Effect of edible active coatings on quality of potato (*Solanum tuberosum* L.) strips after the frying process

Efeito de revestimentos ativos comestíveis na qualidade de batata (*Solanum tuberosum* L.) após fritura

Efecto de recubrimientos activos comestibles sobre la calidad de tiras de patata (*Solanum tuberosum* L.) después del proceso de fritura

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**ABSTRACT**
The present study evaluated the effect of active coverings based on gum arabic incorporated with protein hydrolysates and/or citric acid on the characteristics of fried potato (*Solanum tuberosum* L.) chips. After the minimum processing and whitening, different coatings were applied to the potatoes: control (without coating); 5% (w/v) gum arabic and 2% (w/v) protein hydrolysate with 10% degree of hydrolysis (DH); 5% (w/v) gum arabic and 2% (w/v) citric acid. Afterwards, the chips were vacuum-packed and stored at 4 °C. The different treatments were evaluated at time zero, 3, 5, 7 and 10 days of storage: *in natura*
for total aerobic mesophiles, moulds and yeasts, and thermotolerant coliforms; and characterised for colour ($L^*$, $a^*$, $b^*$), texture, moisture and lipids after frying at 180 °C for 5 min. The evaluated samples did not present thermotolerant coliforms (<0.03 MPN/g). Furthermore, the use of citric acid inhibited moulds and yeasts and delayed the multiplication of total aerobic mesophiles. Luminosity ($L^*$) was significantly reduced in the control treatment. Treatments with 5% (w/v) gum arabic and 2% (w/v) protein hydrolysate (10% and 20% DH, respectively) showed greater redness ($a^*$) and blueness ($b^*$) relative to the control. Applying protein hydrolysate-containing coatings to French fries led to lowered firmness, and reduced moisture and lipid contents at the end of storage. Thus, the coatings with added protein hydrolysates show a promising application in producing fried potato chips with reduced oil content.

**Keywords:** coating, gum arabic, hydrolyzate, peptides, lipid.

**RESUMO**

O presente estudo avaliou o efeito de revestimentos ativos à base de goma arábica incorporadas com hidrolizados proteicos e/ou ácido cítrico nas características de batatas palito fritas (*Solanum tuberosum* L.). Após o processamento mínimo e branqueamento, foram aplicados diferentes revestimentos nas batatas: controle (sem revestimento); 5% (m/v) de goma arábica e 2% (m/v) de hidrolisado proteico com 10% de grau de hidrólise (DH); 5% (m/v) de goma arábica e 2% (m/v) de hidrolisado proteico com 20% de DH; 5% (m/v) de goma arábica e 2% (m/v) de ácido cítrico. As batatas palito foram embaladas a vácuo e armazenadas a 4 °C. Os tratamentos (TT) foram avaliados nos tempos 0, 3, 5, 7 e 10 dias de armazenamento: *in natura* para mesófilos aeróbios totais, bolores e leveduras e coliformes termotolerantes; e caracterizados quanto à cor, textura, umidade e lipídios após fritura a 180 °C/5 min. As amostras não apresentaram coliformes termotolerantes (<0.03 NMP/g). Além disso, o uso de ácido cítrico inibiu bolores e leveduras e retardou a multiplicação de mesófilos aeróbios totais. A luminosidade foi significativamente reduzida no tratamento controle e os TT com 5% de goma arábica e 2% de hidrolisado proteico (10% e 20% DH, respectivamente) apresentaram maior vermelhidão e uma tendência ao azulamento em relação ao controle. A aplicação de revestimentos contendo hidrolisado levou à diminuição da firmeza e à redução do conteúdo de umidade e lipídios no final do armazenamento. Assim, os revestimentos com adição de hidrolizados proteicos apresentam uma aplicação promissora na produção de batata fritas com reduzido teor de óleo.

