Chapter

THE ENRICHMENT OF MASHED POTATOES WITH EXTRA VIRGIN OLIVE OIL: THE EFFECTS ON TEXTURAL, PHYSICAL, STRUCTURAL AND SENSORY CHARACTERISTICS

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ABSTRACT

Growing awareness of the link between diet and health is fast changing consumer habits, so that there has been increasing demand for foods with health-enhancing properties. Extra virgin olive oil (EVOO) has important nutritional characteristics linked to its biophenol content and has very important antioxidant properties. The aim of this chapter was to study the effect of the addition of EVOO on instrumental textural properties, sensory texture profile analysis (TPA), and microstructure of fresh and frozen/thawed mashed potatoes formulated without and with added cryoprotectants (kappa-carrageenan [κ-C] and xanthan gum [XG]). EVOO behaves as soft filler due to droplet aggregates, whereas addition of cryoprotectants led to more structured mashed potatoes (MP) thanks to the gelling properties of κ-C. Both the percentage of added EVOO and processing had a much less significant effect on the texture of the MP containing κ -C and XG, evidencing the ability of this biopolymer blend to impart freeze/thaw stability. All samples with added EVOO were perceived as significantly softer and creamier than the samples without EVOO, whereas all MP samples with added cryoprotectants were perceived as significantly thicker and creamier than those without hydrocolloids. The results have shown that although instrumental textural data were able to explain differences in consistency perceived, structural information is needed to understand differences in creaminess. Back extrusion test is recommended to industry as practical quality control tool in the commercial production of MP with added EVOO.

Keywords: extra virgin olive oil; freezing; mashed potatoes; microstructure; texture profile analysis (TPA), sensory attributes

INTRODUCTION

Various health organizations recommend a daily intake of around 600 g of fruit and vegetables, but few people manage to consume this amount. Led by consumer demand, the food industry has shown an increased interest in the manufacture of healthier and more natural fruit and vegetable food products, such as soups, drinks and sauces [1]. Mashed potatoes (MP) made from 100% fresh potato tubers are in addition a natural vegetable semisolid food, which may also be suitable for freezing as a ready-meal component or as a product in itself such as potato gratin [2].

Olive oil is an important component of the diet of the countries surrounding the Mediterranean Sea. Due to its composition, olive oil is a good source of biophenols [3] as well as lipid-soluble and water-soluble vitamins (tocopherols, β-carotene, and ascorbic acid). In addition, thanks to its balanced fatty acid composition virgin olive oil has highly appreciated nutritional characteristics [4], known for a long time to the people of the Mediterranean region, who use it daily for a variety of culinary purposes. Biophenols with important antioxidant properties and a role in atherogenesis and cancer have been found and quantified in virgin and extra-virgin olive oils [5]. However, consumption has also increased in non-Mediterranean areas thanks to growing interest in the Mediterranean diet and a belief that it prevents certain diseases [3, 6]. A classic white sauce usually contains flour, milk and butter, but olive oil has been added to a white model-sauce to produce an innovative sauce approximating "Mediterranean cooking" [7].

The oil volume fraction exerts profound effects on the physicochemical and viscoelastic properties of emulsions, such as droplet size distribution, creaming, oxidative stability, and rheology [8]. Fat droplets influence the overall physicochemical and sensory properties of foods in a variety of different ways [9]. A great deal of research has been done on the influence of fat droplets on the rheology, stability and flavour of food emulsions, but less is known about their influence on emulsion appearance. Color is one of the major attributes affecting consumer perception of the quality of virgin olive oil [10], and chloroplast pigments (chlorophyll and carotenoids) are mainly responsible for the color of virgin olive oil, ranging from yellow–green to greenish gold [11].

Texture is by far the most important quality criterion for consumer sensory acceptance of freshly prepared and processed potato products, and particularly of frozen/thawed and dehydrated mashed potatoes. A fluffy and medium-consistency texture is desirable, whereas pastiness, gumminess and stickiness are negative attributes [12]. Texture instability remains the most significant challenge for frozen food products, especially with inevitable post-production temperature fluctuations. Loss of moisture and changes in textural attributes often result in significant reduction of product quality.

Previous studies showed that the addition of *κ*-C and XG to MP at a low concentration (each cryoprotectant at 1.5 g/kg) is recommendable on the basis of overall acceptability, especially when the product is going to be frozen [2, 13]. *κ*-C provides the appropriate texture, while XG imparts creaminess and mouthfeel to the product.

Few research has been done on the addition of olive oil in fresh and frozen/thawed mashed potatoes (designated FMP and F/TMP respectively), particularly with EVOO. The use of EVOO rather than commercial olive oil is preferable because of its high concentrations of both unsaturated fatty acids and antioxidant compounds such as polyphenols and tocopherols [14]. The purpose of the present research was to evaluate the effects of adding EVOO on the textural, physical, structural and sensory characteristics of FMP and F/TMP formulated without and with added cryoprotectants.

MATERIALS AND METHODS

Materials

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). *κ*-C (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). EVOO (Carbonell, Spain) was chosen for addition to the MP. Following range-finding experiments, the lower and upper levels of EVOO to be used were set at 10 and 50 g/kg, respectively. A sample without EVOO was also prepared for each type of MP and processing conditions.

Preparation of MP Samples

Tubers were manually washed, peeled and diced. MP were prepared in ~ 2000-g batches from 607.7 g/kg of potatoes, 230.8 g/kg of semi-skimmed in-bottle sterilized milk (fat content, 15.5 g/kg), 153.8 g/kg of water, 7.7 g/kg of salt (NaCl) and the corresponding EVOO concentration (0, 10, 25, and 50 g/kg) using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). MP were prepared without and with added κ-C and XG (MPA and MPB samples, respectively). In the latter case, hydrocolloids (each at 1.5 g/kg) were also added to the rest of the ingredients in the form of a dry powder. All the ingredients were cooked for 35 min at 90°C (blade speed: 40 rpm) [2, 13]. The mash was ground for 40 s (1,200 rpm) and for 20 s (2,600 rpm). The product was at once homogenized through a stainless steel sieve (diameter: 1.5 mm). The highest EVOO concentration was added twice to the MP to evaluate the effect of order of addition and EVOO thermal treatment on MP quality. First, 50 g/kg of EVOO was added along with the rest of the ingredients as indicated above, whereas in the second case the same EVOO concentration (designated "50b" g/kg) was added to the MP before final homogenization. Half of each fresh blend (FMP samples) was analysed immediately and the other half was frozen and thawed (F/TMP samples). Two repetitions of each composition were prepared in different weeks.

Freezing, Thawing and Heating Procedures

MP samples were placed on flat freezing and microwave thawing trays, and then frozen by forced convection with liquid nitrogen vapour in an Instron programmable chamber (model 3119-05, −70/+250°C) at −60°C until their thermal centres reached −24°C [13]. After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (–0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24°C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain). Samples were heated for 20 min at an output power rating of 600 W. Samples were brought up to 55°C by placing them in a Hetofrig CB60VS water bath (Heto Lab Equipment A/S, Birker∅d, Denmark). Sample testing was 55°C, where water and product temperatures were monitored by T-type thermocouples as described elsewhere [2, 15-17].

Instrumental Texture Measurements

Back extrusion (BE) and cone penetration (CP) mechanical tests were performed in order to study the empirical rheological behavior of "semisolid like" samples. Both experiments were performed using a TA.HDPlus Texture Analyser (Stable Micro Systems Ltd, Godalming, UK) equipped with a 300 N load cell. During tests, MP samples were kept at 55°C by means of a Temperature Controlled Peltier Cabinet (XT/PC) coupled to a separate heat exchanger and proportional-integral-derivative control unit. For performance of BE tests, a rig (model A/BE, Stable Micro Systems) was used consisting of a flat 45 mm diameter perspex disc plunger that was driven into a larger perspex cylinder sample holder (50 mm diameter) to force down into the MP samples and flow it upward through the concentric annular space between plunger and the container. The measuring cup was filled with 50 ± 1 g of MP. Product was extruded to a distance of 20 mm at 2 mm/s compression rate. At this point (most likely to be the maximum force), the probe returns to its original position. From the recorded force time curves, texture parameters with physical meaning are calculated, which vary from simple consistency indices to a derived flow behavior index, which is obtained according to the mathematical model suggested by Osorio and Steffe [18]. In this chapter, maximum positive force of extrusion (firmness (N)) and the negative area of extrusion (viscosity index (N s)) have been taken into account in order to describe texture changing in MP samples. For performing the CP tests, a TTC spreadability rig (HDP/SR, Stable Micro Systems) was used, consisting of a 45° conical perspex probe (P/45C) that penetrated a conical sample holder containing 7 ± 0.1 g of MP product. Product was penetrated to a distance of 17.5 mm at 3 mm/s compression rate. CP work per displaced volume (J/m^3) required to accomplish penetration was calculated from the area under the curve up to the "peak" or maximum penetration force, and the average force of the complete curve (N) was also recorded. Texture measurements were performed in quadruplicate and results averaged.

