F-XG0.5, F-XG1.5, F/T-XG0.5 and F/T-XG1.5 samples, and all these were higher than the FC control. In both fresh and processed samples with added HM, ease of swallowing tended to augment with increasing biopolymer concentration; indicating that the disruptive effect caused by HM addition was not perceived negatively by the panellists. In turn, in F and F/T products, palate coating increased significantly with increasing concentration in the samples with added ALM, *k*- or *i*-C, XG or WP. For the F samples with added HM and the F/T samples with added SC, this attribute also increased with concentration. In contrast, in the F/T samples with added HM, as in the F product with added SC, palate coating decreased with increasing quantities of added biopolymer. Higher palate coating is associated with a sensation of prolonged presence on the palate after swallowing, and is therefore believed to negatively affect product sensory quality.

The scores for fibrousness perceived during final and residual phases were significantly higher when dairy proteins were added to the mashed potatoes, and again there were non-significant differences between scores for fibrousness of FC and those of F/T samples with added XG (Table 5). Certainly, both F and F/T samples containing 0.5 and 1.5 g kg⁻¹ added XG were judged more acceptable than FC thanks to their creamy mouthfeel, and excessive

thickening caused by some biopolymers, mainly the two carrageenans, was judged non-desirable by the panellists.

For each biopolymer selected, correlations (r) were established between ITPA consistency, adhesiveness, cohesiveness, CP average penetration, and moisture and adhesiveness perceived in both stages of the process of mastication on the other hand and, denseness, firmness and cohesiveness from sensory TPA analysis on the other. Since the trend of instrumental and sensory texture attributes with increasing concentration was not always the same in the F samples and in their F/T counterparts, correlations were established separately for the fresh product and the processed product. Tables showing all the correlations have been omitted for the sake of brevity. Only the main points relating to correlations between instrumental parameters and sensory texture attributes are mentioned for each analysis. Correlations were poor in the F mashed potato with added ALM pectin, the strongest being the correlation between CP average force and moisture perceived before placing the sample in the mouth (-0.59); in the F/T product, on the other hand, the strongest correlation was between ITPA adhesiveness and adhesiveness perceived at the time of preparing the sample for swallowing (0.87).

In the case of F samples with added HM pectin, the strongest correlation was between ITPA consistency and denseness (0.86), whereas in F/T product the strongest correlation was between ITPA cohesiveness and moisture perceived before placing the sample in the mouth (-0.63). In the case of F mashed potato with added *k*-C, the strongest correlation was found between CP average force and moisture perceived at the time of placing the sample in the mouth (-0.88), whereas in F/T product the strongest correlation was between CP average force and cohesiveness perceived at the time of preparing the sample for swallowing (0.74). In the case of F mashed potato with added *i*-C, ITPA consistency and adhesiveness and CP average force correlated significantly with all the sensory attributes mentioned. The strongest

correlation was between CP average force and denseness (0.92). In the case of F/T mashed potato, the strongest correlation was between ITPA adhesiveness and adhesiveness perceived at the time of preparing the sample for swallowing (0.86).

In the case of F mashed potato with added XG, the strongest correlation was found between ITPA cohesiveness and adhesiveness perceived at the time of preparing the sample for swallowing (-0.76). However, in the case of F/T product with added XG, ITPA consistency and adhesiveness and CP average force correlated significantly correlated with all the sensory attributes mentioned. The strongest correlation was between ITPA consistency and moisture perceived before placing the sample in the mouth (-0.92). In the case of F mashed potato with added WP, the strongest correlation was between ITPA consistency and moisture perceived at the time of placing the sample in the mouth (-0.78), whereas in the F/T product, the strongest correlation was between ITPA cohesiveness and adhesiveness perceived at the time of preparing the sample for swallowing (0.73). In the case of F mashed potato with added SC, the strongest correlation was between CP average force and sensory firmness (0.69), whereas in frozen/thawed product, the strongest correlation, between ITPA cohesiveness and adhesiveness perceived at the time of placing the sample in the mouth, was lower (0.57).