**Palavras-chave:** revestimentos, goma arábica, hidrolisados, pepetídeos, lipídios.

**RESUMEN**

El presente estudio evaluó el efecto de coberturas activas a base de goma arábiga incorporadas con hidrolizados de proteínas y/o ácido cítrico sobre las características de chips de papa frita (*Solanum tuberosum* L.). Luego del mínimo procesamiento y blanqueamiento, a las papas se les aplicaron diferentes recubrimientos: control (sin recubrimiento); 5% (p/v) de goma arábiga y 2% (p/v) de hidrolizado de proteínas con 10% de grado de hidrólisis (DH); 5% (p/v) de goma arábiga y 2% (p/v) de hidrolizado de proteínas con 20% de DH; 5% (p/v) de goma arábiga y 2% (p/v) de ácido cítrico. Posteriormente, los chips se envasaron al vacío y se almacenaron a 4 °C. Los diferentes tratamientos se evaluaron al tiempo cero, 3, 5, 7 y 10 días de almacenamiento: *in natura* para mesófilos aerobios totales, molhos y levaduras, y coliformes termotolerantes; y caracterizado por color ($L^*$, $a^*$, $b^*$), textura, humedad y lípidos después de freír a 180 °C.
durante 5 min. Las muestras evaluadas no presentaron coliformes termotolerantes (<0,03 NMP/g). Además, el uso de ácido cítrico inhibió mohos y levaduras y retrasó la multiplicación de mesófilos aeróbicos totales. La luminosidad (L*) se redujo significativamente en el tratamiento de control. Los tratamientos con 5% (p/v) de goma arábiga y 2% (p/v) de hidrolizado de proteína (10% y 20% DH, respectivamente) mostraron mayor enrojecimiento (a*) y azul (b*) en relación con el control. La aplicación de recubrimientos que contienen hidrolizado de proteínas a las patatas fritas redujo la firmeza y redujo el contenido de humedad y lípidos al final del almacenamiento. Por tanto, los recubrimientos con hidrolizados de proteínas añadidos muestran una aplicación prometedora en la producción de patatas fritas con contenido reducido de aceite.

**Palabras clave:** coberturas, goma arábiga, hidrolizados, péptidos, lípidos.

**1 INTRODUCTION**

The potato (*Solanum tuberosum* L.) is the fourth most consumed food in the world and is considered the most important olive grove in Brazil. The potato that is marketed in the *in natura* form has low commercial value and may present losses, due to physiological disorders and microbial deterioration (Endo *et al*., 2008; Quadros *et al*., 2009). Some processes, such as bleaching and applying coatings, are applied to increase the shelf life (Amaral *et al*., 2017; Hua *et al*., 2015). Minimally processed products can be defined as fruits or vegetables, or a combination of these, that have been peeled or chopped, for example, but maintain quality and freshness (Amaral *et al*., 2017). Processing promotes increased respiration and ethylene production, and the induction and synthesis of phenolic compounds for tissue healing (Moretti, 2007). One of the alternatives for the prolongation of the useful life of such products is the application of edible coatings (Alves *et al*., 2019; Amaral *et al*., 2017; De Araújo Faustino *et al*., 2021; Hua *et al*., 2015; Yu *et al*., 2016).

Currently, global consumption of potatoes as food is shifting from fresh potatoes, in home-made products, to value-added processed food products, such as potato chips. In developed countries, up to 60% of the potatoes consumed daily in the diet are in the form of processed products rather than in the original state (Bradsha; Ramsay, 2005; Pedreschi, Cortés and Mariotti, 2018). French fries are popularly consumed as fast-foods in many countries, including Brazil. The frying of the potato chips is conducted at 150–190 °C for a few minutes, causing physical–chemical and sensorial changes (Hua *et al*., 2015; Krokida, Oreopoulou and Maroulis, 2000).

During the frying process, a mass transfer occurs, represented mainly by the water evaporation (loss), oil absorption and heat transfer (Krokida *et al*., 2000; Yu *et al*., 2016).
This loss of water results in a significant absorption of oil, amounting to about 15–40% of the total weight of the product, which can cause an increase in health risks, such as cardiovascular problems and obesity, for the consumers of this product (Hua et al., 2015; Krokida et al., 2000; Sayon-Orea et al., 2014). As a result, the study of mechanisms that minimise this oil absorption is being carried out by applying edible coatings to products destined for frying (Hua et al., 2015; Varel. Fiszman, 2011; Yu et al., 2016). Some edible coatings, such as those based on hydrophilic polymers, are a good barrier to fats and oils. By frying these coated foods, the coating makes it difficult to absorb the oil, improving its nutritional qualities and reducing the caloric value, due to the low fat content of the final product (Varela; Fiszman, 2011).

Proteins and polysaccharides are commonly used to formulate edible coatings (Prentice-Hernández, 1994). Coatings based on polysaccharides, such as guar gum (Yu et al., 2016), pectin (Hua et al., 2015) and alginate (Amaral et al., 2017) have been applied to the surface of potatoes to minimise oil absorption. These polymers have high water retention capacity and can effectively inhibit moisture evaporation, thereby reducing lipid uptake (Hua et al., 2015).

Gum arabic is a polysaccharide, with excellent ability to form a polymeric matrix (Ali et al., 2013; Cai et al., 2014; Murmu; Mishra, 2018). Gum arabic is obtained from stems or branches of Acacia species and is commonly used in the food industries, due to its toxicological safety. Moreover, all its components consist of multiple polar groups (−OH and C=O) (Murmu; Mishra, 2018).

