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Evaluation of the application of an edible coating and different frying temperatures on acrylamide and fat content in potato chips

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Abstract

The consumption of fried foods and specifically potatoes is associated with the development of cardiovascular and cancer diseases in the population due to these foods contain a high fat level and some toxic compounds such as acrylamide. The aim of the present work was to evaluate the effect of the application of an edible coating developed from whey proteins and rosemary extracts on the reduction of acrylamide and fat in potato chips. The methodology included factorial experimental design, taking as independent variables: percentage of whey protein (5–11%), percentage of rosemary extract (0–2%), and frying temperature (170–190°C). The fat content was determined according to AOAC and acrylamide by LC-ESI-MS-MS. In addition, textural analyses were performed on potato chips. The content of acrylamide oscillated between 130 and 650 μg/kg. The acrylamide content was significantly affected by the frying temperature ($p < 0.05$). The fat content ranged between 8 and 31%. The firmness values ranged between 0.5 and 5.7 N. It can be concluded that the edible coating reduces the content of acrylamide and fat during frying, in addition to improving the firmness of the potato. Therefore, the designed coating could be an alternative to the public health problem generated by the consumption of fried foods.

Practical application

The present investigation shows how the use of coatings from whey proteins with the addition of extracts of natural antioxidants from rosemary can reduce the formation of neo-formed contaminants (acrylamide) and adsorption of fat, which represents a great processing alternative for the industry that allows them to comply with the regulations, recommendations, and existing trends regarding to the consumption of healthier products. In addition, the use of the coating does not affect the sensory quality of the potatoes. This also represents an attractive alternative for consumers who demand increasingly safe and healthy and tasty products, favoring the decrease in the prevalence of degenerative diseases in world population.

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1 | INTRODUCTION

French fries are obtained by a frying process, which involves a total cooking of the food in a fatty medium (oil), at a temperature oscillating between 160 and 200°C. During the frying process, several chemical and physical reactions take place. These reactions modify the organoleptic characteristics of the food (Nieto, 2014), giving the product a certain texture and sensorial aspect and being responsible for the potato snack is in the highest category consumption worldwide. Specifically in Colombia, fried potatoes are mostly consumed as potato chips (snacks) and 24.5–44.4% of the population between 5 and 64 years old consume them weekly (Ministerio de la Protección Social, 2011).

Fried foods are characterized by having a crunchy texture and a pleasant taste, producing satiety and being affordable, and easily acquired products (Gomez, Martinez, & Cardona, 2014). However, FAO and World Health Organization (WHO) indicate that a high consumption of fried foods involves a risk factor for health, because their intake is associated with diseases such as diabetes, heart disease, stroke, and cancer (OMS, 2018). This fact is mainly due to the high energy density and the content of toxic compounds such as trans fatty acids (Suaterna, 2009), cyclic fatty acids, polar compounds (Suaterna, 2009), and acrolein, which can generate a delay in growth in children and hepatotoxicity (Bejarano & Suarez, 2015). Another of the toxic compounds formed during the frying process is acrylamide, classified as probably carcinogenic to humans (group 2A) by the International Agency for Research on Cancer (IARC, 1994). The dietary exposure to acrylamide is associated to the development of some types of cancer, and for that reason, the presence of this compound in foods is a matter of public health (EFSA, 2015). Acrylamide is a highly reactive molecule that is generated in foods at a temperature above 120°C by the reaction between reducing sugars and amino acids, especially asparagine, which are naturally present in food. Acrylamide is mainly found in French fries, potato chips, bread and other bakery products, and coffee and coffee substitutes (EFSA, 2015).

Due to the health concern associated with the fat content and the presence of acrylamide, it is important to look for alternatives that lead to healthier and more safety fried foods. This will help to reduce the risks associated with cardiovascular diseases and the impact of contaminants on health, but maintaining their sensorial and textural characteristics. With this objective, the industry has used different pretreatments in foods such as drying, blanching, osmotic dehydration, and high hydrostatic pressure (HHP) among others (González, Bermúdez, & Morales, 2017). Currently, one of the most outstanding alternatives are the edible coatings (EC), which are defined as a continuous and thin matrix that is structured around the food generally by immersing it in a coating-forming solution (Fernández Valdés et al., 2015). The main function of the EC is to protect the product from mechanical, physical, chemical damages, and microbiological activities that deteriorate it (Falguera, Quintero, Jiménez, Muñoz, & Ibarz, 2011).