Conclusions

Hydrocolloid stabilizers can be used in frozen/thawed mashed potatoes to adjust the consistency and texture. When used in sufficient concentrations, hydrocolloids improve the consistence, helping to enhance intermolecular binding after freezing and thawing. This could be the result of binding of water by hydrocolloid molecules, causing an increase in the resistance to flow in the case of the samples with added ALM, *k*- or *i*-C, XG or SC. The effect of *k*-carrageenans was associated with a more structured system, while a disruptive effect was

1 observed when 8 g kg⁻¹ of HM pectin were added to mashed potatoes. More studies are
2 needed to elucidate the origin of this behaviour. ALM and HM pectins affected more
3 significantly the colour of the product. However, processing significantly reduced ΔE* with
4 respect to FC, except for samples with added WP. F/T mashed potatoes containing WP
5 presented higher ΔE* values than any other F/T products or their F counterparts. The amounts
6 of dairy proteins that can be used are limited by their effects on the taste and odour of the
7 product. Taking the data overall, the results show that amidated ALM pectin, *k*- and *i*-C and
8 XG are suitable for improving the mechanical properties of mashed potatoes, although the
9 amounts of carrageenans that can be used are limited by their effects on the stickiness of the
10 product. Of these hydrocolloids, samples containing 0.5 and 1.5 g kg⁻¹ added XG were preferred
11 for sensory reasons. In the given experimental conditions, HM pectin, WP and SC are not
12 suitable for use in mashed potatoes. ITPA consistency correlated well with sensory texture
13 attributes and appeared to be more precise, repeatable and suitable than any other mechanical
14 parameters as a means of analysing the effects of biopolymer concentration and processing on
15 the texture of this type of products. And finally, the authors are researching into mixtures of
16 different biopolymers to achieve optimum effects.

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Figure legends

Fig. 1 Effects of biopolymer concentration and freezing and thawing processes on ITPA consistency of mashed potatoes.

Fig. 2 Effects of biopolymer concentration and freezing and thawing processes on ITPA adhesiveness of mashed potatoes.

Fig. 3 Effects of biopolymer concentration and freezing and thawing processes on ITPA springiness of mashed potatoes.

Fig. 4 Effects of biopolymer concentration and freezing and thawing processes on ITPA cohesiveness of mashed potatoes.

Fig. 5 Effects of biopolymer concentration and freezing and thawing processes on cone penetration test average force of mashed potatoes.

Fig. 6 Effects of biopolymer concentration and freezing and thawing processes on the total colour difference of mashed potatoes.

1 **Table 1** Notation system for fresh and frozen/thawed mashed potatoes and cryoprotectant contents

System notation	Description and biopolymer content (g kg ⁻¹)
FC	Fresh mashed potatoes without added biopolymers
F/T C	Frozen/thawed mashed potatoes without added biopolymers
F- ALM 1.5, F- ALM 3, F- ALM 5 and F- ALM 8	Fresh mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added amidated low methoxyl (ALM) pectin
F/T- ALM 1.5, F/T- ALM 3, F/T- ALM 5 and F/T- ALM 8	Frozen/thawed mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added amidated low methoxyl (ALM) pectin
F-HM1.5, F-HM3, F-HM5 and F-HM8	Fresh mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added high methoxyl (HM) pectin
F/T-HM1.5, F/T-HM3, F/T-HM5 and F/T-HM8	Frozen/thawed mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added high methoxyl (HM) pectin
F- κ -C1.5, F- κ -C3, F- κ -C5 and F- κ -C8	Fresh mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added kappa-carrageenan (κ -C)
F/T- κ -C1.5, F/T- κ -C3, F/T- κ -C5 and F/T- κ -C8	Frozen/thawed mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added kappa-carrageenan (κ -C)
F- <i>i</i> -C1.5, F- <i>i</i> -C3, F- <i>i</i> -C5 and F- <i>i</i> -C8	Fresh mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added iota-carrageenan (<i>i</i> -C)
F/T- <i>i</i> -C1.5, F/T- <i>i</i> -C3, F/T- <i>i</i> -C5 and F/T- <i>i</i> -C8	Frozen/thawed mashed potatoes with 1.5, 3, 5 and 8 g kg ⁻¹ added iota-carrageenan (<i>i</i> -C)
F-XG0.5, F-XG1.5, F-XG2.5 and F-XG5	Fresh mashed potatoes with 0.5, 1.5, 2.5 and 5 g kg ⁻¹ added xanthan gum (XG)
F/T-XG0.5, F/T-XG1.5, F/T-XG2.5 and F/T-XG5	Frozen/thawed mashed potatoes with 0.5, 1.5, 2.5 and 5 g kg ⁻¹ added xanthan gum (XG)
F-WP1.5, F-WP5, F-WP15 and F-WP25	Fresh mashed potatoes with 1.5, 5, 15 and 25 g kg ⁻¹ added whey protein (WP)
F/T-WP1.5, F/T-WP5, F/T-WP15 and F/T-WP25	Frozen/thawed mashed potatoes with 1.5, 5, 15 and 25 g kg ⁻¹ added whey protein (WP)
F-SC2.5, F-SC5, F-SC7.5 and F-SC10	Fresh mashed potatoes with 2.5, 5, 7.5 and 10 g kg ⁻¹ added sodium caseinate (SC)
F/T-SC2.5, F/T-SC5, F/T-SC7.5 and F/T-SC10	Frozen/thawed mashed potatoes with 2.5, 5, 7.5 and 10 g kg ⁻¹ added sodium caseinate (SC)