Other Quality Parameters

The color of the MP in the pots was measured with a HunterLab model D25 (Reston, VA, USA) color difference meter 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^*, a^* and b^*. A higher L^* value indicated a brighter or whiter sample and values of a^* and b^* indicated red-green and yellow-blue colors. Yellowness index (YI) was calculated as $142.86b^*/L^*$ [17].

Expressible water (E_w) was measured by centrifugal force. Centrifuge tubes containing approximately 10 g of MP were centrifuged at 15,000×g for 30 min in a Sorvall®, RC-5B apparatus (Global Medical Instrumentation, Inc, Clearwater, Minnesota, USA). E_w was expressed as the percentage of liquid separated per total weight of sample in the centrifuge tube [19]. Measurements of color and E_w were performed in quadruplicate and the results averaged.

Sensory Analyses

MP samples were subjected to texture profile analysis (TPA) modified to evaluate vegetables purees according to UNE 87025 (1996) [20], which was used to select and define the sensory attributes included in the profile. A panel of 4 assessors, previously trained according to the ISO guidelines (ISO 8586-1:1993) [21] and with specific exercise in MP for 8 years [15-

17], evaluated the textural attributes of the samples. Profile attributes were classified into four groups [16]. Attributes are listed in the order of the perception according to ISO guidelines (ISO 13299: 2003) [22]: attributes perceived before putting the sample in mouth (granularity and moisture (1)); attributes perceived at the time of putting the sample in the mouth (stickiness, denseness, homogeneity, moisture (2) and firmness); attributes perceived at the time of preparing the sample in the mouth for swallowing (cohesiveness, adhesiveness and fibrousness (1)); attributes perceived during final and residual phases of mastication (ease of swallowing, palate coating and fibrousness (2)). A description of the sensory attributes evaluated during the TPA can be found elsewhere [16].

Samples were evaluated, in duplicate, in morning sessions (11:00 a.m.-1:00 p.m.). Daily for 40 days assessors were given four samples (about 20 g each), for scoring attributes of each group in the texture profile. All the samples were served at 55 ± 1°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. For each sample, panelists evaluated the perceived intensity of the 13 attributes on 8 cm descriptive linear scales labelled at each anchor: (left anchor: 1 = ‘‘not detectable; right anchor: 9 = ‘‘extremely intense’’). To reduce fatigue a rest period of 5 min was taken after scoring each sample.

MP samples were also subjected to an overall acceptability (OA) test based on all sensory attributes (texture, color, taste) on a 9-point hedonic scale (with 8 cm) labelled at each anchor: (left anchor: 1 = “dislike extremely”; right anchor: 9 = “like extremely”). In this case, sensory assessment was conducted by a 14-member untrained panel. Every day, one sample (about 20 g each) was served under the same conditions as indicated above.

Scanning Electron Microscopy (SEM)

MP microstructure was examined by SEM using a Hitachi model S-2.100 microscope (CENIM-CSIC). MP samples were air-dried, then mounted and sputter-coated with Au (200 Ǻ aprox.) in a SPI diode sputtering system metallizer. Photomicrographs were taken with a digital system Scanvision 1.2 of RONTEC (800x1.200 pixel).

Statistical Analysis

A three-way ANOVA with interactions was applied to evaluate how the three factors studied—EVOO concentration, presence or absence of hydrocolloids and performance or not of processing —affected the texture, color, sensory attributes and the OA of the MP. E_w was always zero for the MPB samples; a two-way ANOVA with interactions was applied to evaluate how EVOO concentration and processing affected the E_w of the products. Minimum significant differences were calculated using Fisher's least significant difference test (LSD, 99% for comparison of instrumental parameters and 95% for comparison of sensory attributes and OA). Analyses were performed with Statgraphics® software version 5.0 (STSC Inc., Rockville, MD, USA).

RESULTS AND DISCUSSION

Instrumental Texture Measurements

Table 1 shows the effects of EVOO concentration, cryoprotectant addition and processing on the values of the textural properties derived from the BE and CP tests. Samples with added *κ*-C and XG, as well as those subjected to freezing/thawing, presented significantly higher and lower textural properties than their respective counterparts. Previous studies showed that when *κ*-C/XG blends were added to FMP and F/TMP samples, *κ*-C provided the appropriate texture whereas XG imparted creaminess to the product [2, 13, 23]. Analogously, in starch/XG blends, it was observed that XG does not interfere in potato starch network building [7, 24]. Therefore, addition of both hydrocolloids to MP produces a more structured system which is associated with the gelling properties of *κ*-C. In natural MP, the product was softer than the fresh control after freezing and thawing [15]. MP is a starchy food, and as such may present quality problems such as syneresis and organoleptic and textural changes. These problems have been ascribed to phase separation caused by retrogradation of the starch [19, 25].

Table 1. Effects of EVOO concentration, cryoprotectant addition and freezing/thawing on textural properties of MP

Source	Firmness (N)	Viscosity index (N s)	Work per displaced volume (J/m^3)	Average force (N)
Main effects:				
A: EVOO concentration (g/kg)				
0	6.21 a	-29.33 a	3518.78 a	1.51 a
10	6.08 a	-28.37 a	3462.25 a	1.49 a
25	5.32 b	-26.12 b	2867.16 b	1.23 b
50	4.69 c	-23.06 c	2681.10 b	1.15 b
50b	4.74 c	-23.69 c	2786.29 b	1.19 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	0.26	1.24	227.00	0.097
B: Cryoprotectant addition				
Without *κ*-C and XG	4.71 a	-20.71 a	2333.51 a	1.00 a
With *κ*-C and XG	6.10 b	-31.52 b	3792.72 b	1.63 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	0.16	0.78	143.57	0.06
C: Processing				
Fresh	5.62 a	-26.73 a	3248.00 a	1.39 a
Frozen/thawed	5.19 b	-25.50 b	2878.23 b	1.23 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	0.16	0.78	143.57	0.06
Interactions				
AB	<0.001	<0.001	<0.001	<0.001
AC	0.001	0.18	<0.001	<0.001
BC	<0.001	<0.001	<0.001	<0.001
ABC	<0.001	<0.001	<0.001	<0.001

MP, mashed potato; EVOO: extra virgin olive oil; κ-C: kappa-carrageenan; XG: xanthan gum; LSD, least significant difference.

With respect to the effect of EVOO addition, the maximum textural property values were registered in the samples without EVOO, although differences between textural properties of samples with 10 g/kg added EVOO and those without EVOO were non-significant (Table 1). However, increasing EVOO concentration produced softer, liquid-like systems, indicating that EVOO behave as soft filler. This result is to be expected as increasing concentrations of liquid oil are added to the product, increasing the oil-phase volume fraction. In oil-in-water emulsions, the extent of the linear region decreased with increasing oil-phase volume fraction from 20 to 40% v/v [26]. For their part, Dickinson and Chen [8] suggested that oil/water emulsions may undergo a behavior transition from predominantly entropic behavior to predominantly enthalpic behavior, with increasing oil-phase volume fraction.

The ANOVA also showed that the three binary interactions had a significant effect on instrumental firmness, work per displaced volume and average force (Table 1). This means that the effect of EVOO concentration on the texture depended on the presence of κ-C and XG, and on the freezing/thawing of the systems. Besides, EVOO concentration and cryoprotectant addition (AB) and cryoprotectant addition and processing (BC) interactions also significantly affected the viscosity index from the BE tests.

From the variation in the firmness value based on EVOO concentration for both MPA and MPB samples shown in Figure 1a, one can observe that firmness was lower in the MPA than in the MPB samples; moreover, the variation in sample firmness was much greater when EVOO content increased from 10 to 50 g/kg in the MPA samples than in the MPB ones. Also, when the concentration of added EVOO was increased, the firmness value behaved similarly in the FMP and F/TMP samples (Figure 1b); in both cases, the increase in EVOO content led to reduced firmness, without important differences between 50 and 50b g/kg. As droplet concentration increases, the droplets are polydispersed and the samples present a less close packing structure. In mayonnaise, increasing walnut oil content increases the diameter of oil droplets and consequently reduces viscoelastic properties [27].