The incorporation of fish protein hydrolysates or other bioactive compounds into coatings may contribute to the reduction of enzymatic browning and microbial degradation, attributed to their antioxidant and antimicrobial action (Da Rocha et al., 2018). In this context, the present study applied active coatings based on gum arabic incorporated with protein hydrolysates and/or citric acid to raw potato (S. tuberosum L.) chips and evaluated the effect of the coatings on the chips after the frying process.

2 MATERIAL AND METHODS

2.1 MATERIAL

The potatoes (S. tuberosum Asterix) and soybean oil (Imcopa, Brazil) were purchased from producers in the city of São José do Norte (latitude: 32º00'53"S;
longitude: 52°02'30"W), Brazil. Argentine croaker (*Umbrina canosai*) was supplied by the fishing industry of Rio Grande, Brazil. Analytical grade gum arabic and glycerol were purchased from Synth (Brazil). The enzyme Alcalase was kindly supplied by Novozymes (Araucária, Brazil). The other reagents used were of analytical grade.

2.2 OBTAINING MYOFIBRILLAR FISH PROTEIN

The myofibrillar fish (*U. canosai*) proteins (MFP) were obtained by successive washes in distilled water and brine (50 mM NaCl), cooled according to the method described by Limpan, Prodpran, and Benjakul Prasarpran (2010), with modifications. The wet MFP was lyophilised (L108, Liotop freeze dryer, San Carlos, Brazil) at –55 °C and 50 μHg for 48 h, comminuted using a knife mill (Tecnal, TE-633, Piracicaba, Brazil), sieved through a 42-mesh sieve (0.35 mm) (Bertel, Caieiras, Brazil) and stored at –18 °C until use.

2.3 OBTAINING THE PROTEIN HYDROLYSATES

The MFP was enzymatically hydrolysed, as described by Raghavan and Kristinsson (2009) and accompanied by the pH-stat method, with modifications. Briefly, MFP was homogenised in distilled water at a ratio of 2% (w/v; protein/distilled water) in a jacketed glass reactor coupled to an ultrathermostatic bath (Q212S, Quimis, Diadema, Brazil) under constant stirring in a shaker (Marconi, Piracicaba, Brazil) at 300 rpm. The conditions of the protein dispersions were adjusted to the optimum parameters for Alcalase (pH 8 and 50 °C) for 10 min. Enzymatic hydrolysis was initiated by addition of the enzyme in the proportion of 30 U/g protein, according to the specific activity (13.3 U/mg protein) determined by the method described by Sigma (2013). The degree of hydrolysis (DH) was monitored according to Adler-Nissen (1986). The enzymatic hydrolysis was conducted until the desired DH was reached, 10 or 20% according to data reported by Da Rocha *et al.* (2018).

2.4 MINIMUM PROCESSING OF POTATOES

The potatoes of the Asterix cultivar were minimally processed, as detailed by Endo *et al.* (2008), with temperature modification to 18 °C. The selected potatoes were
washed with drinking water, sanitised with chlorinated water (200 ppm NaOHCl) at 4 °C for 10 min, and manually peeled with sterile stainless-steel knives. The potatoes were reduced to a size of 10 mm × 10 mm × 70 cm, with the aid of a manual slicer, dipped rapidly into potable water at 4 °C, sanitisation in chlorinated water at 5 ppm for 10 min, and then rinsed in potable water at 4 °C. The potato chips were bleached by immersion in hot water at 85 °C for 4 min and cooled by immersion in potable water at 4 °C. Excess water was withdrawn using disposable absorbent paper.

2.5 ELABORATION OF ACTIVE COATINGS

Active gum arabic coatings were prepared from the dispersion of 5 g gum arabic in 100 mL of distilled water at 40 °C for 90 min (Murmu; Mishra, 2017). Glycerol (8%, w/v) was added as a plasticiser. Then, 2% (w/v) MFP protein hydrolysates (10 and 20% DH) or 2% (w/v) citric acid were added, respectively.

2.6 APPLICATION OF COATINGS

Based on preliminary tests, the minimally processed and bleached potatoes were immersed in the different coatings: control (no coating); 5% (w/v) gum arabic and 2% (w/v) protein hydrolysate with 10% DH (GAH10); 5% (w/v) gum arabic and 2% (w/v) protein hydrolysate with 20% DH (GAH20); 5% (w/v) gum arabic and 2% (w/v) citric acid (GACA); for 2 min, based on Amaral et al. (2017). The coated potato strips were kept in a forced air circulation oven at 40 °C for 20 min to eliminate excess filmogenic solution and packaged (200 g) in ethylene vinyl alcohol packs of nylon–high-density polyethylene. Prior to sealing, the air was automatically removed by vacuum (Selovac, Brazil) for 45 s. The potatoes were stored at 4 °C and evaluated at times zero, 3, 5, 7 and 10 days of storage.