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1 **Table 2** Description of the sensory attributes evaluated by the trained panel during the texture profile analysis (TPA)

Attributes	Description
Perceived before placing the sample in the mouth	
Granularity	Geometric property reflecting the size and shape of the particles (the terms “creamy, floury, lumpy, gritty and grainy” are used to convey an ascending scale of perception of particle size).
Moisture	Surface property reflecting the absorption of water by the mashed potato (the commonest terms are: dry, moist, juicy, succulent and watery).
Perceived at the time of placing the sample in the mouth	
Stickiness	Mechanical textural property reflecting the effort required to separate the food from another surface (e.g., a spoon).
Denseness	Property reflecting the degree of solidness or compactness of the sample.
Homogeneity	Property reflecting the degree to which the sample is free of particles or irregularities.
Moisture	Property reflecting the water content of the mashed potato.
Firmness	Generic term describing the ability of the mashed potato to resist a permanent change of shape (the intensity is perceived as the level of force required to compress a sample between tongue and palate).
Perceived upon preparing the sample in the mouth for swallowing	
Cohesiveness	Mechanical property reflecting the effort required to reduce the mashed potato to a state suitable for swallowing, taking into account the potato’s resistance to disintegration.
Adhesiveness	Mechanical textural property reflecting the effort required to separate the food from any surface inside the mouth (teeth, gums, palate); the intensity is perceived as the level of force required to separate the compressed sample from bucal surfaces (especially the palate) with the tongue.
Fibrousness	Property reflecting the fibre content perceived during preparation of the sample in the mouth prior to swallowing.
Perceived during final and residual phases of the mastication process	
Ease of swallowing	Property reflecting the ease with which the mashed potato is transferred to the back of the palate and swallowed.
Palate coating	Property reflecting the sensation of mashed potato remaining on the palate after swallowing or ingestion.
Fibrousness	Property reflecting the fibre content perceived during actual swallowing or ingestion of the mashed potato, and the sensations perceived in the residual phase.

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Table 3 Sensory attributes perceived before and at the time of placing the sample in the mouth, and at the time of preparing the sample for swallowing: fresh and frozen/thawed mashed potatoes with added amidated low and high methoxyl (ALM and HM) pectins, kappa- and iota-carrageenans (κ -C and i -C), and controls