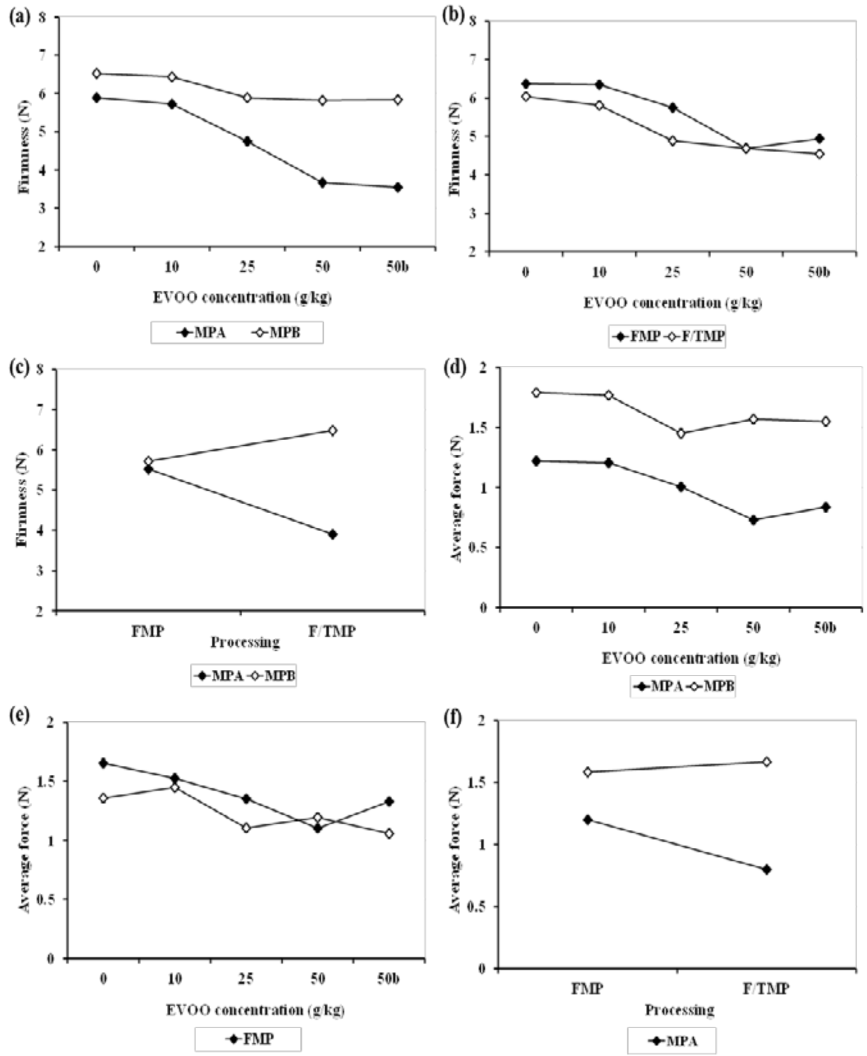

Figure 1. Textural properties of mashed potatoes with added extra virgin olive oil (EVOO). (a–c) Firmness; (d–f) Average force; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

From the variation in the firmness based on processing, the firmness value developed differently for the MPA and MPB samples (Figure 1c). Processing significantly reduced sample firmness in the MPA samples but significantly increased it in MPB samples. This behavior can be explained, taking account that much stronger and more cohesive networks are formed when solutions of XG are frozen and thawed [28]. The effect of XG may be explained by amylose/XG interactions, which compete against amylose/amylose interactions, retarding or even preventing retrogradation. Also, the addition of small amounts of XG to white sauces made with starches from different sources significantly improves freeze/thaw stability [29].

In turn, the variation in average force with EVOO concentration or both MPA and MPB samples (Figure 1d) was similar to that observed in firmness. In this case of the MPB samples, the ones with 25 g/kg EVOO added had poorer consistency, whereas in the MPA systems, the ones with 50 g/kg had poorer consistency. When the EVOO concentration was increased, the average force decreased in both FMP and F/TMP samples (Figure 1e), although in the latter case adding 10 g/kg EVOO slightly increased the average force as compared with the control without EVOO. Both the BE firmness and the CP average force values were greater when the EVOO was added after cooking (50b g/kg) in the FMP samples but not in the F/TMP samples. When the processing-dependent variation in average force was plotted (Figure 1f), the changes in that value were also similar to those observed for firmness (Figure 1c). Plots for the viscosity index and the work per displaced volume have been omitted.

Color Measurements and Expressible Water

All of the three factors studied significantly changed the color parameters, although processing did not significantly affect the YI (Table 2). An increase in EVOO level favors higher L^* value (lightness) due to an increase in the overall light scattering associated with the scattering properties of fat [9]. As the EVOO concentration increased, there was an increase in redness (decreasingly negative a^* values) and in yellowness (YI), associated with the augmented pigment content of the MP. The pigment profile of the virgin olive oil comprises chlorophyll a, chlorophyll b and derivative pigments associated with the acidic medium of the oil extraction process [10].

Table 2. Effects of EVOO concentration, cryoprotectant addition and freezing/thawing on color measurements and expressible water of MP

Source	*L**	*a**	YI	E_w (%)
Main effects:				
A: EVOO concentration (g/kg)				
0	60.79 a	-3.85 a	10.14 a	22.42 b
10	62.95 b	-3.70 b	13.73 b	25.73 a
25	63.68 c	-3.54 c	18.58 c	20.72 d
50	66.04 d	-3.11 d	24.08 d	21.52 c
50b	65.70 e	-3.14 d	23.47 e	21.85 b, c
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	0.07	0.02	0.20	0.71
B: Cryoprotectant addition				
Without *κ*-C and XG	62.85 a	-3.59 a	16.74 a	-
With *κ*-C and XG	64.81 b	-3.34 b	19.26 b	-
P values	<0.001	<0.001	<0.001	-
LSD (99%)	0.04	0.01	0.13	-
C: Processing				
Fresh	63.33 a	-3.53 a	18.03 a	21.01 a
Frozen/thawed	64.33 b	-3.40 b	17.97 a	23.89 b
P values	<0.001	<0.001	0.17	<0.001
LSD (99%)	0.04	0.01	0.13	0.45
Interactions				
AB	<0.001	<0.001	<0.001	-
AC	<0.001	<0.001	<0.001	<0.001
BC	<0.001	0.34	<0.001	-
ABC	<0.001	<0.001	<0.001	-

MP, mashed potato; EVOO: extra virgin olive oil; κ-C: kappa-carrageenan; XG: xanthan gum; L*: lightness (L* = 0 [black], L* = 100 [white]), a*: color position between green and red (-a* = green, +a* = red); YI: yellowness index; LSD, least significant difference.

*L** increased when *k*-C and XG were added to the MP, which could be partially due to their absolute water-holding capacity (WHC) as discussed below. Also, *a** was higher in the MPB than in the MPA samples, indicating significant raise sample redness. The loss of greenness associated with cryoprotectant addition was probably due to the presence of XG in the system as found previously [17].

Increased lightness in the F/TMP samples as compared with their FTM counterparts may have been partly due to the formation of fissures produced by the growth of ice crystals during freezing, which favors the release of water; this would transmit the light more rather than capturing it. For its part, the loss of greenness found in the processed samples (*a** values nearer to 0) as compared with the fresh counterparts could be due to slight non-enzymatic browning (Maillard reaction) during microwave thawing.

On the other hand, the three interactions had a significant effect on *L** and YI (Table 2). Moreover, AB and EVOO concentration and processing (AC) interactions significantly affected the *a** value. The variation in the *L** value based on EVOO concentration in both MPA and MPB samples (Figure 2a) shows that increased EVOO concentration produced an increase in the *L** value in both samples. The influence of droplet characteristics on the optical properties of colored oil-in-water emulsions has been studied [9]. The lightness of the emulsions increased with increasing droplet concentration and decreasing droplet size. As the droplet concentration increases, so does the reflectance because the droplets scatter light more effectively and hence the light beam is unable to penetrate further into the product and be absorbed.

The differences between the *L** values of the MPA samples and their MPB counterparts increased with increasing the EVOO content (Figure 2a). In emulsions, XG is added to the aqueous phase to prevent droplets from rapidly creaming and coalescence [26, 30].

