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Rheological, sensory, and microstructural properties of fresh and frozen/thawed mashed potatoes enriched with different proteins

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ABSTRACT
In this study, the effect of the addition of soybean protein isolate (SPI), whey protein isolate (WPI), whole milk powder (WMP), and sodium caseinate (SC) on the rheological, physical, sensory, and structural properties of fresh and frozen/thawed mashed potatoes formulated with added cryoprotectants [kappa-carrageenan (κ-C) and xanthan gum (XG)] was compared. Steady shear flow rate curves indicated a non-Newtonian fluid and exhibited typical shear thinning (pseudoplastic) behavior ($n<1$) with all added proteins. The results showed that there is no significant change in the apparent viscosity ($\eta_{app}$) of fresh mashed potatoes (FMP) and frozen/thawed mashed potatoes (F/TMP) with added WMP and SC at a concentration of 5 g/kg. While the addition of SPI at a concentration of 10 g/kg increased the $\eta_{app}$ and pseudoplasticity, which indicates that the SPI behaves as harder fillers. Based on the sensory evaluation results, WPI and WMP could incorporate to FMP without losing the sensory quality of the product. F/TMP samples with addition of SPI were judged more acceptable than other processed samples, evidencing the ability of this protein to reduce the influence of freeze/thaw process.

1. Introduction
China is the largest potato producer in the world, without any doubt potato is the most powerful food supplement for the solution of the increasingly severe food crisis in China (Wu, 2016). Government policy now focuses on encouraging the production of potatoes to help diversify the country’s staple crops. The development of the potato industry and the consumption of potatoes as a staple food is an important step in China’s agricultural development. Mashed potatoes (MP), made from 100% fresh potato tubers, are important segments of convenience food industry and also suitable food for freezing as a ready-meal component or as a product in itself (Álvarez, Fernández, & Canet, 2005). The most important quality parameters for the consumer acceptance of FMP and F/TMP are the taste and texture (Álvarez, Fernández, Jiménez, & Canet, 2011; Downey, 2003). Freezing and thawing of MP can have a detrimental effect on their sensory and water-holding properties. Different strategies including the freezing temperature (–80, –40, or –24°C), the use of rapid freezing methods (blast freezing or liquid nitrogen evaporation), and thawing mode (microwave or overnight at 4°C) (Álvarez et al., 2005; Alvarez, Fernández, & Canet, 2010; Downey, 2002) have been studied to minimize the effect of freezing and thawing on the quality of MP. Recently, the research tended to study the ability of some additives to enhance the nutritional value of MP and...
minimize the damage of freezing and thawing process. In this regard, Álvarez, Fernández, and Canet (2009) and Fernández, Canet, and Alvarez (2009) reported that the addition of kappa-carrageenan (κ-C) and xanthan gum (XG) at a low concentration (1.5 g/kg) to MP could improve the overall acceptability (OA) and minimize damage arising from freezing and thawing. Additionally, the effect of soybean protein isolate (SPI), which contains 90% protein and usually used in the food industry (Zhu, Liu, Fu, & Zhao, 2016), on physico-chemical, functional and sensory characteristics of MP products has been reported. Obtained results showed that SPI concentrations had a significant impact on rheological properties of MP (Álvarez, Fernández, Olivares, & Canet, 2012). The effect of whey protein concentrate, pectin,ulin and extra virgin olive oil to modify the rheological, thermal, structural properties and sensory quality of MP has also been studied (María Dolores Alvarez, Fernández, Olivares, & Canet, 2010; Conforti, Lupano, & Yamul, 2013).

Considering the Chinese consumers demand for natural and healthy convenience food, the food industry has shown increasing interest in the manufacture of MP with high nutritional value and good storage stability during freezing. Few studies compare the effect of the addition of different proteins to improve the physicochemical, functional properties, and sensory characteristics of MP. Therefore, the purpose of the present research was to investigate the effect of the addition of four proteins [SPI, whey protein isolate (WPI), whole milk powder (WMP) and sodium caseinate (SC)] on the rheological, sensory and microstructure properties of FMP and F/TMP, to be suitable for Chinese consumer behavior.