Several authors have reported the use of EC to reduce the presence of toxic or fatty compounds in different dietary matrices. De Grandi Castro Freitas et al. (2009) showed the reduction of fat absorption during the frying process of a frozen cassava product by means of coatings formulated with pectin, whey protein, and soy protein isolate. In a similar way, Albert and Mittal (2002) described the application of 11 hydrocolloids for the design of different EC to reduce the fat content in a cereal such as biscuit and cookies. Sothornvit (2011) obtained similar results in fried banana chips, who achieved a reduction in oil content in banana chips between 17–25%, using edible coatings made with guar gum or xanthan gum. However, Suyatma, Ulfah, Prangdimurti, and Ishikawa (2014) found that the use of hydrocolloids combined with the blanching of the banana, affected the reduction of the percentage of acrylamide in bananas chips. Regarding potato chips, Mallikarjunan, Chinnan, Balasubramaniam, and Phillips (1997), Zeng et al. (2010), Kim, Lim, Bae, Lee, and Lee (2011), Al-Asmar, Naviglio, Giosafatto, and Mariniello (2018) found that the coatings helped to reduce oil absorption. Zeng et al. (2010) compared the effects of eight hydrocolloids concluding that pectin, alginic acid, and xanthan gum significantly reduced the acrylamide formation in potato chips. Similar results have been presented by Kurek, Ščetar, and Galić (2017) and Mousa (2018) who found reductions between 33 and 45% for potato chips, using calcium caseinate and calcium pectinate, and gum Arabic as a coating, respectively. Another alternative for the reduction of acrylamide and fat absorption is the use of antioxidant extracts or polyphenols (Dueik & Bouchon, 2016Liu et al., 2015), which are natural compounds found in fruits (Silva & Sirasa, 2018), vegetables (Andarwulan et al., 2012), herbs and spices (Embuscado, 2015). In this sense, acrylamide formation has been reported to be reduced in French fries by the addition of polyphenolic extracts of grapes (Kalita, Holm, & Jayanty, 2013Xu et al., 2015) and rosemary extracts (Urbančič, Kolar, Dimitrijević, Demšar, & Vidrih, 2014).

Currently, there are no reports in the literature on the combined use of EC of whey with rosemary antioxidant extract for the reduction of acrylamide and fat in potato chips, and therefore, this study is a first contribution to the development of this type of applications. The objective of this research was to develop an edible coating made from concentrated whey protein added with rosemary extract, and to study the effect on the reduction of acrylamide and fat content in potato chips. The effect on the texture and sensory quality of the product was also evaluated using commercial and street vending samples as reference.

2 | MATERIAL AND METHODS

2.1 | Samples and chemicals

Raw potatoes used in this study were *Diacol Capiro* variety (same batch and brand), which were acquired in a local market. Commercial potato chips (same batch and brand) were also purchased in local market, whereas street vending samples were acquired in a potato stand close to the University. Chemicals included glycerol (PanreacQuímica, Spain), ascorbic acid (Hach), gelatin (Quala S.A., Colombia), and palm oil (C.I. Inversiones Americano S.A., Colombia). The concentrated whey protein powder (CWP 80%) and the rosemary fatty extract (*Rosemarinus officinalis* L.) were obtained from Tecnas SA (Medellín/Colombia).

2.2 | Sample treatment

Potatoes were washed with distilled water before peeling and cut into slices with a thickness of 1 ± 0.2 mm, using a manual cutting machine (Home Collection, Colombia). Subsequently, they were immersed in a solution of 0.05% ascorbic acid, with a potato/acid solution ratio of 2:10, for 15 min to avoid enzymatic browning. Once the contact time was over, the excess product solution was removed with the help of a disposable towel (Yu, Li, Ding, Hang, & Fan, 2016).

2.3 | Formulation and preparation of the coating

For the formulation and subsequent preparation of the coatings, the methodology proposed by De Grandi Castro Freitas et al. (2009) was followed, with some modifications. Initially, the concentrated whey protein (5, 8, or 11 g) was dissolved in 100 mL of distilled water, and 9 g of glycerol was added as a plasticizer. After that, the solution was heated in a water bath (Lauda, Germany) at 90 ± 2°C for 30 min.

In parallel, 2 g of gelatin were dissolved in 40 mL of distilled water. This solution was heated in a water bath for 8 min at 90 ± 2°C. Once the two solutions were prepared, they were mixed and homogenized in an Ultra Turrax disperser (Microdistech, MDT 1000) at a speed of 14,000 rpm for 60 s. Once the two solutions were prepared, the rosemary oily extract (7 g) was added, and then, the mixture was homogenized. Once the coatings were prepared, they were stored in glass jars at 4 ± 1°C until use.

2.4 | Application of the coating

The edible coating was applied to the potatoes according to the methodology proposed by De Grandi Castro Freitas et al. (2009). Briefly, each slice of potato was immersed in the coating for 15 s. Subsequently, the potatoes were dried in an oven (Binder, Model ED 115, Germany) with forced circulation for 35 min at 50 ± 2°C.

2.5 | Frying process

The frying process was carried out following the methodology of Rimac-Brnčić, Lelas, Rade, and Šimundić (2004), with some modifications. An electric fryer (Hamilton Beach, Model 35021) with a capacity of 2 L was used. A calibrated thermocouple was used to monitor the temperature of the frying oil. The ratio potato/oil palm was 1:21 in all frying treatments. Samples were fried for 120 s at temperatures ranging between 171 and 190°C, according to the experimental design shown in Table 1.

2.6 | Characterization of coated potato chips

2.6.1 | Physical–chemical characterization

For the characterization of the potato chips with coating, and commercial sample and street vending potato, the moisture and fat content was determined according to the AOAC (2005).