Sensory attributes	Perceived before placing the sample in the mouth		Perceived at the time of placing the sample in the mouth				Perceived at the time of preparing the sample for swallowing			
System notation	Granularity	Moisture	Adhesiveness	Denseness	Homogeneity	Moisture	Firmness	Cohesiveness	Adhesiveness	Fibrousness
FC	1.67 a	4.45 d, e	4.45 b	4.62 a	8.05 d	5.92 d	6.42 c, d	5.00 c	6.02 d	1.55 a
F/T C	4.00 e	1.97 a	7.90 e	8.17 d	4.07 a	2.30 a	8.45 a	7.97 f	8.22 a	3.12 e
F-ALM1.5	2.40 b	4.72 d, e	4.40 b	5.82 b	5.70 b	5.65 d	5.92 d, e	3.20 a	4.02 f	2.57 d
F-ALM3	2.30 b	5.57 f, g	3.67 a	4.70 a	8.87 e, f	6.27 d, e	5.60 e	4.07 b	3.35 g	2.55 d
F-ALM5	2.70 b, c	5.97 g	6.25 c, d	4.12 a	7.82 d	6.80 e, f	5.65 e	4.70 b, c	4.22 f	1.72 a, b
F-ALM8	3.22 c, d	5.92 g	6.72 d	4.50 a	7.00 c	7.00 f	4.60 f	6.47 d	6.75 c	1.65 a
F/T-ALM1.5	2.27 b-d	5.10 e, f	4.67 b	5.85 b	6.42 c	4.87 c	6.50 c, d	6.50 d	7.62 b	2.35 c, d
F/T-ALM3	2.75 b-d	4.15 c, d	6.02 c	5.97 b	5.62 b	3.55 b	6.70 b, c	7.30 e	8.60 a	2.52 d
F/T-ALM5	3.32 d	3.40 b, c	7.47 e	7.40 c	8.35 d, e	3.77 b	7.22 b	7.72 e, f	5.55 d, e	2.12 b-d
F/T-ALM8	3.20 c, d	2.87 b	7.72 e	7.60 c, d	9.15 f	2.42 a	8.15 a	4.70 b, c	5.32 e	1.92 a-c
LSD (95%)	0.58	0.77	0.61	0.72	0.65	0.71	0.64	0.65	0.53	0.46
FC	1.67 a	4.45 c, d	4.45 c	4.62 b	8.05 b	5.92 e, f	6.42 d, e	5.00 c	6.02 c	1.55 a
F/T C	4.00 c, d	1.97 a	7.90 f	8.17 d	4.07 a	2.30 a	8.45 g	7.97 a	8.22 a	3.12 d
F-HM1.5	4.30 d	2.87 b	6.37 e	6.60 c	3.60 a	3.65 b	6.72 e	3.67 e	6.85 b	2.27 c
F-HM3	2.50 b	5.02 d, e	5.47 d	6.12 c	7.67 b	4.02 b	6.20 c-e	4.02 d, e	4.30 f	1.82 a-c
F-HM5	3.40 c	5.95 f	3.85 b	4.57 b	8.25 b, c	6.55 f	5.10 a, b	4.45 c, d	4.62 e, f	1.75 a, b
F-HM8	1.82 a, b	6.80 g	2.60 a	2.22 a	8.12 b, c	5.47 d, e	4.45 a	6.92 b	2.90 g	1.62 a, b
F/T-HM1.5	5.32 e	2.90 b	7.35 f	8.05 d	8.97 c, d	2.85 a	7.67 f	7.40 a, b	7.95 a	3.00 d
F/T-HM3	4.50 d	4.27 c	5.30 d	6.22 c	8.02 b	4.35 b, c	5.97 c, d	5.02 c	5.67 c, d	3.05 d
F/T-HM5	2.40 a, b	4.30 c	3.60 b	6.32 c	8.97 c, d	4.82 c, d	5.62 b, c	4.57 c, d	5.12 d, e	2.07 b, c