2. Material and methods

2.1. Materials

The potatoes utilized were fresh tubers (Solanum tuberosum, L., Eshu-8) from Southern Potato Research Centre of China (Enshi). The Samples were stored in a chamber at 8 ± 1°C and 85% relative humidity throughout the experiment period. SPI with the trade name Shandong Yuwang Group (Dezhou, China) was used in this study. WPI, WMP and SC were obtained from Tengzhoushi Xiangning Biological Engineering Ltd. (Tengzhou, China). The composition of the proteins used in this study is given in Table 1. While (κ-C) (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were supplied by Shandong Fufeng Fermentation Ltd. (Linyi, China).

2.2. Preparation of MP

Fresh potato tubers were manually washed, peeled, and diced. According to pre-experiment for sensory characteristics, the MP were set up in ~1150 g batches as following: 721.2 g/kg of potatoes, 270.4 g/kg of water, 5.4 g/kg of salt, 1.5 g/kg of either κ-C or XG. The potatoes were steam cooked for 20 min. Then, the appropriate amount (2.5, 5.0, 7.5, and 10.0 g/kg) of each protein was previously dissolved in 270.4 g/kg of water at 60°C for 20 min using magnetic stirring until complete dilution. Afterward, all ingredients were cooked for 20 min at 100°C with manually stirring, and the amount of liquid evaporated was determined by weighing the ingredients before and after boiling. The evaporated liquid was replaced by an equal weight of boiling water. The mixture was immediately ground for 40 s (blade speed: 2000 rpm) using a food processor (Philips HR2094) and homogenized through a stainless-steel sieve (20 mesh). After preparation, half of each FMP sample was immediately analyzed, and the other half was packed in 200 × 150 mm² polyethylene plastic bags, sealed under light vacuum (~0.03 MPa) on a manifold vacuum sealer (DZ-280/2SZ, China), then frozen and thawed (F/TMP) as described below. MP without adding protein were prepared and served as control.

2.3. Freezing and thawing procedures

MP were frozen according to the method described by Álvarez, Fernández, Solas, and Canet (2011) briefly; MP samples were frozen with liquid nitrogen vapor in a self-made chamber (Figure 1) until their thermal centers reached −40°C (freezing rate: 1 ± 0.10°C/min). Products temperatures were observed by digital thermometer (−50–1300°C, TM902C, China). After freezing, samples were placed in a freezer (BC/BD-429TS, China) and stored at −24°C for at least 1 month before thawing. Frozen MP were unpacked and then thawed in a microwave oven (MM721NG1-PW, China) for 2 min. Samples were irradiated for 1 min of each side with output power ratings of 800 W and then removed from the microwave and stirred manually with a spoon for 1 min to achieve uniform sample temperature distribution. After thawing, the temperature at the samples thermal center was 50 ± 5°C in all samples.

2.4. Steady shear measurements

Steady shear measurements were carried out with a controlled stress rheometer (AR2000ex, TA Instruments, US) at 55°C with smooth plates (40 mm diameter and 2 mm gap) and a solvent trap to prevent moisture loss during tests. Before conducting rheological measurements, samples were loaded and allowed to relax for 5 min to reach 55°C. Samples temperature were kept constant during measurements using a Peltier Plate system (−40–200°C; TA Instruments, US). Samples flow rate curves were measured by recording shear stress (γ) values when shearing with an increasing shear rate (γ) from 0.1 to 100/s for 15 min, which is the range of interest in food texture studies (Bistany & Kokini, 1983). Each curve presented is a typical one out of three runs. Viscosity values in the upward viscosity/shear rate curves at a shear rate of 50/s (η_app,50) were taken as the apparent viscosity of the samples. This value would represent the approximate viscosity felt in the mouth (Bourne, 2002).