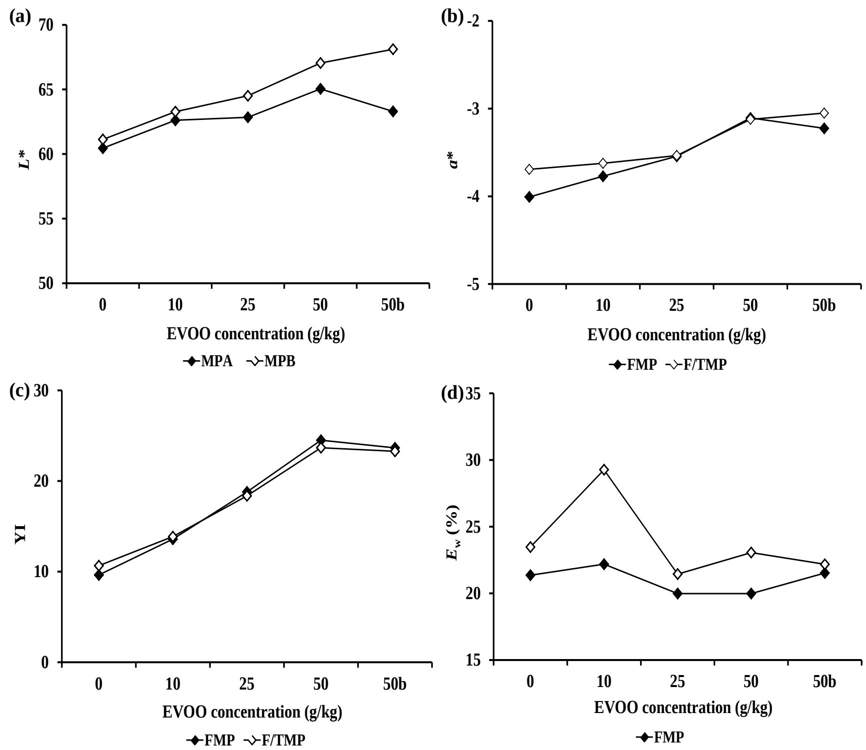

Figure 2. Color parameters and expressible water of mashed potatoes with added extra virgin olive oil (EVOO). (a–c) *L**, lightness; *a**, red-greenness; YI, yellowness index; (d) E_w, expressible water; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

In this chapter, oil droplet diameters were not measured, but it is probable that the droplets in the MPB samples were smaller than in the ones without cryoprotectants, as the presence of XG in the system would prevent coalescence. The reason why the *L** values were lower in the MPA samples, then, is that reflectance decreases with increasing droplet diameter. Note that in the MPB samples, the *L** value was greater when the EVOO was added after cooking (50b g/kg), whereas in the MPA systems it was greater in the samples with 50 g/kg EVOO added before cooking. This discrepancy could also be related to the presence of cryoprotectants in the system. MP with EVOO added before final homogenization would be expected to have larger droplets because the oil was not thoroughly triturated. In the presence of XG, the droplets scatter light more effectively when the oil is not so strongly entrapped in the matrix. In the MPA samples on the other hand, reflectance probably decreased because the scattering efficiency of the droplets decreases above a certain droplet size [9].

In turn, as the droplet concentration increases, more reflected light travels through the oil phase of the MP being absorbed by the pigments mentioned earlier, intensifying the color of the MP (Figures 2b, 2c). However, as regards to YI values, there were small differences between FMP and F/TMP samples. Anyway, the color differences found between samples, although significant, should not be of major importance in practical terms.

E_w changed significantly with EVOO concentration and processing (Table 2), and the AC interaction had a significant effect on the WHC of the samples (Figure 2d). In this chapter, addition of κ-C and XG reduced the E_w of both FMP and F/TMP samples to 0%, corroborating the well-established ability of XG to reduce water separation [2, 16, 29], and evidencing the existence of XG-water or XG-water-XG interactions in the systems. XG is an anionic, hygroscopic material of exceptional pseudoplasticity [31]; its texturizing effect can be achieved at low gum concentration because of unusual water holding ability. Also, adding XG (0.3% w/w) to corn starch pastes (10% w/w) minimized amylose retrogradation, syneresis and rheological changes after freezing [32]. Certainly, the E_w values confirm that XG effectively stabilizes MP against syneresis when no more than 1.5 g/kg is added.

Besides, WHC was greater in the FMP samples than in their F/TMP counterparts at all EVOO concentrations (Figure 2d). This result is probably related to structural damage caused by freezing. The addition of EVOO at low concentrations significantly increased E_w, mainly in the processed samples, which is likely due to that the interchain spaces were occupied by oil, displacing the water [34]. However, the addition of EVOO at higher concentrations significantly reduced water loss, probably because excess oil hindered the release of water from the starch matrix. EVOO by itself was not effective in enhancing the WHC of MP. In any case E_w percentages were also quite high (>20) in both FMP and F/TMP samples without added EVOO, evidencing the presence of weak starch–water or starch–water–starch interactions in all the systems. Water separation in the MPA samples is related to starch retrogradation and consequent reduction of WHC [33].

Sensory Analyses

Attributes Perceived before Putting the Sample in Mouth

All the three main factors and their interactions significantly ($P < 0.05$) affected the scores for granularity and moisture (1) (Table 3). One can observe that at all EVOO concentrations, granularity scores were greater in the MPA samples (Figure 3a) and likewise in the fresh products (Figure 3b). Christianson et al. [35] indicated that gums like XG affect the gelatinization and retrogradation of starch through strong associations with amylose, resulting in reduced amylose–amylose interactions. In turn, presence of XG reduced granularity in the F/TMP systems by assisting new starch/water interactions and consequent water absorption. In both MPA and MPB samples, panelists judged granularity lowest in the samples with more than 10 g/kg added EVOO. The effects of EVOO on granularity are related to the lubricating and coating properties conferred by the oil as reported for vanilla custard desserts [36].

In turn, moisture (1) decreased significantly with respect to MPA samples with the addition of cryoprotectants in both FMP and F/TMP (Figure 3c). Panelists detected greater ability to hold water molecules in MPB samples, confirming the results for E_w values. Similarly, panelists detected less aqueousness in the processed samples than in the fresh ones, probably due to water loss.

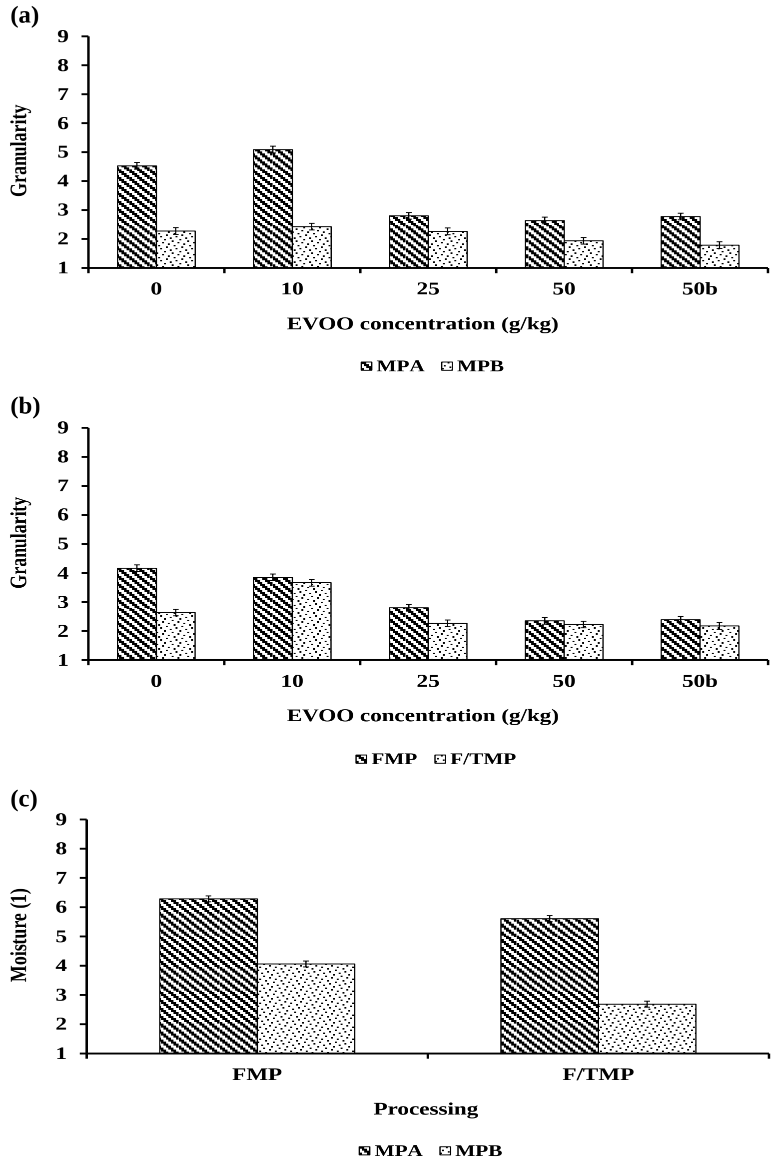

Figure 3. Texture profile analysis sensory attributes of mashed potatoes with added extra virgin olive oil (EVOO) perceived before of putting the sample in the mouth: (a, b) Granularity; (c) Moisture (1); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