2.6.2 | Measurement of firmness

The firmness analysis included coated chips, as well as commercial potatoes and potatoes distributed in street vending. The firmness of the potato chips was determined using a texture analyzer (TAXT plus,

TABLE 1 Multilevel factorial experimental design and physical and physicochemical characterization of French fries with a coating based on whey protein and rosemary extract, commercial potatoes and street vending

Treatment	Frying temperature °C	Protein %	Rosemary extract %	Firmness N	Moisture %	Fat %	Acrylamide µg/kg
1	171	11	2	1.134 ± 0.189	6.7 ± 0.5	8.0 ± 0.1	186 ± 8
2	190	11	2	5.721 ± 1.763	9.3 ± 0.6	25.5 ± 0.3	292 ± 2
3	171	11	0	3.103 ± 0.573	4.6 ± 0.7	31.5 ± 0.9	451 ± 8
4	190	8	2	0.888 ± 0.444	11.4 ± 0.8	15.5 ± 0.2	296 ± 18
5	171	5	2	1.704 ± 0.874	8.3 ± 0.7	17.5 ± 0.8	131 ± 13
6	190	11	0	3.704 ± 0.947	5.9 ± 0.4	9.5 ± 0.4	650 ± 16
7	190	5	2	2.810 ± 0.767	19.7 ± 0.5	9.8 ± 0.3	229 ± 7
8	190	5	0	3.678 ± 1.097	5.3 ± 0.5	15.8 ± 0.7	485 ± 8
9	171	5	0	1.311 ± 0.080	33.4 ± 0.3	15.5 ± 0.1	138 ± 4
10	190	8	0	3.190 ± 0.953	11.5 ± 0.1	10.0 ± 0.8	320 ± 27
11	171	8	2	0.516 ± 0.075	5.0 ± 0.3	11.5 ± 0.5	146 ± 10
12	171	8	0	1.087 ± 0.834	16.7 ± 0.5	21.0 ± 0.9	86 ± 0.2
Commercial	—	—	—	3.500 ± 0.380	6.0 ± 0.2	17.5 ± 0.1	549 ± 72
Street vending	—	—	—	3.000 ± 0.670	5.5 ± 0.9	32.0 ± 0.9	233 ± 11

Stable Microsystems), as described by Yang, Achaerandio, and Pujolà (2016). The operating conditions used for the measurement were: pretest speed of 1 mm/s, test speed of 1 mm/s, posttest speed of 1 mm/s, distance of advance of 8 mm, and force of shot of 0.981 N. A SMS ball probe P/0.25s was also used.

2.6.3 | Determination of acrylamide

Acrylamide was determined as described by Mesías and Morales (2015). Grounded sample (0.500 g) was weighed and mixed with 9.4 mL of water in polypropylene centrifugal tubes. Two milliliters of hexane were added in the tubes to remove the fat content of the potato chips. Mixture was spiked with 100 μL of a 5 μg/mL [$^{13}C_3$]-acrylamide methanolic solution as internal standard and later homogenized (Ultra Turrax, IKA, Mod-T10 basic, Germany) for 10 min. Afterwards, sample was treated with 250 μL of each Carrez I (15 g potassium ferrocyanide/100 mL water) and Carrez II (30 g zinc acetate/100 mL water) solutions and centrifuged (9,000 *g* for 10 min) at 4°C. Hexane was removed, and samples were cleaned up by using of Oasis-HLB cartridges. Solution was filtered through a 0.45-μm filter into an amberlite LC-MS vial. Sample extracts and calibration standards were analyzed by LC-ESI-MS-MS, as described by Mesías and Morales (2015). The accuracy of this method for potato crisps has been recently demonstrated in three proficiency tests launched by the Food Analysis Performance Assessment Scheme (FAPAS) program, yielding a *z*-score of 0.2 (Test 3065, May–June 2016), −0.2 (Test 3071, Feb–March 2017) and −0.3 (Test 3080, Feb–March 2018). Precision (reproducibility) was lower than 10%, and recovery between 84 and 109%. The limit of the quantitation was set at 20 μg/kg. Analyses were performed in duplicate, and results were expressed as μg/kg of product. The determination of the acrylamide content was made to the coated potato chips, commercial potatoes and potatoes distributed in street vending.

2.6.4 | Determination of antioxidant capacity and total phenolic compounds

Sample preparation

The extraction of antioxidant compounds from potato chips and fresh potato was carried out following the methodology described by Contreras-Calderón, Guerra-Hernández, and García-Villanova (2009). Sample (1 g) was subjected to the extraction, and extract was stored at −18°C until use. Both extraction and measurements were made in triplicate.

ABTS

The analysis of ABTS was carried out according to Contreras-Calderón et al. (2009). One hundred microliters of extract diluted appropriately (1/10) with distilled water was used for the determination, and the absorbance was measured at 730 nm (Spectrophotometer UV-3300, Mapada Instruments). Aqueous solutions of Trolox (concentrations between 0 and 200 M) were used for the calibration. The results were expressed as micromoles of trolox equivalents (TE)/100 g of dry matter.

Total polyphenols

The content of total polyphenolic compounds was determined using the Folin–Ciocalteu method (Contreras-Calderón et al., 2016). The absorbance was measured at 725 nm (UV-3300 Spectrophotometer, Mapada Instruments). Aqueous solutions of gallic acid (concentrations between 0 and 1,000 mg/L) were used for the calibration. The results were expressed as milligram of gallic acid equivalents (GAE)/100 g of dry matter.