### Table 1. Composition of the studied proteins with codes used for their identification (as provide by the company).

| Proteins used in this research | Codes | Protein | Lactose | Fat | Water | Ash |
|-------------------------------|-------|---------|---------|-----|-------|-----|
| Soy protein isolate           | SPI   | 90      | 1       | 5   | 4     |
| Whey protein isolate          | WPI   | 80      | 6       | 5   | 4     |
| Whole milk powder             | WMP   | 24      | 39      | 28  | 5     | 4   |
| Sodium caseinate              | SC    | 90      | 1       | 2   | 5     | 2   |
2.5. Microstructure properties

2.5.1. Scanning electron microscopy

The microstructure of MP was analyzed by scanning electron microscopy (SEM) using a JSM-5610LV microscope (JEOL Ltd.). MP samples were air-dried, then mounted and sputtered coated with Au (200 Å approx.) in SPI diode sputtering system metallizer. Photomicrographs were taken with a digital system Scanvision 1.2 of RONTEC (8001.200 pixel).

2.5.2. Particle size distribution

MP was dissolved in distilled water (15%, w/v) and stirred for 30 s using the vortex to ensure that the particles were completely dispersed. Then, the samples were conducted to particle size analysis by light scattering using a Mastersizer 2000 equipped with a Hydro 2000 MU dispersion unit, from Malvern Instruments Ltd. (Malvern, Worcestershire, UK). The pump speed was set at 3000 rpm, and the refractive index and absorption parameter of the disperse phase were 1.330 and 0.001, respectively. Particle size was reported as the mean and standard deviation ($n = 3$) of the volume mean diameter ($D_{43}$) (Arzeni et al., 2012).

2.6. Measurement of color

Instrumental measurement of the color of the MP was carried out with a Konica Minolta model CR-400/410 (Tokyo, Japan) color difference meter fitted with a 10-mm diameter aperture, and the results were expressed by the CIELAB system concerning illuminant D65. The parameters determined in this study were $L^*$ (−$L^*$ refers to 0 [black] and +$L^*$ refers to 100 [white]), $a^*$ (−$a^*$ refers to greenness and +$a^*$ refers to redness), $b^*$ (−$b^*$ refers to blueness and +$b^*$ refers to yellowness), as recommended by the International Commission on Illumination (Illumination, 1978). The results displayed the average of eight times measurements.

2.7. Sensory analysis

Sensory evaluation was conducted by a 10-member panel with specific training according to the ISO guidelines (ISO 8586-1:2012). Each sample was tested twice and average scores calculated. Thus, each sample was tested 20 times in all. Samples were subjected to a descriptive quantitative method adapted for each product (Stanley, 1988). Panelists were asked to evaluate samples for texture (consistency, adhesiveness, creaminess, and fibrousness), appearance (authentic color, off-colors, shine, and uniformity), and taste (sweetness, authentic taste, and off-taste). Scores were awarded on a scale of 1–9, in which 1 indicated total absence of the sensory attribute and 9 a very definite attribute.

2.8. Statistical analysis

All data were subjected to one-way analysis of variance using SPSS17.0 software (SPSS Inc., Chicago, IL, USA) to analysis the effect of adding proteins, proteins concentration, and freezing/thawing process on the rheological, sensory, and microstructural properties of the MP. $P$-values with ($P < 0.05$) were considered statistically significant. Where significant differences were present, individual combinations were compared using the least significant difference test (99%) (data are not shown). FMP and F/TMP without the addition of the proteins have been included as controls.

3. Results and discussion

3.1. Rheological behavior of the MP

Steady shear flow rate curves of FMP and F/TMP with and without added proteins appear in Figure 2. The variation of the shear stress values with the shear rate indicated a non-Newtonian fluid and exhibited typical shear thinning (pseudoplastic) behavior ($n < 1$) with all added proteins. It has been reported that the MP are non-Newtonian at most temperatures and pseudoplastic behavior of MP was due to the flow behavior of potato starch and other additives (Canet, Alvarez, Fernández, & Luna, 2005; Fernández, Alvarez, & Canet, 2008).