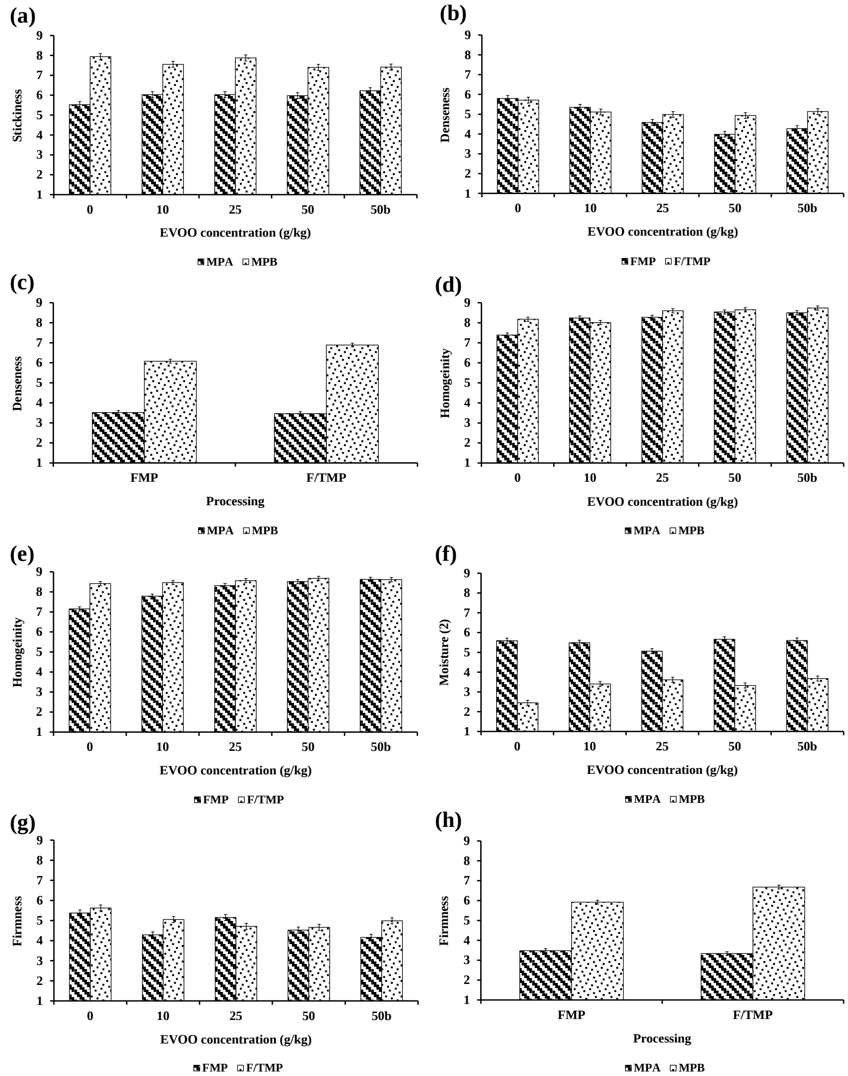

Figure 4. Texture profile analysis sensory attributes of mashed potatoes with added extra virgin olive oil (EVOO) perceived at the time of putting the sample in the mouth: (a) Stickiness; (b, c) Denseness; (d, e) Homogeneity; (f) Moisture (2); (g, h) Firmness; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

Table 3. Effects of EVOO concentration, cryoprotectant addition and freezing/thawing on sensory attributes of MP perceived before and at the time of putting the sample in the mouth

Sensory attributes	Perceived before putting the sample in the mouth		Perceived at the time of putting the sample in the mouth				
Source	Granularity	Moisture (1)	Stickiness	Denseness	Homogeneity	Moisture (2)	Firmness
Main effects:							
A: EVOO concentration	<0.001	0.022	0.487	<0.001	<0.001	<0.001	<0.001
B: Cryoprotectant addition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C: Processing	<0.001	<0.001	0.542	<0.001	<0.001	<0.001	0.002
Interactions							
AB	<0.001	0.002	0.002	0.236	<0.001	<0.001	0.044
AC	<0.001	0.003	<0.001	<0.001	<0.001	0.082	<0.001
BC	0.015	0.001	0.611	<0.001	0.970	0.003	<0.001
ABC	<0.001	<0.001	<0.001	0.143	<0.001	<0.001	<0.001

EVOO: extra virgin olive oil; MP: mashed potatoes.

Table 4. Effects of EVOO concentration, cryoprotectant addition and freezing/thawing on sensory attributes of MP perceived at the time of preparing the sample for swallowing and during the final and residual phases of mastication, and overall acceptability

Sensory attributes	Perceived at the time of preparing the sample for swallowing			Perceived during the final and residual phases of mastication			Overall acceptability (OA)
Source	Cohesiveness	Adhesiveness	Fibrousness (1)	Ease of swallowing	Palate coating	Fibrousness (2)	
Main effects:							
A: EVOO concentration	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B: Cryoprotectant addition	<0.001	<0.001	<0.001	<0.001	0.520	<0.001	<0.001
C: Processing	0.002	<0.001	<0.001	<0.001	0.601	<0.001	<0.001
Interactions							
AB	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
AC	0.292	0.818	<0.001	0.003	<0.001	<0.001	<0.001
BC	0.083	<0.001	<0.001	0.126	<0.001	<0.001	0.055
ABC	<0.001	<0.001	<0.001	0.211	<0.001	<0.001	0.015

EVOO: extra virgin olive oil; MP: mashed potatoes.

Attributes Perceived at the Time of Putting the Sample in the Mouth

Stickiness scores were significantly higher in the MPB samples, although there were no differences in these scores as a consequence of EVOO concentration or processing (Table 3, Figure 4a). In turn, the three factors significantly affected scores for denseness, homogeneity, moisture (2) and firmness. Denseness was significantly higher in the processed samples than in the fresh samples only when EVOO was added at the highest concentrations (Figure 4b).

Also, denseness was lower in the MPA than in the MPB samples (Figure 4c), and only in this latter case were denseness scores significantly higher in the F/TMP samples than in their FMP counterparts. When EVOO concentration was increased, homogeneity increased in both MPA and MPB samples (Figure 4d). Note that the presence of EVOO in the systems rendered differences in homogeneity among MPA and MPB samples less appreciable. Also, when EVOO concentration was increased (Figure 4e), homogeneity increased in the FMP products, but was almost constant in the processed samples. This indicates a positive effect of adding EVOO to MP, as the negative effect of freezing on this attribute is masked by the oil. Panelists detected reduced moisture (2) in the MPB samples and in the processed systems, and when the EVOO concentration was increased, moisture (2) significantly increased when cryoprotectants were also added (Figure 4f).

In turn, panelists detected reduced firmness in the samples with added EVOO, without added cryoprotectants and without processing. One can observe that the processed samples with the lower and higher EVOO concentrations were the firmest, whereas in the systems with 25 g/kg added EVOO, the fresh samples had similar firmness than the control (Figure 4g). In the MPA samples, there were no differences between firmness scores in fresh and processed samples (Figure 4h); however, panelists detected increased firmness in processed MP with added κ-C and XG, matching the result for textural properties in MPB samples (Figures 1c, 1f).

Attributes Perceived at the Time of Preparing the Sample in the Mouth for Swallowing

EVOO concentration, cryoprotectant addition and processing also had a significant effect on cohesiveness, adhesiveness and fibrousness (1) (Table 4). When EVOO concentration was increased, cohesiveness and adhesiveness scores decreased significantly in the MPB samples (Figures 5a, 5b).

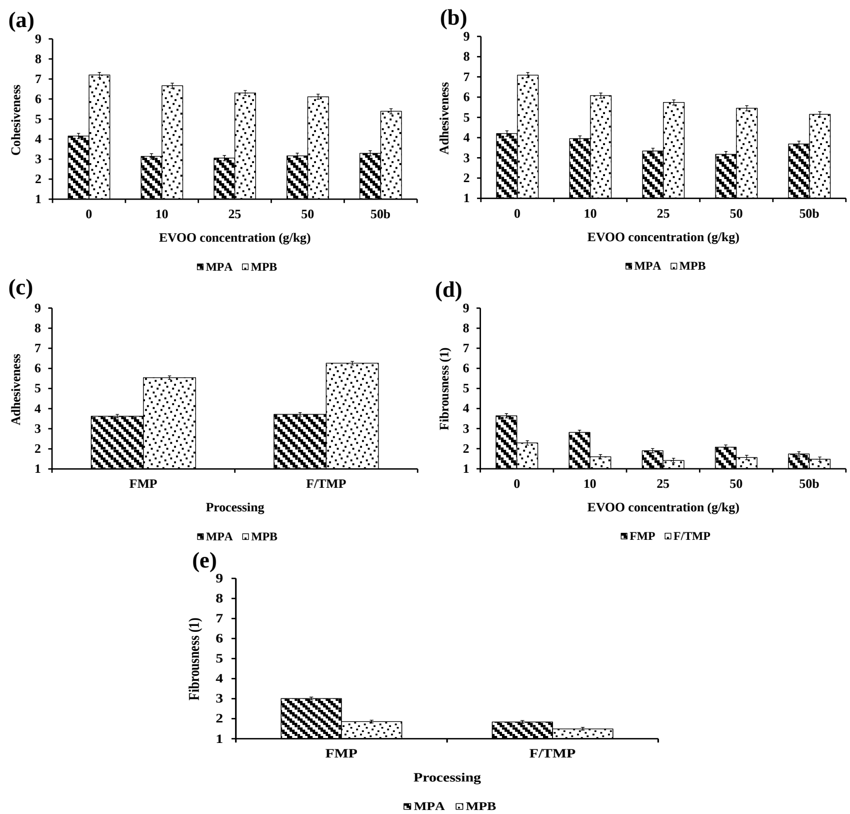

Figure 5. Texture profile analysis sensory attibutes of mashed potatoes with added extra virgin olive oil (EVOO) perceived at the time of preparing the sample for swallowing: (a) Cohesiveness; (b, c) Adhesiveness; (d, e) Fibrousness (1); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

In the MPA samples, there were no significant differences between the adhesiveness scores of fresh and processed samples (Figure 5c), whereas panelists scored the processed MPB samples higher for adhesiveness than their fresh counterparts. Scores for fibrousness (1) also decreased with increasing EVOO concentration, with cryoprotectant addition and with processing (Figures 5d, 5e). Again, addition of cryprotectants reduced differences in fibrousness (1) between fresh and processed samples. This is probably related to the fact that the hydrocolloids can make systems in the rubbery state more viscous, reducing molecular mobility and preventing retrogradation [32].