2.7 | Sensorial analysis

The sensorial evaluation was carried out in the Sensorial Food Analysis Laboratory of the University of Antioquia. Participants were trained judges, aged between 25 and 55 years. The test used was a sensory profile by multidimensional approach according to NTC 3932 of 1996, where descriptors of appearance, smell, taste, and texture were evaluated taking into account a rating scale of 0–5 (0 was absent and 5 was very intense). For the general quality descriptor, an acceptance scale of 1–3 was established, where 1 was the lowest quality and 3 was the highest. The sensory analysis was made to the commercial sample, and to the coated potato with lower content of acrylamide and fat, according to the experimental design.

2.8 | Statistical analysis

To analyze the effect of the application of the edible coating on the reduction of acrylamide and fat levels in potato chips, a multilevel factorial experiment design was applied. Three independent variables were evaluated: percentage of concentrated whey protein (5, 8, and 11%), percentage of rosemary extract (0 and 2%), and frying temperature (171°C and 190°C). Moisture, firmness, fat, and acrylamide content were analyzed as response variables. The data were analyzed by means of an ANOVA table with a level of significance of 95%. In addition, the main interactions of the factors on the analyzed responses were tested. All statistical analyses and graphic illustrations were studied using the statistical software STATGRAPHICS Centurion XVI. The experimental design is shown in Table 1.

3 | RESULTS AND DISCUSSION

3.1 | Physicochemical characterization of coated potato chips

Table 1 shows the results for the firmness, moisture, fat, and acrylamide values obtained for the different treatments. Figure 1A–D shows the main effects for each of the dependent variables studied in terms of the independent variables analyzed. Figure 2 represents the force–distance test to obtain the firmness values of the potato chips.

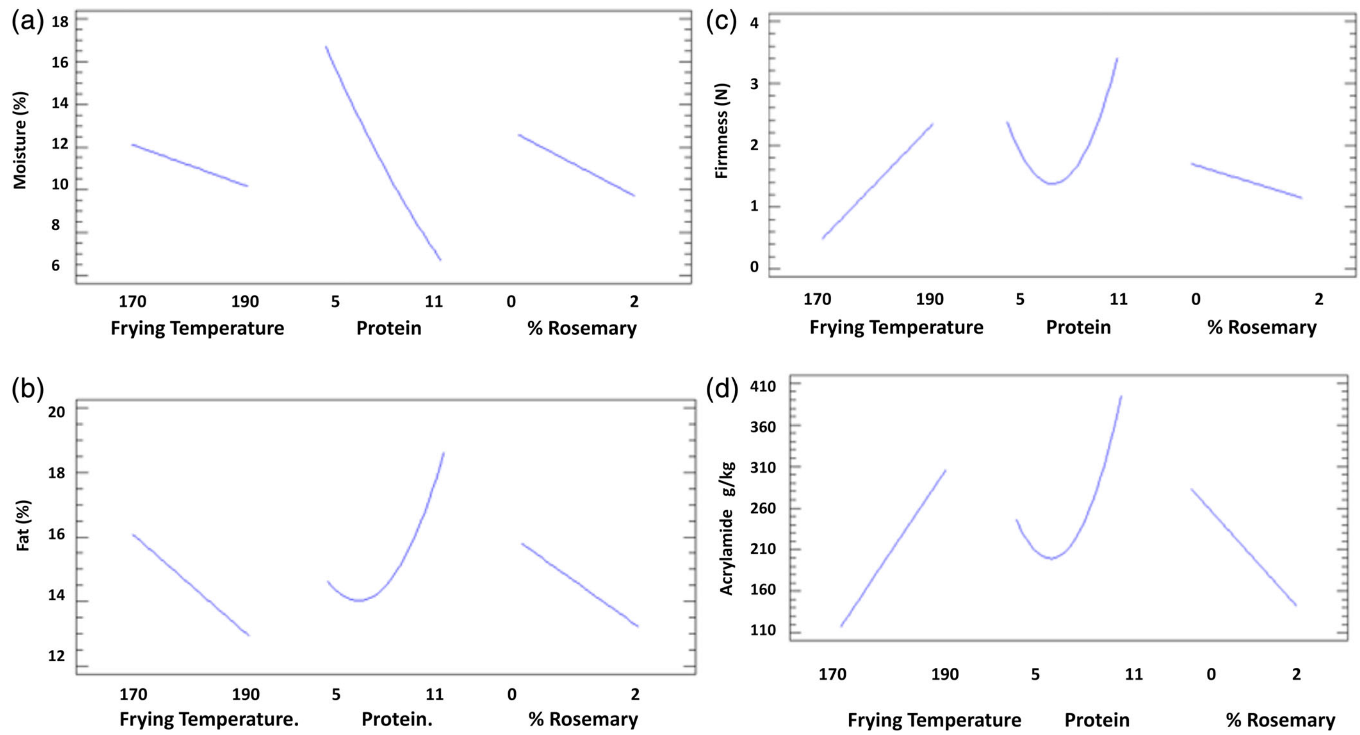

FIGURE 1 Effects of frying temperature, whey protein, and rosemary extract on (A) moisture, (B) fat, (C) firmness, and (D) acrylamide in French fries