According to the pre-sensory evaluation results (data not shown), the water content of all MP samples used in this study was less than conventional level, to meet the requirements of the Chinese consumers. That resulted in deformity...
of the structure of FMP and F/TMP with and without proteins addition when the shear rate increased. Therefore, the flow curves behavior of tested samples taken no systematic trend with stress rate (Figure 2), which suggested that the low water content led to the creation of a coarsely aggregated that cause the weakened structure of MP.

As a general trend, most of the FMP and F/TMP with added proteins presented higher resistance to flow when compared with controls, and the highest resistance to flow emerged with the addition of SPI (Figure 2(c)). It is noteworthy that the resistance to flow increases with increasing the concentration of SPI, that probably due to the low water content in the MP recipe. However, sensory evaluation results showed that the MP become fluffy with adding high concentration of SPI. These findings correlate favorably with Álvarez et al. (2012) who found that the electrostatic repulsive force between SPI proteins and negatively charged phosphate groups on anionic potato starch would become predominant that prevent the interaction between amylose/amylopectin matrix and protein molecules.

These findings have obtained with all added proteins except for WPI with F/TMP (Figure 2(d)), the resistance to the flow decreased with increasing the concentration of WPI. Similarily, Conforti et al. (2013) reported that both whey protein concentrate and pectin decreased the consistency of MP weakening its structure in all concentration assayed. That may due to the flow behavior of potato starch and biopolymers like whey proteins and pectin ruined the pseudoplastic behavior of MP (Fernández et al., 2008).

Figure 3 shows the effect of added proteins on the apparent viscosity of FMP and F/TMP at 50/s ($\eta_{app,50}$), no significant change in the apparent viscosity ($\eta_{app}$) was exhibited for FMP and F/TMP with added WMP, and SC at a concentration of 5 g/kg. Similar results were obtained by Fernández et al. (2008) with the addition of XG to MP. On the other hand, the apparent viscosity ($\eta_{app}$) of FMP and F/TMP increased significantly ($P<0.5$) by adding 2.5–10 g/kg SPI, reaching the highest value in F/TMP by adding 10 g/kg SPI as compared with control samples. This probably due to the high capacity of SPI for water absorption, which resulting in increasing the apparent viscosity and hardness of FMP and F/TMP (Fiora, Pilosof, & Bartholomai, 1990; Hussain, 2007). Consequently, less free water was available in the FMP and F/TMP with the addition of SPI, which explain the increasing in apparent viscosity of MP.

Furthermore, F/TMP samples containing 5 g/kg WPI has an apparent viscosity ($\eta_{app}$) significantly lower than corresponding control samples. It has been reported that the interactions between WPI and pectin in MP are important as they would influence the physical structure of the product modifying the texture and the rheological properties (Conforti et al., 2013). However, the addition of WPI has no significant effect on the apparent viscosity of FMP compared with control samples (Figure 3). These outcomes are in contrast with Fernández et al. (2008) who found that the addition of WPI and SC increased the thickness of FMP mainly when added at levels of 1.5 and 2.5–7 g/kg, respectively.