2.7 MICROBIOLOGICAL ANALYSES

The effect of the different coatings on the useful life of minimally processed potato chips was evaluated, in triplicate, at times zero, 3, 5, 7 and 10 days of storage, according to the standard method of the American Public Health Association (APHA, 2001). 25 g of the potato chips were transferred to a sterile blender with 225 mL of 0.1%
(w/v) sterile peptone water (Himedia, India), and homogenised at room temperature for 2 min. Appropriate dilutions were subsequently prepared for the following bacteriological determinations: (i) total aerobic mesophiles using the pour plate method in plate count agar (Oxoid, England) and incubation at 35 °C for 48 h; (ii) moulds and yeasts using the spread plate technique in potato dextrose agar and incubation at 25 °C for 3–5 days; (iii) thermotolerant coliforms, using the most-probable-number (MPN) technique, also known as the multi-tube method, in sodium lauryl sulphate broth and EC broth. The microbiological count (total aerobic mesophiles, and moulds and yeasts) was expressed as log colony-forming units per gram of sample (log CFU/g).

2.8 FRYING PROCESS

After storage at 4 °C for zero, 3, 5, 7 and 10 days, the coated and uncoated potatoes (control) were fried using a potato: soybean oil ratio of 1:30 (w/v) at 180 °C for 5 min in a thermostatically-controlled fryer filled with 3 L of soybean oil, as described by Yu et al. (2016). All fried potato chips were drained for 1 min and cooled to room temperature before each analysis.

2.9 CHARACTERISATION OF FRIED POTATO CHIPS

2.9.1 Colour

The colour of the shoestring potatoes was determined in triplicate by recording the International Commission on Illumination (CIE) colour coordinates ($L^*$, $a^*$, $b^*$), measured using a chromometer (Minolta CR-400, Osaka, Japan), as described elsewhere (ICD, 1986). In this three-dimensional system, luminosity ($L^*$) is achromatic and ranges from 0 (black) to 100 (white); $a^*$ = greenness–redness ($-a^*$: green; $+a^*$: red); and $b^*$ = blueness–yellowness ($-b^*$: blue; $+b^*$: yellow).

2.9.2 Texture

The firmness was determined by using a texture analyser (TA.XTplus, Stable Micro Systems, Surrey, UK), as reported by Hua et al. (2015), modified by using the HBS-5S probe at room temperature. During the test, the probe was programmed to move
5.0 mm at a speed of 5 mm/s to break the potato chips. For each treatment, six potato chips were evaluated.

2.9.3 Determination of lipids and moisture

The effect of the different coatings on oil absorption (method 925.30) and moisture (method 960.39) were assessed, by adopting the standard methods of analysis (AOAC, 2000).

2.10 Statistical analysis

All the results were submitted to analysis of variance (ANOVA), and the means were compared by Tukey’s test at the 5% level of significance, using Statistica version 5.0 (StatSoft, Inc., Tulsa, OK, USA).

3 RESULTS AND DISCUSSION

3.1 MICROBIOLOGICAL ANALYSES

Antimicrobial peptides are being studied as an alternative to the synthetic compounds used in food preservation (Jiang et al., 2014; Kim et al., 2017; Najafian; Babji, 2012; Sila et al., 2014). These peptides generally have low molecular mass, are cationic, and about 50% are hydrophobic (Najafian; Babji, 2012).

Some studies have investigated the use of protein hydrolysates and other compounds as active agents in food systems or biodegradable films (Gómez-Guillén et al., 2009; Rocha et al., 2018). For this reason, the MFP protein hydrolysates were incorporated into gum arabic-based formulations for the application as edible coatings to reduce the oil uptake in French fries. Table 1 shows the results of the counts of total aerobic mesophiles, moulds and yeasts, and thermotolerant coliforms.

On the different days of analysis, it was found that the sample count was <0.03 MNP/g for all treatments evaluated. These values, related to the microbiological quality of the French fries, were below the limit recommended by the Resolution of the Collegiate Board of Directors No. 12 of the National Sanitary Surveillance Agency, indicating that the product elaborated is appropriate for consumption (BRASIL, 2001). The adequate
hygienic-sanitary practices, such as the use of sterile utensils and sanitisation with chlorinated water are likely to have led to these results. In addition, the potatoes of all treatments were bleached, which reduced the surface microbial load. Chhe et al. (2018) described bleaching as a heat treatment operation that besides inactivating enzymes, may decrease the surface microbial load.