F/T-HM8	2.25 a, b	5.20 e	2.85 a	4.82 b	9.30 d	5.07 d	5.27 b	3.97 d, e	4.25 f	1.75 a, b
LSD (95%)	0.79	0.66	0.58	0.68	0.86	0.70	0.70	0.64	0.59	0.50
FC	1.67 a	4.45 b	4.45 b	4.62 b	8.05 d	5.92 e	6.42 b	5.00 b	6.02 b	1.55 a
F/T C	4.00 e	1.97 f	7.90 c	8.17 c, d	4.07 a	2.30 a, b	8.45 d	7.97 d	8.22 c, d	3.12 e
F- κ -C1.5	2.40 b	5.87 a	3.22 a	3.22 a	7.82 c, d	6.45 f	4.72 a	3.47 a	2.57 a	2.07 b, c
F- κ -C3	3.45 d, e	3.32 c	7.42 c	7.77 c	8.45 d-f	2.95 d	7.87 c	6.77 c	7.87 c	2.12 b, c
F- κ -C5	3.22 c, d	3.32 c	7.87 c	8.07 c	7.10 c	2.27 a, b	7.77 c	8.12 d, e	8.15 c, d	2.25 b, c
F- κ -C8	4.02 e	2.27 e, f	8.87 d	8.80 d, e	8.95 e, f	2.55 b-d	9.02 e, f	8.62 e, f	8.72 d, e	2.52 c, d
F/T- κ -C1.5	3.35 d, e	3.25 c	7.60 c	7.72 c	8.25 d, e	3.05 d	7.55 c	7.72 d	7.77 c	1.85 a, b
F/T- κ -C3	2.60 b, c	3.10 c, d	8.62 d	8.85 e	9.15 f	2.40 a-c	9.00 d-f	8.77 f	8.57 d, e	2.02 a-c
F/T- κ -C5	3.02 b-d	2.65 d, e	9.22 d	8.82 d, e	8.50 d-f	2.82 c, d	8.67 d, e	8.80 f	9.15 e, f	2.22 b, c
F/T- κ -C8	5.30 f	1.92 f	8.80 d	9.37 e	5.50 b	1.92 a	9.25 f	9.35 g	9.40 f	2.77 d, e
LSD (95%)	0.70	0.45	0.72	0.66	0.74	0.51	0.55	0.51	0.60	0.51
FC	1.67 a, b	4.45 b	4.45 b	4.62 b	8.05 c	5.92 b	6.42 b	5.00 b	6.02 b	1.55 a
F/T C	4.00 g	1.97 e	7.90 c	8.17 c, d	4.07 a	2.30 d, e	8.45 d, e	7.97 c	8.22 c	3.12 e
F- i -C1.5	1.50 a	5.47 a	3.60 a	4.37 b	6.85 b	6.52 a	4.47 a	3.87 a	3.52 a	1.77 a, b
F- i -C3	2.20 b-d	5.67 a	3.55 a	3.55 a	8.92 d-f	5.52 b	4.17 a	3.50 a	3.70 a	1.55 a
F- i -C5	2.17 b, c	2.55 c, d	8.12 c	8.05 c	9.02 d-f	3.27 c	7.87 c, d	8.30 c	8.22 c	1.60 a, b
F- i -C8	2.20 b-d	2.07 d, e	9.15 d	8.75 e	8.67 d	2.20 d-f	9.00 e, f	9.07 e, f	9.12 d	2.40 d
F/T- i -C1.5	2.92 e, f	2.82 c	9.27 d	8.62 d, e	8.77 d, e	2.62 d	7.70 c	8.47 c, d	8.50 c	1.97 c
F/T- i -C3	2.72 d, e	2.15 d, e	9.17 d	8.87 e	9.47 f, g	1.92 e, f	8.97 e, f	8.97 d, e	9.10 d	1.80 a, b
F/T- i -C5	2.47 c-e	2.00 e	9.45 d	8.65 d, e	9.67 g	1.70 f	9.40 f	9.40 e, f	9.62 e	1.52 a
F/T- i -C8	3.35 f	1.85 e	9.55 d	9.15 e	9.30 e-g	1.77 f	7.47 c	9.62 f	9.60 e	1.60 a, b
LSD (95%)	0.55	0.50	0.40	0.55	0.55	0.51	0.70	0.58	0.40	0.40