3.2. Microstructure properties of MP

For a better understanding of the effect of adding proteins on sensory and rheological attributes of MP, the microstructure of the FMP and F/TMP samples was studied by examining the average size of particles (Table 2) and SEM (Figure 4). Little is known about the effect of added proteins on the particle size of FMP and F/TMP. In this study, we investigated...
the particle characters of FMP and F/TMP formulated without and with added proteins. The results showed that the addition of proteins at different concentration (0, 2.5, 5, 7.5, and 10 g/kg) had no significant effects on particle size distribution of FMP (Table 2). Probably, this is because proteins particles are held together with MP by physical interaction, and possibly particles size of added proteins is too small to cause any change to the particles of the whole MP mixture. Moreover, the protein can form a thin film on the surface of potato cells. Thus, texture of MP became smoother after the addition of the proteins. However, the film is too thin to affect the particle diameter of the whole mixture, because the diameter of potato cells or cell debris is bigger than the thickness of the film. On the contrary, F/TMP formulated with WPI and WMP showed smaller size particles when compared with the control, which resulting from a large surface exposed to interaction with water (Chiavaro, Vittadini, & Corradini, 2007). These results justified the decreasing in the apparent viscosity (ηapp,50) for the F/TMP with added WPI. On the other hand, the addition of SPI and SC caused increase in the particles size of F/TMP (Table 2) that may be caused by improvement protein–protein interactions as manifested by the increase in elasticity and viscosity (M. D. Álvarez, Olivares, Blanch, & Canet, 2013).

Figure 4 shows the microphotograph of FMP without and with added different proteins. The outcomes indicated that the FMP formed from single potato cells, some ruptured cells as well as cell fragments that are embedded in an extracellular starch phase blended with gelled κ-C and XG (Álvarez et al., 2012). On the contrary, it has been reported that the manufacturing process for MP leads to damage all the potato cell structure that yielding a smooth structure (Álvarez et al., 2011; Conforti et al., 2013). The microphotograph of the FMP with added SPI (Figure 4(b)), the protein network consist of small clusters of SPI and protein aggregation clumps, and it is easy to distinguish between the starch matrix and protein network. It is worthy to mention that the environmental conditions (pH, ionic strength, and mineral content); protein composition (extent of denaturation, and concentration); and processing conditions (heating and cooling rates) are the major factors that affect the nature of the protein gel formed (Turgeon & Beaullieu, 2001). Therefore, the presence of SPI probably led to absorbing a great amount of water that caused facilitated loss of the original cell shape and also increasing rigidity. That would account for the fact that the rheological properties were higher in MP formulated with SPI than other samples.

Additionally, the microphotographs of the FMP with WPI, WMP, and SC (Figure 4(c–e)) show significant differences from the respective controls without added proteins. The addition of WPI affects the microstructure of MP and make the surface smoother (Figure 4(c)), indicating the coating properties occurred by WPI and that confirming the results of the rheological and sensory evaluation. A similar effect has been reported for MP with added whey protein concentrate (Conforti et al., 2013). Additionally, the MP with added WMP (Figure 4(d)) shows considerably less

Table 2. Effects of protein additives and frozen/thawed (F/T) processes on the apparent viscosity of mashed potatoes: (a) represent the effect of SPI at different concentration (2.5, 5, 7.5, 10 g/kg) on the apparent viscosity of FMP and F/TMP; (b) showed the effect of the four proteins (SPI, WPI, WMP, and SC) at a concentration of 5 g/kg on the apparent viscosity of FMP and F/TMP.

| Protein (g/kg) | Fresh mashed potato | Frozen/Thawed mashed potato |
|---------------|---------------------|----------------------------|
|               | SPI | WPI | WMP | SC  | SPI | WPI | WMP | SC  |
| C             | 190.86 ± 6.41a | 190.86 ± 6.41a | 190.86 ± 6.41a | 190.86 ± 6.41a | 173.45 ± 6.73b | 173.45 ± 6.73b | 173.45 ± 6.73c | 173.45 ± 6.73b |
| 2.5           | 204.84 ± 9.27a | 187.70 ± 0.35a | 195.46 ± 8.40a | 200.44 ± 7.04a | 192.17 ± 2.06a | 179.54 ± 0.30ab | 209.73 ± 0.90a | 216.54 ± 7.81a |
| 5             | 200.15 ± 10.32a | 190.97 ± 5.55a | 199.67 ± 7.19a | 194.29 ± 6.89a | 189.05 ± 2.43a | 186.09 ± 1.99a | 207.11 ± 0.30a | 195.83 ± 9.40ab |
| 7.5           | 193.77 ± 6.90a | 189.32 ± 11.53a | 184.84 ± 11.11a | 193.25 ± 4.50a | 194.23 ± 0.55a | 180.71 ± 1.12ab | 192.23 ± 2.04ab | 202.95 ± 26.36ab |
| 10            | 193.90 ± 7.86a | 187.26 ± 0.68a | 189.14 ± 1.21a | 194.45 ± 28.50a | 191.14 ± 6.49a | 181.29 ± 7.25ab | 180.63 ± 1.22c | 186.71 ± 19.01ab |