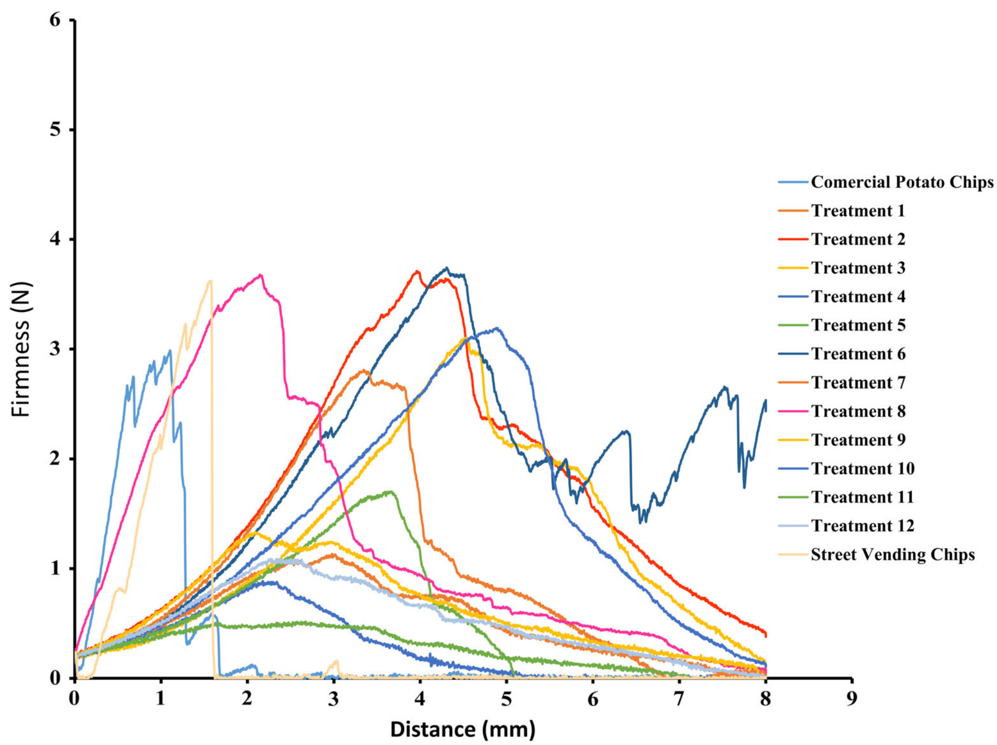

FIGURE 2 Force–distance test for the different treatments analyzed

3.1.1 | Moisture

The moisture values for potato chips ranged from 4.6 to 33.4% (Table 1). This range agrees with results found by Mousa (2018) in French fries coated with gum arabic and antioxidant extracts and by Aminlari, Ramezani, and Khalili (2005) in fried potatoes coated with concentrated whey protein and egg white. Different conditions did not significantly affect the moisture content of the potato (p > 0.05). However, as shown in Figure 1A, the higher frying temperature, protein level in the coating, and rosemary content involve the lower moisture content in potato chips. This finding is due to the fact that when the temperature increases, the evaporation rate of water increases, leading to lower moisture content (Alvis, Gonzalez, & Arrázola, 2001). In the case of the protein, on the one hand, higher processing temperatures induce denaturation by unfolding to form a network that traps water. Nevertheless, on the other hand, plasticization by water reduces protein–protein interactions, promotes mobility of the polymer chain, increases free volume, and as a result, increases the water diffusion, resulting then in reduced moisture in the final product (Kurek et al., 2017). Regarding the rosemary extract added to the coating, the higher lipid content partially changes the protein configuration, increasing its hydrophobic character on the surface (Djagny, Wang, & Xu, 2001). Guerrero, Nur Hanani, Kerry, and de la Caba (2011) reported that the films with higher hydrophobicity showed an increase in the speed of water diffusion. This interaction can favor the lower moisture content in the coated potato chips when the amount of rosemary extract added in the coating is increased (Figure 1A). Finally, moisture content for commercial and street vending chips was 5–6%, respectively.

3.1.2 | Fat

The fat content of potato chips subjected to the different treatments ranged between 8.0 and 31.5%. In general, this content was not significantly affected ($p > 0.05$) by the factors studied (frying temperature, protein, % rosemary). However, 8 of the 12 coated potatoes presented a fat content below that found in commercial chips (17.5%), and all of them were lower than the fat content observed in the street vending chips (32.0%). As depicted in Figure 1B, the fat content decreased at higher frying temperature, higher rosemary content, and lower protein level. Moyano and Pedreschi (2006) reported that the higher the frying temperature, the lower the fat content in potato chips, which is in accordance with the results found in this investigation. In that sense, Suaterna (2009) found that the fat absorption in plant structures decreases at frying temperatures between 180 and 200°C, a range close to the frying temperatures of the present study. This phenomenon occurs because the crust prevents the movement of the steam bubbles toward the medium, preventing the moisture of the food to be replaced by oil. In addition, the formation of the crust attributes properties to the food similar to those of an insulation material (Alvis et al., 2001). Therefore, fat content in the potatoes (Figure 1B). As described by Moreira, Sun, and Chen (1997), this finding can be probably explained due to the union between the polymer and the surface of the food was not adequate and perforations in the surface of the coating were formed favoring then the oil absorption because of high capillary forces. In contrast, it is possible that the coating based on whey protein was not sufficiently adhered to the potato. This behavior is described in Figure 1B. In contrast, Aminlari et al. (2005) found that potato chips with whey protein coating exhibited less oil. In summary, oil absorption is influenced by different factors such as the time and temperature of frying, the quality of the oil, the previous treatments, and the composition (both the coating and the food) (Kurek et al., 2017), and many of which were controlled in the present study.