Attributes Perceived during Final and Residual Phases of Mastication

The three factors studied had a significant effect on ease of swallowing and fibrousness (2) (Table 4), whereas only EVOO concentration had a significant effect on palate coating. In samples both without and with added cryoprotectants (Figure 6a) and in both FMP and F/TMP samples (Figure 6b), ease of swallowing scores increased with increasing oil content. However, only when EVOO was added at concentrations of 0 and 10 g/kg, the scores for this attribute were higher in the samples without cryoprotectants and in the processed samples. Panelists also scored the samples with added EVOO significantly higher for palate coating than the ones made without EVOO (Figures 6c, 6d).

Scores for palate coating were higher in the MPA samples with 25 and 50 g/kg added EVOO than in their MPB counterparts (Figure 6c), and the EVOO content had a much smaller effect in the F/TMP samples than in the fresh counterparts (Figure 6d). Palate coating scores for MPA samples decreased after processing, whereas scores for MPB samples increased with respect to the fresh products (Figure 6e). Also, in the MPA samples, the addition of EVOO at all concentrations significantly reduced sample fibrousness (2) (Figure 6f). A complete dependence study was performed on the instrumental textural properties versus sensory attribute scores. Low correlations between instrumental and sensory ratings were found. Previous publications by other researchers generally agree on good to excellent correlations for hardness (based on calculated "*r*" values) [37].

Correlations for other parameters are usually less good and product-dependent. In this chapter, relatively good correlations with sensory denseness and adhesiveness scores were found only in the case of viscosity index (R^2 = 0.81 and 0.76, respectively). Differences in consistency observed among samples were explained by viscosity index, but not the variation in granularity or fibrousness, determining the sample creaminess.

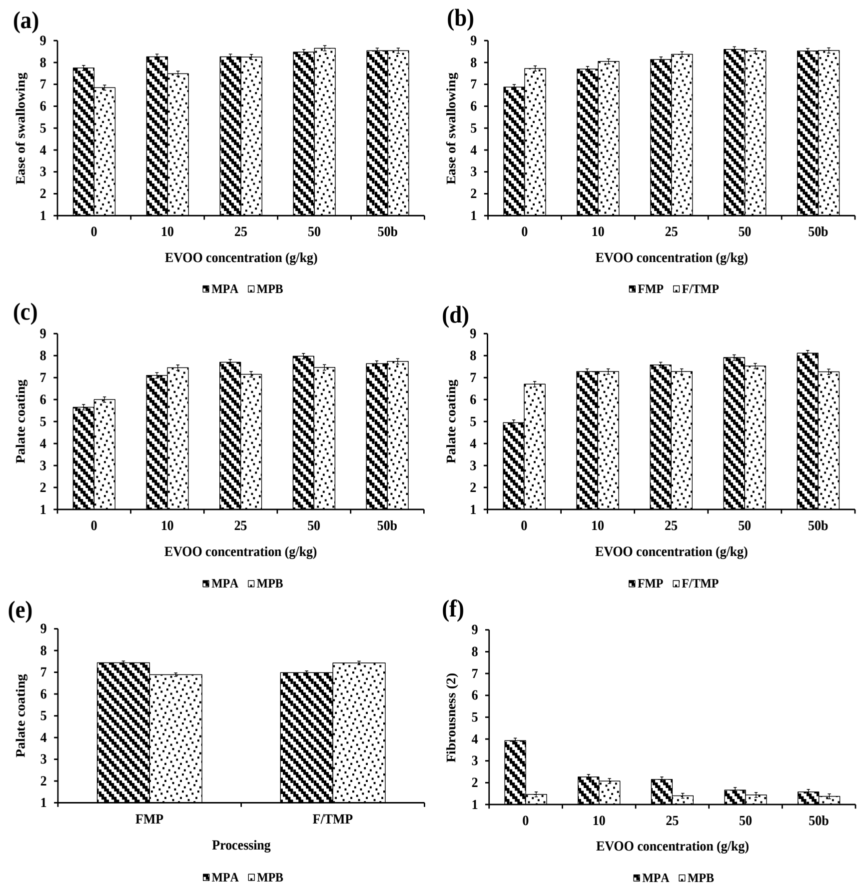

Figure 6. Texture profile analysis sensory attributes of mashed potatoes with added extra virgin olive oil (EVOO) perceived during the final and residual phases of mastication: (a, b) Ease of swallowing; (c-e) Palate coating; (f) Fibrousness (2); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

Overall Acceptability

EVOO concentration, cryoprotectant addition and processing had a significant effect on the OA of the samples (Table 4). Scores for OA increased significantly with increasing EVOO content in both MPA and MPB samples (Figure 7a), and likewise in both FMP and F/TMP samples (Figure 7b). Similarly, a positive relationship between oil content and sensory acceptability has been observed in a set of Polish commercial mayonnaises [38] and in salami [14]. In this chapter, the main differences between samples without and with added EVOO were ascribed to either an aromatic or a creamy note detected in the oil-added MP. Samples with higher percentages of EVOO produced less sensation of dryness and roughness, more sensations of flavor, creamy and fatty mouthfeel and after-feel than the samples without added oil. Fat is a well-known enhancer of creaminess sensations [36]. The latter authors suggested that the possible mechanism by which fat affects the sensory attributes include lubrication and flavor release. The effects of fat on odor and flavor attributes may be related to the flavor-releasing properties of fat.

Panelists scored the MPB and F/TMP samples higher for OA (Figures 7a, 7b). This is probably related to the presence of XG in the systems. It was found that samples containing blends of κ-C and XG [2, 13], were preferred organoleptically due to the creamy mouthfeel they produced. The effects of XG on mouth texture may be related to its WHC, as perceived by the panelists.

Besides, in the processed MPB samples, there were no significant differences between the OA scores given to the MP at any concentration of added EVOO (which were the highest). This has important consequences for the formulation of EVOO-based MP. Results indicate that in the presence of κ-C and XG, if the EVOO content is reduced to below 25 g/kg, the OA score for the product does not decrease, and hence its consumer acceptability is not adversely affected.

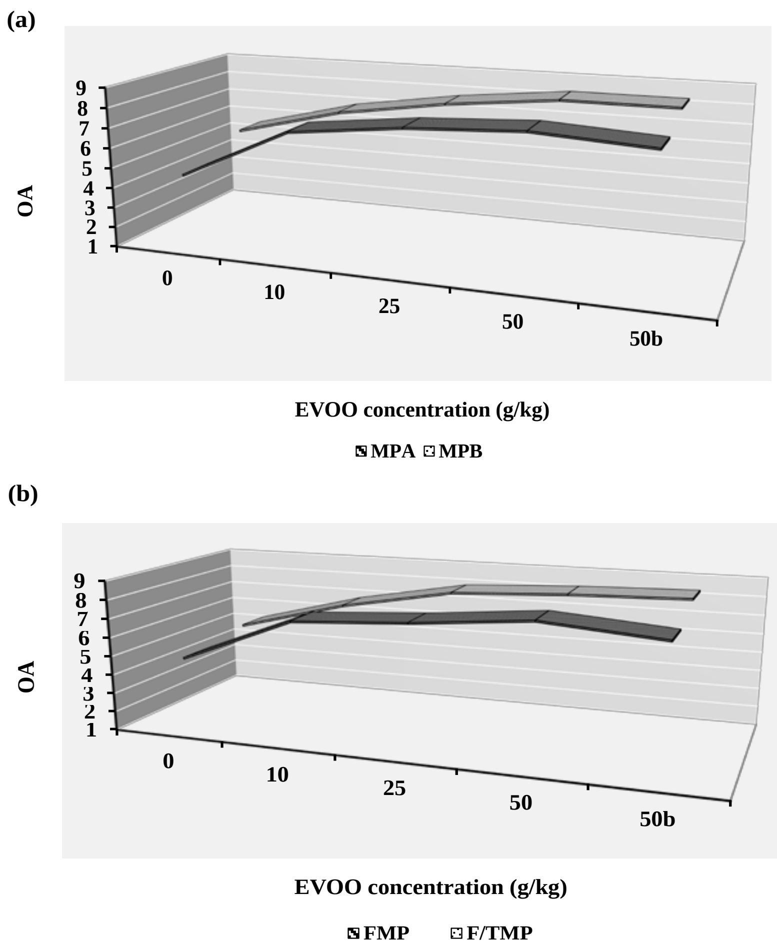

Figure 7. Overall acceptability of mashed potatoes with added extra virgin olive oil (EVOO); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