Values are means ± SD (standard deviation) of triplicate assays. Different letters indicate significant differences inside each group (p < 0.05). C referred to control samples without added protein, soybean protein isolate (SPI), whey protein isolate (WPI), whole milk powder (WMP), and sodium caseinate (SC). Los valores corresponden a las medias ± DE (desviación estándar) de ensayos en triplicado. Las letras distintas indican la existencia de diferencias significativas en cada grupo (p < 0.05). La C corresponde a las muestras de control sin proteína, aislado de proteína de soya (SPI), proteína de suero de leche aislada (WPI), leche entera en polvo (WMP) o caseinato de sodio (SC) adicionados.
cohesive and coarse gel structure, because the WMP blend absorbs a great amount of water, and thus produced a softer system with a lower viscosity (Conforti et al., 2013).

Previous results proved that the structure formation in MP is extremely complex. Thus, the interaction between potato starch and different proteins (SPI, WPI, WMP, and SC) with different concentration affects the MP microstructures in different ways.

Figure 4. Effects of protein additives at concentration 5 g/kg on the microstructure of mashed potato, where (a) refers to control, (b) refers to mashed potato enriched with soy protein isolate (FMP-SPI), (c) refers to mashed potato enriched with whey protein isolate (FMP-WPI), (d) refers to mashed potato enriched with whole milk powder (FMP-WMP), and (e) refers to mashed potato enriched with sodium caseinate (FMP-SC).

| Table 3. The effect of proteins addition, proteins concentration, and frozen/thawed treatment on the color parameters of mashed potatoes. |
|---|---|---|---|---|---|---|---|---|
| Color parameters | Protein (g/kg) | Fresh mashed potato | Frozen/Thawed mashed potato |
| | SPI | WPI | WMP | SC | SPI | WPI | WMP | SC |
| a* | C | −3.67 ± 0.06b | −3.67 ± 0.06b | −3.67 ± 0.06c | −3.67 ± 0.06b | −4.06 ± 0.04a | −4.06 ± 0.04a | −4.06 ± 0.04b | −4.06 ± 0.04a |
| | 2.5 | −3.27 ± 0.29a | −4.41 ± 0.07d | −4.12 ± 0.05c | −3.65 ± 0.03b | −4.09 ± 0.02a | −4.14 ± 0.19a | −4.57 ± 0.02b | −4.04 ± 0.04a |
| | 5 | −3.48 ± 0.10a | −3.93 ± 0.04c | −3.68 ± 0.05c | −3.45 ± 0.07a | −4.06 ± 0.13a | −4.67 ± 0.05b | −4.61 ± 0.03b | −3.94 ± 0.03a |
| | 7.5 | −3.26 ± 0.07a | −3.72 ± 0.10c | −4.05 ± 0.04d | −3.09 ± 0.03a | −3.66 ± 0.09a | −4.31 ± 0.08b | −4.55 ± 0.06c | −3.77 ± 0.01a |
| | 10 | −3.33 ± 0.04a | −3.88 ± 0.13c | −4.03 ± 0.08d | −3.43 ± 0.03a | −4.29 ± 0.09b | −4.56 ± 0.03b | −4.70 ± 0.02c | −4.23 ± 0.11b |
| b* | C | 11.64 ± 0.16AB | 11.64 ± 0.16C | 11.64 ± 0.16C | 11.64 ± 0.16C | 11.72 ± 0.10AB | 11.72 ± 0.10C | 11.72 ± 0.10AB | 11.72 ± 0.10C |
| | 2.5 | 11.96 ± 0.13AB | 10.97 ± 0.30C | 11.94 ± 0.51C | 10.89 ± 0.34D | 11.65 ± 0.13B | 10.22 ± 0.74C | 11.41 ± 0.51B | 13.34 ± 0.12A |
| | 5 | 12.58 ± 0.39B | 13.53 ± 0.16A | 11.60 ± 0.27C | 13.01 ± 0.18B | 12.50 ± 0.26B | 13.91 ± 0.23A | 11.17 ± 0.02B | 13.39 ± 0.33A |
| | 7.5 | 13.02 ± 0.33A | 13.29 ± 0.44B | 12.98 ± 0.41B | 12.87 ± 0.13B | 12.82 ± 0.14A | 12.44 ± 0.48AB | 11.86 ± 0.13B | 12.33 ± 0.35AB |
| | 10 | 13.02 ± 0.21A | 14.26 ± 0.61AB | 13.63 ± 0.57B | 14.86 ± 0.29A | 12.51 ± 0.71AB | 13.15 ± 0.28AB | 13.23 ± 0.55A | 12.22 ± 0.29AB |