Different letters in the same column for each biopolymer selected indicate significant differences $P < 0.05$.

LSD, least significant difference. Values are given as mean scores of eight determinations.

Table 4 Sensory attributes perceived before and at the time of placing the sample in the mouth, and at the time of preparing the sample for swallowing: fresh and frozen/thawed mashed potatoes with added xanthan gum (XG), dairy proteins (WP and SC), and controls

Sensory attributes	Perceived before placing the sample in the mouth		Perceived at the time of placing the sample in the mouth					Perceived at the time of preparing the sample for swallowing		
System notation	Granularity	Moisture	Adhesiveness	Denseness	Homogeneity	Moisture	Firmness	Cohesiveness	Adhesiveness	Fibrousness
FC	1.67 a	4.45 d, e	4.45 b	4.62 b	8.05 a	5.92 a, b	6.42 b, c	5.00 d	6.02 b	1.55 b-d
F/T C	4.00 d	1.97 a	7.90 f	8.17 e	4.07 b	2.30 f	8.45 a	7.97 a	8.22 a	3.12 a
F-XG0.5	1.72 a	5.90 f	3.42 a	3.97 a	9.30 c, d	6.40 a	4.77 f	3.95 e-g	3.05 f	1.52 b-d
F-XG1.5	1.62 a	4.62 d, e	3.70 a	4.45 a, b	9.32 c, d	5.57 b	5.02 f	3.60 g	3.45 e, f	1.45 c, d
F-XG2.5	2.52 b	3.52 c	4.35 b	4.80 b	9.37 c, d	4.42 c, d	5.62 e	3.72 f, g	4.90 c	1.62 b, c
F-XG5	3.35 c	2.70 b	5.10 c	4.80 b	8.95 c	4.20 d	6.40 c, d	4.40 e	4.32 c, d	1.72 b
F/T-XG0.5	1.80 a	4.77 e	5.10 c	5.72 c	9.52 d	4.90 c	5.85 e	4.20 e, f	3.80 d, e	1.42 c, d
F/T-XG1.5	1.70 a	4.07 c, d	6.00 d	6.50 d	9.72 d	4.42 c, d	5.95 d, e	5.62 c	5.60 b	1.30 d
F/T-XG2.5	1.67 a	2.00 a	7.30 e	7.05 d	9.32 c, d	3.12 e	6.90 c	6.57 b	8.02 a	1.57 b, c
F/T-XG5	2.00 a, b	2.40 a, b	8.07 f	8.85 e	9.47 d	2.80 e, f	7.90 b	7.67 a	8.45 a	1.30 d
LSD (95%)	0.48	0.56	0.48	0.55	0.48	0.52	0.55	0.56	0.62	0.27
FC	1.67 a	4.45 a	4.45 b	4.62 b	8.05 a	5.92 a	6.42 c-e	5.00 b	6.02 c	1.55 a
F/T C	4.00 b	1.97 f, g	7.90 e	8.17 f	4.07 d	2.30 g	8.45 a	7.97 f	8.22 a	3.12 b, c
F-WP1.5	5.40 d	2.80 d, e	6.67 d	5.20 b, c	7.70 a	2.82 e-g	6.92 c	8.02 f	8.10 a	3.30 b-d
F-WP5	4.70 c	2.80 d, e	6.62 d	5.95 d	6.07 b	2.70 f, g	5.72 f	5.02 b	8.00 a	3.67 c, d
F-WP15	4.95 c, d	3.97 a, b	5.65 c	5.35 c	5.92 b	4.90 b	5.87 e, f	5.30 b	5.42 e	2.95 b
F-WP25	8.35 f, g	3.57 b, c	3.25 a	3.17 a	2.67 f	3.77 c, d	4.22 g	3.37 a	3.02 f	7.02 f
F/T-WP1.5	6.70 e	1.62 g	7.15 d	7.85 f	6.30 b	2.92 e, f	7.65 b	7.60 e, f	7.22 b	3.77 d
F/T-WP5	8.02 f	3.17 c, d	5.45 c	6.75 e	5.12 c	3.32 d, e	6.72 c, d	7.17 e	5.90 c, d	5.07 e
F/T-WP15	8.75 g, h	2.32 e, f	8.72 f	6.70 e	3.40 e	4.20 c	6.22 d-f	6.05 c	5.10 e	8.07 g
F/T-WP25	9.07 h	4.32 a	6.67 d	6.30 d, e	3.27 e, f	5.25 b	6.45 c, d	6.62 d	5.55 d, e	7.52 f, g
LSD (95%)	0.64	0.66	0.54	0.59	0.66	0.57	0.56	0.54	0.46	0.64
FC	1.67 a	4.45 a	4.45 a	4.62 a	8.05 e	5.92 a	6.42 b	5.00 a	6.02 b	1.55 a
F/T C	4.00 b	1.97 f	7.90 d, e	8.17 e, f	4.07 a	2.30 e	8.45 d	7.97 c	8.22 c, d	3.12 c
F-SC2.5	2.52 a	4.32 a	5.60 b	7.07 d	9.02 f	5.57 a	7.00 b, c	8.10 c, d	5.12 a	2.35 b
F-SC5	4.25 b	3.27 b, c	6.95 c	5.85 b, c	7.12 d	3.47 c	6.67 b, c	7.92 c	7.92 c	3.05 c
F-SC7.5	4.70 b	2.62 d, e	8.15 d, e	6.37 c	8.27 e	2.67 d, e	5.27 a	6.97 b	7.82 c	4.37 d
F-SC10	7.45 c	2.45 d, e	8.77 f, g	5.52 b	4.37 a	3.02 c, d	5.65 a	4.90 a	8.75 d, e	5.85 e
F/T-SC2.5	4.02 b	3.45 b	7.77 d	7.17 d	5.05 b	4.40 b	6.72 b, c	9.20 e	8.32 c, d	6.30 e
F/T-SC5	4.85 b	2.45 d, e	7.70 d	7.60 d, e	6.65 c, d	2.22 e	7.22 c	9.07 e	9.00 e, f	4.80 d
F/T-SC7.5	4.35 b	2.82 c, d	8.77 f, g	7.82 e	6.27 c	2.42 d, e	7.20 c	8.50 d	9.02 e, f	2.45 b
F/T-SC10	6.60 c	2.32 e, f	9.10 g	8.55 f	7.15 d	2.45 d, e	7.22 c	7.65 c	9.40 f	2.77 b, c
LSD (95%)	0.86	0.46	0.60	0.64	0.63	0.66	0.67	0.52	0.56	0.57