3.1.3 | Firmness

Table 1 and Figure 2 show the different values for the firmness of the coated potato chips. In general, treatments 1, 4, 5, 9, and 11, reached values of threshold of creep (rupture of bark) between 0.5 and 2 N indicating a state of low rigidity and high weakness. The other treatments had a yield threshold between 3 and 4 N, being considered as rigid and fragile potato chips (Bourne, 2002). The firmness values obtained for street vending and commercial chips were on average 3 and 3.5 N (Table 1), respectively. These values were similar to those of treatments 3, 6, 7, 8, and 10. All the treatments presented micro fractures (Figure 2), which are a sign of crispy products (Bourne, 2002). The results obtained in the present study are in agreement with those reported by Granda, Moreira, and Tichy (2004), who analyzed this parameter in potatoes of the Atlantic variety, under traditional frying conditions, obtaining values of compression force between 3 and 4 N. In a similar way, Morales, Jimenez, Garcia, Remedios, and Ignacio (2014), reported firmness values between 3 and 5 N for French fries with added natural extracts.

Regarding the analysis of variance (ANOVA), none of the factors significantly affected the firmness ($p > 0.05$). However, a positive effect of the whey protein on the firmness of the potatoes was observed (Figure 1C). In this sense, higher whey protein content in the coating lead to greater values of the firmness in the chips, in agreement with the results obtained for treatments 2, 3, 6, 7, 8, and 10. It could be explained due to the whey protein has the capacity to form gel when subjected to heating temperatures. It increases the retention of water and the elasticity of the final product (Yamul, 2008) and makes the food harder and less crispy. Some authors affirm that the concentration of proteins is directly related to the firmness of the gels and, therefore, of the final product (Juárez et al., 2011). This agrees with the moisture values presented in Table 1 and with those reported by Lucas, Dumar, Vasco, and Cuellar (2011), who found values between 2 and 43%, for different treatments.

Similarly, the evaluation of the effect of rosemary extract content on the firmness of potato chips (Figure 1C) shows that the greater the presence of extract is, the lower the firmness. This happens because the interaction protein–extract induces a weakening of the protein–protein structure, causing less rigidity and therefore less firmness in the potato chips (Choulitoudi, Ganiari, Tsironi, & Ntzimani, 2017). In addition, increasing the frying temperature gives a greater firmness (Figure 1C), that can be attributed to dehydration occurring in shorter time. This fact causes a structural contraction, improving the interaction between plant walls and intensifying the firmness of the final product (Kalogianni & Papastergiadis, 2014).

Equation (1) shows the technological model obtained for the firmness of the potatoes with coating subjected to frying. The equation presents an R^2 of 75%, which can be used to predict the firmness according to the frying conditions.

$$F = 5.7783 - 3.8291P - 2.0231R + 0.0287T + 0.0217PR + 0.0075PT + 0.0087RT + 0.1639P^2 \tag{1}$$

(F): Firmness of potato chips; (P): percentage of concentrated whey protein; (R): percentage of rosemary extract; (T): frying temperature.

3.1.4 | Acrylamide

Table 1 shows the acrylamide values obtained for each treatment, which ranged between 86 and 650 μg/kg of sample. Values were below 750 μg/kg, which is the benchmark level indicated for potato chips by the EU Regulation 2158/2017 (European Commission, 2017). Acrylamide content in analyzed samples was similar to data reported by Pedreschi, Mariotti, Granby, and Risum (2011), who reduced the acrylamide content of potato chips (from 2047 to 158 μg/kg), applying some pretreatments including scalding and immersion in asparaginase solution. Jung, Choi, and Ju (2003) also demonstrated the reduction of acrylamide by 73%, using a pretreatment with citric acid solution. In contrast, acrylamide values in the present study were lower than those described by Urbančič et al. (2014), who found values in potatoes fried in sunflower oil that oscillate between 184 and 1,295 (μg/kg). In the present study, potatoes were immersed in an ascorbic acid solution at low concentration (0.05%) to avoid significant effects on the antioxidant capacity of the samples and as a consequence on acrylamide formation (Capuano, Oliveiro, Açar, Gökmen, & Fogliano, 2010).

The statistical analysis (ANOVA) showed that the acrylamide content was significantly affected by the frying temperature ($p < 0.05$) (Figure 1D). The heating conditions favor the dehydration of the product, and therefore, the substrates (carbonyl group—free amino acid) converge more easily. Gökmen, Palazoglu, and Senyuva (2006) suggest that temperatures above 150°C significantly promote the formation of acrylamide, although other authors establish the level at temperature around 175°C (Yasuhara, Tanaka, Hengel, & Shibamoto, 2003).