Values are means ± SD (standard deviation) of triplicate assays. Different letters in the same column for each protein indicate significant differences (p < 0.05). C referred to control samples without added protein, soybean protein isolate (SPI), whey protein isolate (WPI), whole milk powder (WMP) and sodium caseinate (SC). The a* represented the red/green opponent colors, while the yellow/blue opponent colors are represented by b*.

Los valores corresponden a las medias ± DE (desviación estándar) de ensayos en triplicado. Las letras distintas en la misma columna para cada una de las proteínas indican la existencia de diferencias significativas (p < 0.05). La C corresponde a las muestras de control sin proteína, aislado de proteína de soya (SPI), proteína de suero de leche aislada (WPI), leche entera en polvo (WMP), y caseinato de sodio (SC) adicionados. a* representa los colores opuestos rojo/verde; b* representa los colores opuestos amarillo/azul.
3.3. Effect of protein addition and F/T processes on the color of MP

The color of MP is one of the most important quality attributes, which affects the appearance of the final product. The yellow color of MP is usually more accepted by the consumers (Conforti et al., 2013). The \( a^* \) (red/green) and \( b^* \) (yellow/blue), are a quality parameter that describes the color change, have been used in this study to know the effect of added proteins, the proteins concentrations, frozen/thawed treatment and the interaction between them on the color of MP. As shown in Table 3, the increase in the proteins concentration or the freezing and thawing processes and the interaction has effect significantly \( (P \leq 0.5) \) on the color parameters in all cases, when the concentration of WPI, WMP and SC reached (7.5 or 10 g/kg) the \( b^* \) of FMP significantly \( (P \leq 0.5) \) increased. After freezing and thawing processes, \( b^* \) increased significantly \( (P \leq 0.5) \) to be (12.15 ± 0.71, 13.15 ± 0.28, and 13.23 ± 0.55) with the adding 10 g/kg of SPI, WPI, and WMP, respectively. These results mean that the addition of proteins could eliminate the influence of F/TMP treatment on the \( b^* \). Conforti et al. (2013) stated that the addition of whey protein concentrate to F/TMP could enhance the yellowness of MP to meet the consumer requirements.