Microstructure Examination of MP

To achieve a better understanding of the sensory and rheological results and the effect of adding cryoprotectants and of freezing/thawing, the microstructure of the MP samples was studied by SEM (Figures 8-11). Figure 8a shows a microphotograph of the fresh control without either added cryoprotectants or oil. Cooked cells are still distinguishable and firmly bound together by a continuous network of amylose. However, in the fresh control without added EVOO but with added cryoprotectants (Figure 8b), less complete cells are visible, appearing separated from one another and embedded in a continuous network of amylose and κ-C in which starch granules and XG aggregates are entrapped. Probably, the presence of cryoprotectants occluding a great amount of water probably facilitated loss of the original cell shape.

Microphotographs of the corresponding processed counterparts (Figures 9a, 9b) show that freezing and thawing of MPA and MPB samples resulted in completely dissolved cells. Part of the intracellular water was drawn out osmotically because of freezing-induced concentration of the cell mass. Cell tearing is probably caused by the formation of ice crystals. Fresh MPA sample contain more complete cells (Figure 9a), which could give them greater mechanical strength; this would justify that the values of the textural properties were higher in fresh MPA samples than in their processed counterparts. In turn, the processed MPA sample without added EVOO (Figure 9a) developed a spongy appearance due to amylose and amylopectin retrogradation occurring during freezing and frozen storage [32].

The microphotograph of processed MPB sample without added EVOO (Figure 9b) shows the presence of fibers or strands. According to Giannouli and Morris [28], during freezing, XG chains are forced to align and associate by conversion of water to ice crystals. The forced associations survive upon thawing to give a cryogel network. It is likely that such strands are related to this XG conformational transition, as they were observed in most of the F/TMP containing cryoprotectants. Formation of strands can be explained by a progressive increase in local concentration of the polymer as liquid water is converted into ice crystals, promoting intermolecular associations.

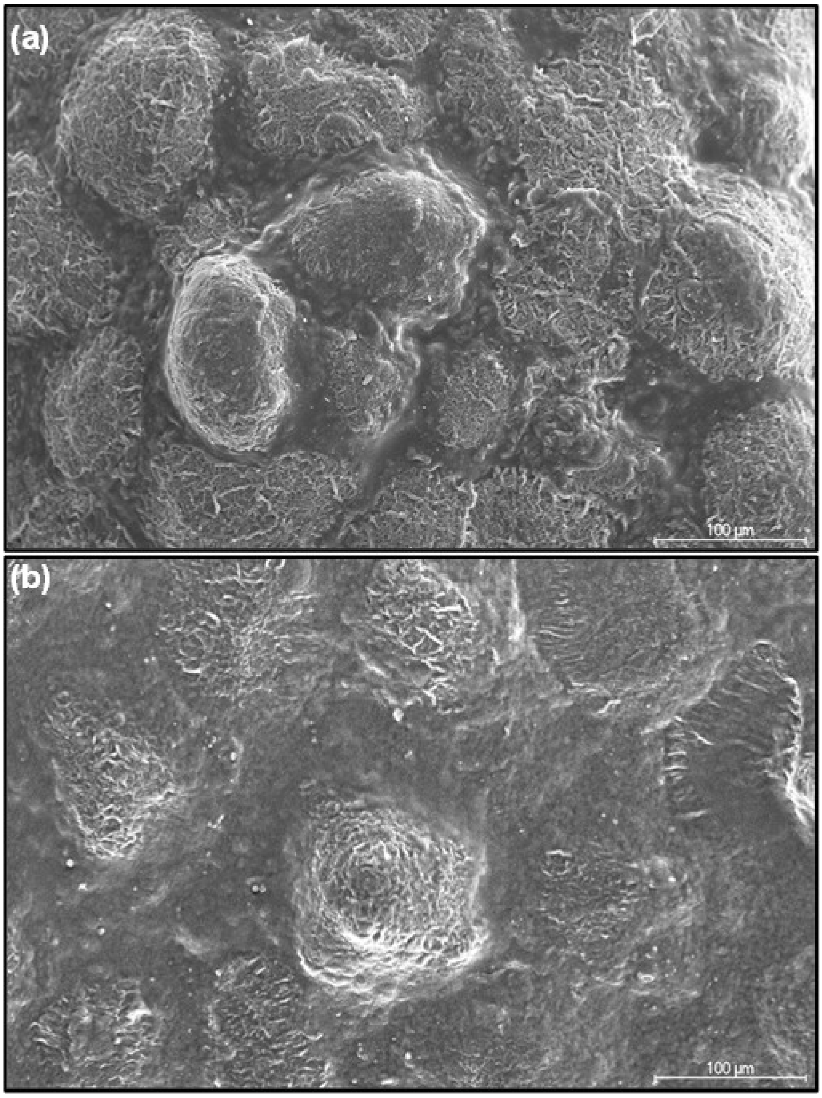

Figure 8. Microphotographs of mashed potatoes (a) Fresh sample without added cryoprotectants; (b) Fresh sample with added cryoprotectants; Magnification was 200 (bar = 100 µm).

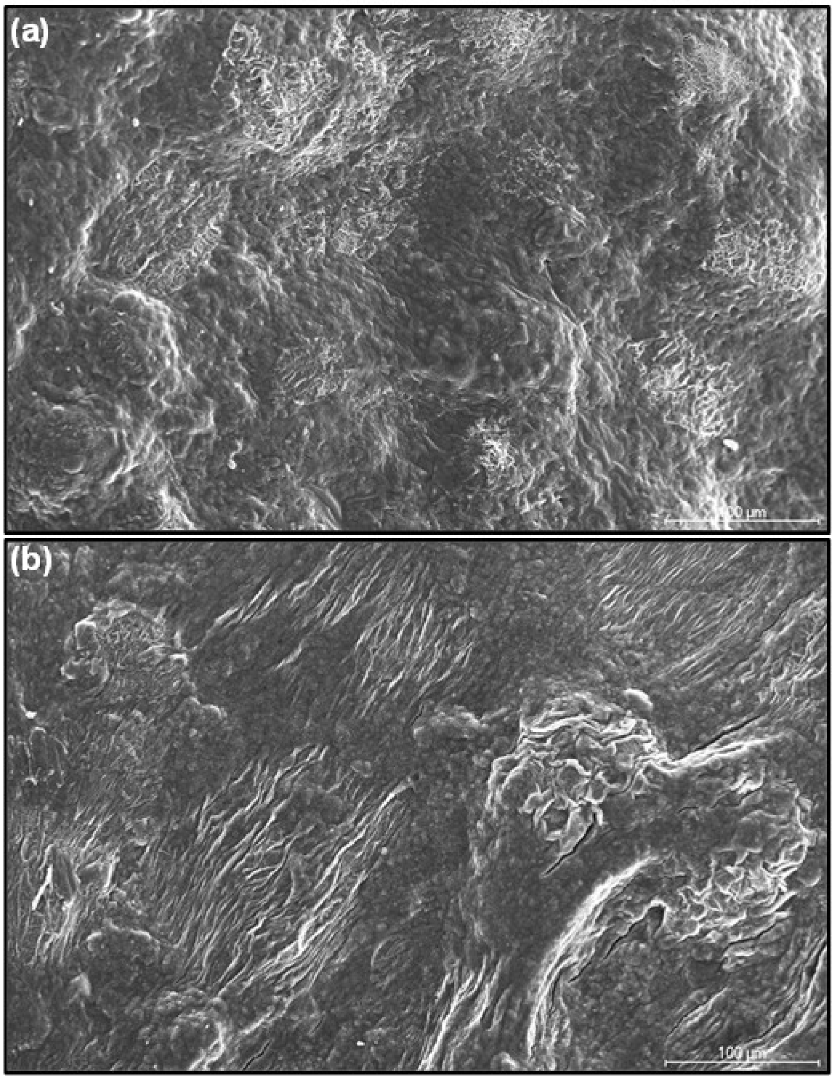

Figure 9. Microphotographs of mashed potatoes (a) Frozen/thawed sample without added cryoprotectants; (b) Frozen/thawed sample with added cryoprotectants; Magnification was 200 (bar = 100 µm).