Figure 1D depicts that acrylamide content tends to decreases when the coating contains a higher percentage of rosemary extract; however, the changes were not significant ($p > 0.05$). This result is in agreement with the results reported by Urbančič et al. (2014), who found that the formation of acrylamide is reduced by about 38%, when rosemary extract was used frying sunflower oil. In that sense, the literature reports that natural antioxidants can interact with acrylamide precursors in two of the most important reactions that lead to their formation: the Maillard reaction and the oxidation of lipids (Ciesarová, Suhaj, & Horváthová, 2008). In the case of the Maillard reaction, a fragment of the reducing sugar present in the potato reacts with the conjugate system of polyphenols with antioxidant capacity of rosemary extract, thus preventing the sugar from binding with asparagine to form acrylamide (Schieberle, Kohler, & Granvogl, 2005). These results are in concordance with those reported by Jin, Wu, and Zhang (2013), who demonstrated that the acrylamide content was reduced in fried potato slices when rosemary herb was added to the olive oil. Similarly, Hedegaard, Granby, Frandsen, Thygesen, and Skibsted (2008) added aqueous extract, and these authors added aqueous extract of rosemary, rosemary oil, and dried rosemary leaves to a bread model, thus reducing the acrylamide content by 62, 67, and 57%, respectively, compared to bread without rosemary. In addition, Cheng, Chen, Zhao, and Zhang (2015) significantly reduced the formation of acrylamide by adding flavonoids in potatoes. However, several studies have described that the reduction in acrylamide formation is related to the presence of phenolic groups (Cheng et al., 2015; Zhu, Cai, Ke, & Corke, 2009), because they can precipitate amino acids (Jin et al., 2013). Equation (2) shows the technological model obtained for the content of acrylamide in coated potato chips, with an R^2 of 87%, which can be used to predict the acrylamide content according to the frying conditions.

$$\begin{aligned} A = & -2620,760 - 41,691\,(P) + 722,782\,(R) + 18,571\,(T) \\ & + 12,004\,(P^2) - 15,056\,(PR) - 0.612\,(PT) - 3,728\,(RT) \end{aligned} \tag{2}$$

3.2 | Determination of antioxidant capacity and total phenolic compounds

Taking into account the results obtained, the best treatment was number 7, as it promoted the lowest content of acrylamide and fat and potato chips exhibited firmness close to that of the commercial chips. For that reason, the effect of frying on antioxidant capacity and total polyphenols was only measured in this sample (Table 2).

The concentration of antioxidants in potato chips increased 1.8 times as compared with the raw potato, which may be due to the addition of the rosemary extract and Maillard reaction during processing (Contreras-Calderón et al., 2016). As demonstrated in previous studies (Capuano et al., 2010), the application of ascorbic acid solution at low concentration (0.05%) does not affect to the final antioxidant capacity of the treated samples. Values found in the present study were greater than those reported by Nemś and Pęksa (2018) who observed values from 68 to 90 μmol TE/100 g of dry matter in different varieties of potatoes grown in the Czech Republic. However, a higher content of antioxidants has been found in sweet potato varieties grown in Colombia (111–458 μmol TE/100 g of fresh weight) (Molina Cita et al., 2015), in purple potatoes that were processed by jet drying, with temperatures ranging from 50 to 80°C (4200–4,500 μmol TE/100 g of dry matter) (Qiu, Wang, Song, Deng, & Zhao, 2018) and in processed potatoes as crisp (1,000–6,500 μmol TE/100 g of dry matter) (Serpen & Gökmen, 2009).

However, values for total phenolic content of fresh potato decreased 2.1 times after frying (Table 2). These values are in the range reported in potatoes grown in Chile (from 191 to 1864 mg GAE/100 g) (Ah-Hen et al., 2012). These differences may be due to the type, conditions and agricultural practices of each crop, degree of maturation, and so on. In general, the antioxidant capacity can be increased by the addition of extract and the Maillard reaction,

TABLE 2 Antioxidant capacity (ABTS) and total phenolic content for the treatment 7 before and after frying

Analysis	Sample	Concentration/ 100 g dry matter
ABTS (μmol TE)	Fresh potato	688 ± 45
	Coated French fries	1,271 ± 102
Total phenolic content (mg AGE)	Fresh potato	518 ± 38
	Coated French fries	246 ± 5

Abbreviations: TE, Trolox equivalent; GAE, gallic acid equivalent.

although part of the natural polyphenols can be lost during the thermal treatment (Contreras-Calderón et al., 2016), and this occurred in this study after frying the coated potato chips. However, it is also reported that polyphenols react with reducing sugars to form other compounds that are not measured in the polyphenols determination (Ciesarová et al., 2008), suggesting that the concentration of phenolic compounds can decrease or increase (Taylor & Duodu, 2015).

3.3 | Sensorial analysis

The sensory evaluation was performed only to treatment 7 and to the commercial sample (Figure 3). The appearance parameter (Figure 3A), presented lower values respect to the commercial sample. It may be due to a low uniformity in color and irregularity in the form was observed. This result was also reported by Mousa (2018), who assured that the coated potatoes had a different appearance because of the higher moisture. However, this fact does not indicate a lack of acceptance by the consumer. The appearance of the potato is a frequent problem at industrial level, because it depends on the chemical composition of the tuber (reducing sugars). This composition, in turn, depends on many environmental and storage factors, because the reducing sugars determine the quality of the fried potato, providing a darker color and a bitter taste due to the participation in non-enzymatic browning reactions (Dilmer, 2007).