In the control sample of FMP, the parameter \( a^* \) was (3.67 ± 0.06). By adding WPI (2.5–10 g/kg) and WMP (7.5–10 g/kg), the \( a^* \) value decreased significantly \( (P \leq 0.5) \), while \( a^* \) values increased significantly by adding (2.5–10 g/kg) SPI or (5–10 g/kg) SC, compared with control (Table 3). These results indicate that the addition of SPI or SC increased the greenness of FMP, whereas addition of WMP or WPI caused loss of greenness. After freezing and thawing processes, the

![Figure 5](image_url)

**Figure 5.** Effects of protein additives (at different concentration 2.5, 5, 7.5, 10 g/kg) and frozen/thawed (FT) processes on the sensory properties of mashed potato: (a) and (b) represent FMB, and F/TMP enriched with SPI; (c) and (d) represent FMB and F/TMP enriched with WPI; (e) and (f) represent FMB, and F/TMP enriched with WMP, while (g) and (h) represent FMB, and F/TMP enriched with SC.

**Figura 5.** Efectos de la adición de proteínas (en concentraciones diferentes de 2.5, 5, 7.5, 10 g/kg) y de los procesos de congelamiento/descongelamiento (FT) en las propiedades sensoriales del puré de papa. A y B corresponden a FMB y a F/TMP enriquecido con SPI; C y D corresponden a FMB y a F/TMP enriquecido con WPI; E y F corresponden a FMB y a F/TMP enriquecido con WMP; G y H corresponden a FMB y a F/TMP enriquecido con SC.
α* values of MP samples with all added proteins significantly decreased compared with the FMP, which may be resulting from increasing the concentration of protein that leads to the lighter color of the MP samples.

3.4. Effect of proteins and F/T cycle on sensory properties of MP

The effect of adding different proteins with different concentrations on the sensory properties of FMP and F/TMP was studied (Figure 5). The adhesiveness of the FMP decreased significantly (P ≤ 0.5) with the addition of SPI, WPI, and SC (Figure 5(a,c,g)); however, no effect has been noticed with the addition of WMP on the adhesiveness (Figure 5(e)). SPI, WPI, and WMP (Figure 5(a,c,e)) have increased significantly (P ≤ 0.5) the consistency and fibrousness of the FMP. The creaminess and OA of FMP have significantly (P ≤ 0.5) decreased with the addition of SPI and SC (Figure 5(a,g)), while WPI and WMP (Figure 5(c,e)) increased significantly (P ≤ 0.5) the sensory of creaminess and OA. After F/T process, panelists distinguished significantly between F/TMP and FMP. Furthermore, all sensory quality parameters (except for adhesiveness) increased significantly (P ≤ 0.5) with the addition of SPI (Figure 5(b)). On the contrary, the addition of WPI (Figure 5(d)) led to decrease all sensory quality parameters significantly (P ≤ 0.5) (except for hardness). All texture quality parameters increased significantly (P ≤ 0.5) with the addition of SC (Figure 5(h)), however with increasing the concentration of SC the OA decreased significantly (P ≤ 0.5), which caused off-flavor of the tested samples. In an earlier work, a disruptive effect was observed in the F/TMP with added SC, which makes it not suitable for use in MP industry (M. Alvarez, Canet, & Fernández, 2008). It is worth mentioning that the addition of WPI and WMP (Figure 5(d,f)) resulted in light off-flavor in tested samples of F/TMP. As a general trend, the addition of WPI and WMP can significantly increase the quality of FMP when compared with SPI and SC, while for F/TMP, the addition of SPI increased the sensory quality parameters of MP.

4. Conclusion

The addition of SPI, WPI, WMP, or SC and processing significantly affected the physical, structural, and sensory characteristics of MP. Results showed that four proteins added and F/T processing had a great impact on rheological properties of the MP. The effects on rheological properties were most notable when 10 g/kg SPI was added. WPI, WMP, and SC increased b* of FMP significantly and eliminate the influence of F/T treatment on the color parameters. Moreover, the addition of WPI and WMP increased the small size particles in the F/T samples. F/T MP containing WPI and WMP presented higher sensory evaluation than any other F/T products.

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