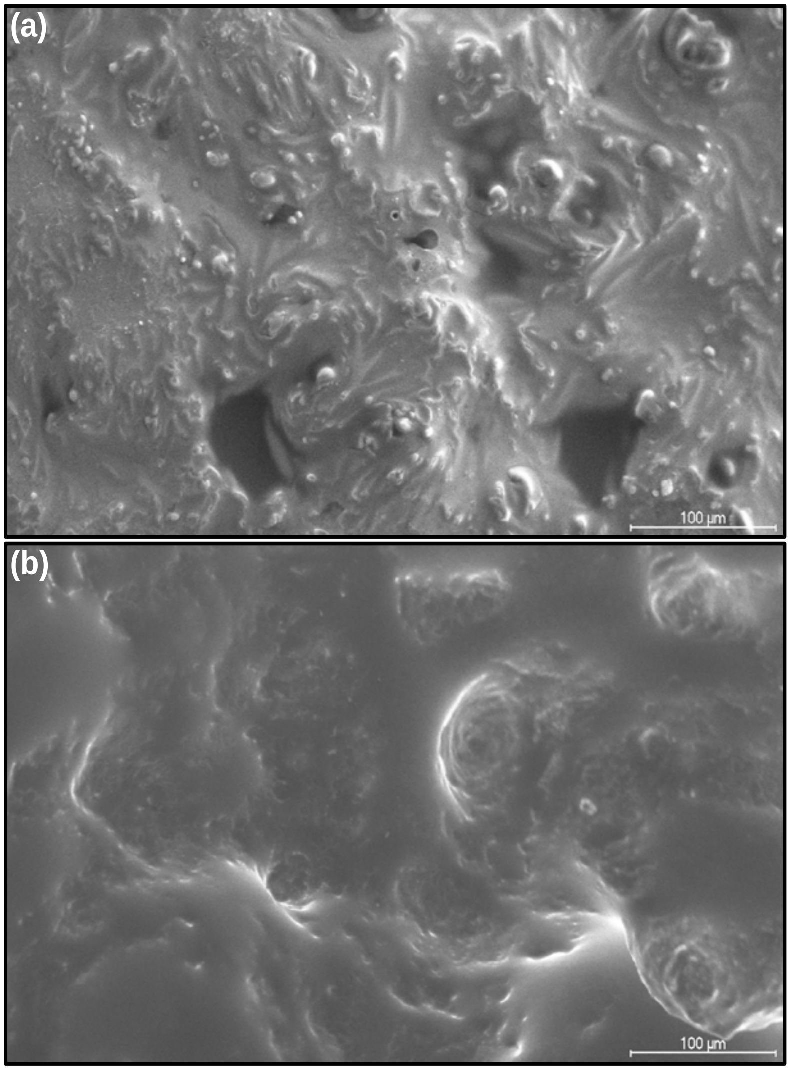

Figure 10. Microphotographs of mashed potatoes (a) Fresh sample without added cryoprotectants and with 50 g/kg added EVOO; (b) Fresh sample with added cryoprotectants and with 50 g/kg added EVOO; Magnification was 200 (bar = 100 µm).

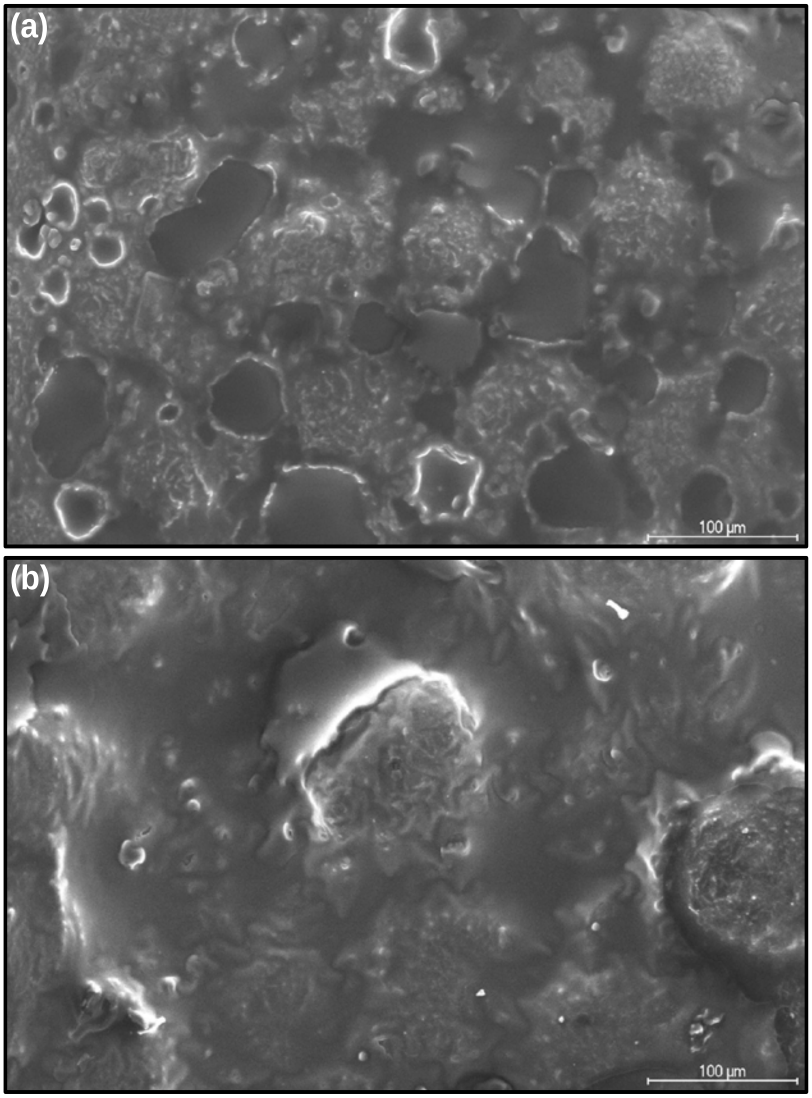

Figure 11. Microphotographs of mashed potatoes (a) Frozen/thawed sample without added cryoprotectants and with 50 g/kg added EVOO; (b) Frozen/thawed sample with added cryoprotectants and with 50 g/kg added EVOO; Magnification was 200 (bar = 100 µm).

Figure 10 shows microphotographs of the counterparts of the samples shown in the Figure 8, but with 50 g/kg added EVOO. When EVOO was added, a dispersed thin phase or layer of oil formed, enveloping all the microstructures constituting the MP. Figure 10a shows some oil droplets in the MPA sample, probably formed by aggregation through steric and/or electrostatic forces [6], whereas Figure 10b shows no oil droplets in presence of κ-C and XG. In MPA samples, freezing also had a negative influence on the formation of oil droplet clusters (Figure 11a; it is likely that the structural damage caused by freezing enabled the oil droplets to come close enough together to aggregate. Microphotograph of the processed sample with 50 g/kg added EVOO (Figure 11b) shows that white gel structures are also discernible in the presence of cryoprotectants.

Addition of XG to salad dressings induces depletion flocculation of the droplets and formation of a three dimensional weak gel network structure that retards the process of droplet creaming [30]. Adding a hydrocolloid causes protein-coated droplets to aggregate and be excluded from the region of continuous phase between them. Therefore, in the MP with added κ-C and XG and oil, the XG may have been adsorbed onto the surface of the droplets, enhancing stability against flocculation and coalescence and forming the white film observed in both microphotographs (Figures 10b, 11b). On the other hand, there are no noticeable differences between FMP and F/TMP samples with added κ-C and XG and oil, confirming that the addition of κ-C and XG significantly reduced quality differences between FMP and their F/TMP counterparts.

CONCLUSION

The addition of either EVOO or cryoprotectants and processing significantly affected the physical, structural and sensory characteristics of MP, although the effect of EVOO concentration depended on the presence of cryoprotectants and on freezing/thawing. Increased EVOO concentration resulted in less structured systems and enhancement of color due to an increase in overall light scattering and pigment content. Addition of κ-C and XG improved thickness, possibly through the exclusion effect of swollen starch granules promoting gelation of the κ-C. Addition of EVOO in increasing concentrations enhanced the sensory quality of MP in terms of reduced granularity, denseness, cohesiveness, adhesiveness and fibrousness, and increased homogeneity, ease of swallowing and palate coating. Instrumental texture measurements were able to distinguish the variations in mechanical textural attributes scored by the panellists. Conversely, geometrical textural attributes (granularity, homogeneity and fibrousness) have to be support by structural traits. Creaminess was the most crucial factor for OA of the products and could be explained by the presence of EVOO aggregates observed by microstructure analysis. Samples with 50 g/kg added EVOO were judged the best of all. There is a possibility of using EVOO in combination with MP to provide a highly nutritious product with improved physicochemical, functional and sensory characteristics.

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