Different letters in the same column for each biopolymer selected indicate significant differences $P < 0.05$.

LSD, least significant difference. Values are given as mean scores of eight determinations.

Table 5 Sensory attributes perceived during the final and residual phases of mastication: fresh and frozen/thawed mashed potatoes with added different cryoprotectants, and controls

Sensory attributes Perceived during the final and residual phases of mastication process				Sensory attributes Perceived during the final and residual phases of mastication process			
System notation	Ease of swallowing	Palate coating	Fibrousness	System notation	Ease of swallowing	Palate coating	Fibrousness
FC	8.42 a, b	4.15 c	1.37 a	FC	8.42 c	4.15 b	1.37 a, b
F/T C	7.75 c	5.75 e	3.35 e	F/T C	7.75 b	5.75 c, d	3.35 d
F-ALM1.5	9.00 a	2.80 b	2.57 d	F-XG0.5	9.10 d	3.45 a	1.40 a, b
F-ALM3	7.00 d, e	1.85 a	2.22 b-d	F-XG1.5	9.17 d	5.47 c	1.72 c
F-ALM5	7.60 c, d	2.30 a, b	2.17 b-d	F-XG2.5	7.97 b, c	6.22 d	1.57 b, c
F-ALM8	4.27 h	6.32 e	1.35 a	F-XG5	7.70 b	7.70 f	1.72 c
F/T-ALM1.5	5.05 g	4.90 d	2.27 b-d	F/T-XG0.5	9.35 d	5.42 c	1.50 a-c
F/T-ALM3	6.67 e, f	3.77 c	2.37 c, d	F/T-XG1.5	9.67 d	5.75 c, d	1.20 a
F/T-ALM5	6.35 f	5.00 d	2.00 b, c	F/T-XG2.5	7.05 a	6.02 c, d	1.37 a, b
F/T-ALM8	8.12 b, c	7.95 f	1.87 b	F/T-XG5	7.52 a, b	6.97 e	1.32 a, b
<i>LSD (95%)</i>	<i>0.65</i>	<i>0.66</i>	<i>0.47</i>	<i>LSD (95%)</i>	<i>0.65</i>	<i>0.68</i>	<i>0.31</i>
FC	8.42 a-d	4.15 b	1.37 a	FC	8.42 a	4.15 b, c	1.37 a
F/T C	7.75 d, e	5.75 c	3.35 b, c	F/T C	7.75 a	5.75 d	3.35 b
F-HM1.5	4.97 g	2.62 a	3.72 c	F-WP1.5	5.30 c, d	5.95 d	4.67 c
F-HM3	8.55 a-c	5.67 c	1.85 a	F-WP5	5.32 c, d	5.67 d	3.42 b
F-HM5	7.17 e	7.77 e, f	1.62 a	F-WP15	5.67 c, d	6.90 e	3.17 b
F-HM8	8.70 a, b	7.25 d, e	1.90 a	F-WP25	2.37 g	7.90 f	6.05 d
F/T-HM1.5	7.77 c-e	8.35 f, g	2.87 b	F/T-WP1.5	5.85 c	3.60 a, b	4.65 c
F/T-HM3	6.37 f	8.87 g	3.07 b	F/T-WP5	5.07 d, e	3.52 a, b	5.02 c