In the descriptors of odor (Figure 3B), the coated potato presented higher qualification in the oily, sweet, and toasted odor attributes, which is well perceived by the consumer (Mousa, 2018). In contrast, the commercial sample presented greater intensity in the rancid descriptor. Regarding flavor attributes (Figure 3C), the coated potato showed greater intensity in the flavor of potato starch, oily, toasted, and vegetable but without a rancid smell or flavor, which was described in the commercial potato which can be explained because it has been found that palm oil does not affect the organoleptic properties of fried foods (Pangloli, Melton, Collins, Penfield, & Saxton, 2002). However, in the texture attributes (Figure 3D), the coated sample had a higher score in the attributes of hard, rubbery, and chewy texture,

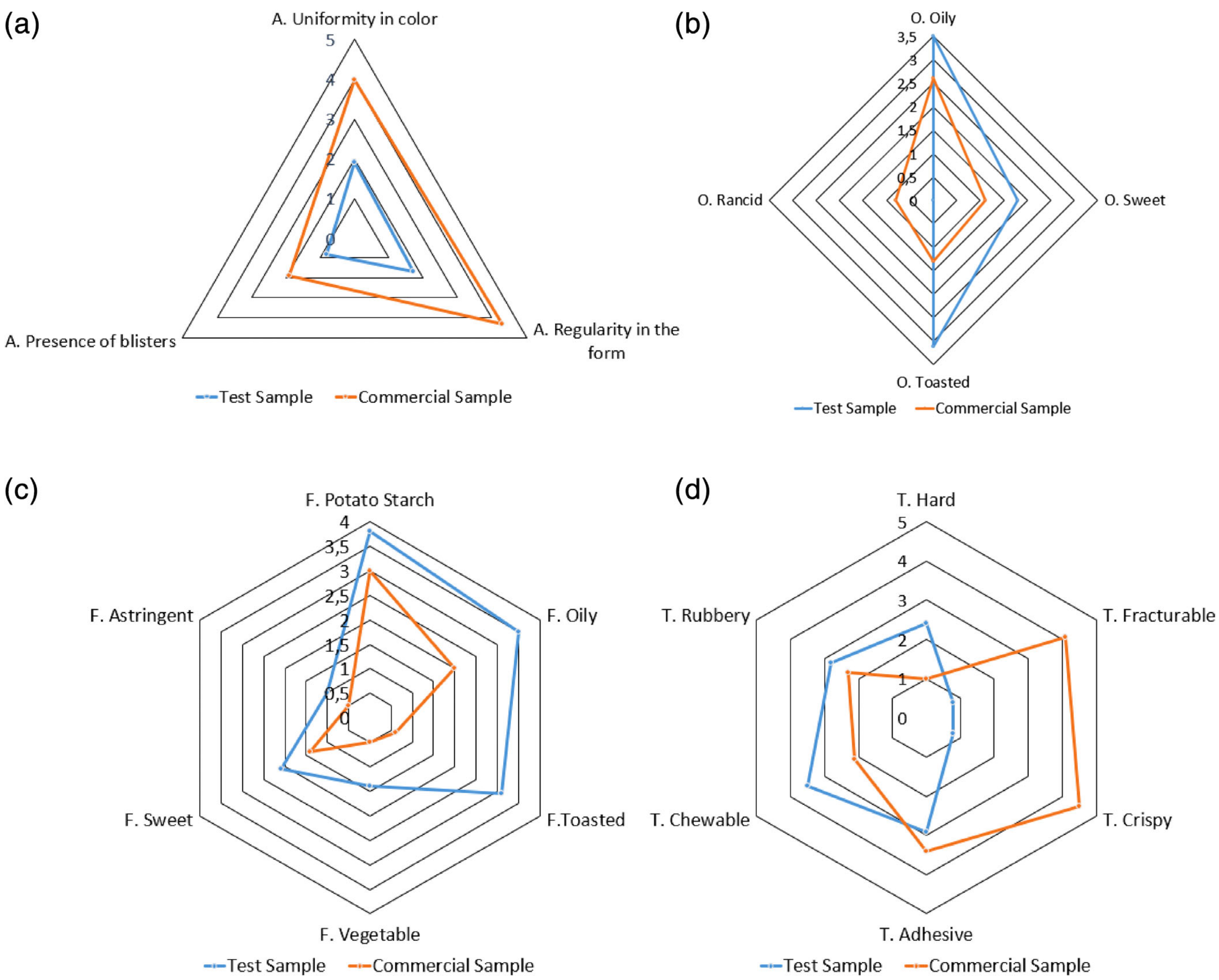

FIGURE 3 Sensory profile by multidimensional approach for treatment 7 and commercial sample: (A) appearance attributes, (B) odor attributes, (C) taste attributes, (D) texture attributes

whereas the commercial sample obtained a higher score in the attributes fracturable, crispy, and adhesive. It is mainly due to the coagulation of the proteins, the gelling of the starch, and the partial dehydration suffered by the product (Singh, Blaisdell, Herum, Stevens, & Cahill, 1985).

4 | CONCLUSIONS

An edible coating based on protein and rosemary antioxidant extract for potato chips was developed. In addition, the acrylamide content obtained in this research complies with the EU Regulation 2158/2017. On average, the protein content increased the firmness of the fried potato, having values similar to those from a commercial potato chip. The coating model allowed developing a potato chip with lower content of acrylamide and fat, preserving the sensory and textural properties of this type of products, and with a higher content of antioxidants. Despite more studies are required, the use of edible coatings with antioxidants may be a viable alternative for the reduction of acrylamide and fat content in potato chips, which contributes to the improvement of public health.

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