F/T-HM5	8.27 b-d	7.55 e	1.70 a	F/T-WP15	4.47 e	3.50 a	8.15 e
F/T-HM8	9.07 a	6.67 d	1.72 a	F/T-WP25	3.32 f	4.77 c	8.30 e
<i>LSD (95%)</i>	<i>0.78</i>	<i>0.78</i>	<i>0.55</i>	<i>LSD (95%)</i>	<i>0.65</i>	<i>0.64</i>	<i>0.52</i>
FC	8.42 e	4.15 a	1.37 a	FC	8.42 a	4.15 a	1.37 a
F/T C	7.75 d	5.75 c	3.35 d	F/T C	7.75 b	5.75 c	3.35 d
F-κ-C1.5	8.25 d, e	5.75 c	1.82 a, b	F-SC2.5	7.55 b	7.57 d	2.65 c
F-κ-C3	6.85 c	6.90 d	1.80 a, b	F-SC5	6.25 c	6.35 c	3.60 d
F-κ-C5	5.27 b	6.77 d	2.07 b, c	F-SC7.5	4.52 d	4.50 a, b	4.42 e
F-κ-C8	4.80 b	7.42 d, e	2.30 b, c	F-SC10	3.47 e	5.07 b	5.35 f
F/T-κ-C1.5	5.05 b	3.52 a	1.95 b	F/T-SC2.5	7.30 b	4.55 a, b	6.15 g
F/T-κ-C3	4.90 b	4.00 a	1.92 b	F/T-SC5	5.87 c	5.92 c	4.60 e
F/T-κ-C5	4.07 a	4.95 b	2.15 b, c	F/T-SC7.5	3.12 e	7.50 d	3.55 d
F/T-κ-C8	4.07 a	7.62 e	2.55 c <	F/T-SC10	3.62 e	7.75 d	2.00 b
<i>LSD (95%)</i>	<i>0.62</i>	<i>0.66</i>	<i>0.52</i>	<i>LSD (95%)</i>	<i>0.59</i>	<i>0.67</i>	<i>0.59</i>
FC	8.42 a	4.15 b	1.37 a	FC	8.42 a	4.15 b	1.37 a
F/T C	7.75 b	5.75 c	3.35 d	F/T C	7.75 b	5.75 c	3.35 d
F-i-C1.5	8.92 a	3.05 a	1.60 a, b	F-i-C1.5	8.92 a	3.05 a	1.60 a, b
F-i-C3	7.05 c	4.75 b	1.55 a, b	F-i-C3	7.05 c	4.75 b	1.55 a, b
F-i-C5	5.57 d	7.37 d	1.85 b, c	F-i-C5	5.57 d	7.37 d	1.85 b, c
F-i-C8	3.50 f	8.77 e	1.62 a, b	F-i-C8	3.50 f	8.77 e	1.62 a, b
F/T-i-C1.5	7.45 b, c	5.45 c	2.20 c	F/T-i-C1.5	7.45 b, c	5.45 c	2.20 c
F/T-i-C3	5.12 d, e	5.50 c	1.72 a, b	F/T-i-C3	5.12 d, e	5.50 c	1.72 a, b
F/T-i-C5	4.95 e	5.60 c	1.50 a, b	F/T-i-C5	4.95 e	5.60 c	1.50 a, b
F/T-i-C8	3.22 f	7.52 d	1.57 a, b	F/T-i-C8	3.22 f	7.52 d	1.57 a, b
<i>LSD (95%)</i>	<i>0.62</i>	<i>0.67</i>	<i>0.38</i>	<i>LSD (95%)</i>	<i>0.62</i>	<i>0.67</i>	<i>0.38</i>

Different letters in the same column for each biopolymer selected indicate significant differences $P < 0.05$.
LSD, least significant difference. Values are given as mean scores of eight determinations.

Figure1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6