At zero storage time, the microbial multiplication of the total aerobic mesophiles was not verified. At the end of the 10th day of storage, treatments GAH10 (3.89 log CFU/g) and GAH20 (3.40 log CFU/g) presented a significantly higher count than the other treatments tested \((p < 0.05)\). The GACA treatment was effective in inhibiting the multiplication of total aerobic mesophiles, suggesting that citric acid migrated easily to the food surface, delaying microbial propagation.

A similar result was found by Endo et al. (2008), who used cellulosic films incorporated with citric acid for the prolongation of the useful life. Citric acid is an organic acid that can retard and/or prevent the essential reactions within the cells of the

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Days</th>
<th>Control</th>
<th>GAH10</th>
<th>GAH20</th>
<th>GACA</th>
</tr>
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<tbody>
<tr>
<td>Total aerobic mesophiles</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Log UFC/g</td>
<td>3</td>
<td>2.12 ± 0.23Bc</td>
<td>1.57 ± 0.36Cc</td>
<td>2.58 ± 0.04Ab</td>
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<tr>
<td></td>
<td>5</td>
<td>3.14 ± 0.05Ab</td>
<td>3.02 ± 0.03Bb</td>
<td>2.20 ± 0.04Cd</td>
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<tr>
<td></td>
<td>7</td>
<td>3.53 ± 0.18Aa</td>
<td>3.22 ± 0.11Ab</td>
<td>2.32 ± 0.00Bc</td>
<td>3.41 ± 0.12Ab</td>
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<tr>
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<td>10</td>
<td>2.91 ± 0.19Bb</td>
<td>3.89 ± 0.04Aa</td>
<td>3.40 ± 0.00Ab</td>
<td>2.06 ± 0.51Ch</td>
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<tr>
<td>Moulds and yeasts</td>
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<td>2.45 ± 0.21Ac</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Log UFC/g</td>
<td>3</td>
<td>2.55 ± 0.11Ac</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
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<td>-</td>
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<td></td>
<td>7</td>
<td>3.90 ± 0.26Ab</td>
<td>3.61 ± 0.30Ab</td>
<td>2.90 ± 0.52Bb</td>
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<tr>
<td></td>
<td>10</td>
<td>5.14 ± 0.01Ba</td>
<td>5.11 ± 0.05Ba</td>
<td>6.04 ± 0.03Ba</td>
<td>-</td>
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<tr>
<td>Fecal coliforms</td>
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<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
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<tr>
<td>MPN/g</td>
<td>3</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
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<td></td>
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<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
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<tr>
<td></td>
<td>7</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
<td>&lt; 0.03</td>
</tr>
</tbody>
</table>

No multiplication; MPN: most probable number. Control (no coating); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) protein hydrolysate with 10% DH (GAH10); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) protein hydrolysate with 20% DH (GAH20); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) citric acid (GACA). Equal capital letters on the same line indicate that there is no significant difference \((p > 0.05)\) for the same storage day between the different samples. Equal lowercase letters in the same column indicate that there is no significant difference \((p > 0.05)\) for the same treatment between the different storage days.

Source: Authors.
microorganism by adding H\(^+\) ions, decreasing the intracellular pH, causing loss of cell viability (Manab et al., 2011).

The same behaviour was observed for the count of moulds and yeasts, as shown in Table 1, where GACA was significantly more effective (\(p < 0.05\)) than the other evaluated treatments in inhibiting these microorganisms. Other treatments with active coatings containing protein hydrolysates (GAH10 and GAH20) inhibited the growth of moulds and yeasts up to the 5th day of storage only. These data highlighted the antimicrobial action of citric acid, which has been verified in many studies investigating the application of coatings and films incorporated with different organic acids to several types of products (Endo et al., 2008; Manab et al., 2011; Mani-López, García, & López-Malo, 2012). Da Rocha et al. (2018) evaluated the antimicrobial effect of MFP protein hydrolysates on 26 different microorganisms, and also did not verify the impact on moulds and yeasts.

3.2 COLOUR

Colour is an important parameter in food quality, such as French fries. The colour change during the frying process occurs due to the Maillard reaction, a non-enzymatic darkening, which depends on the content of reducing sugars and amino acids or proteins on the surface of potato chips, as well as the temperature and frying time (Hua et al., 2015). Table 2 shows the colour (\(L^\ast, a^\ast, b^\ast\)) of the fried potatoes. In the present study, the initial luminosity (\(L^\ast\)) of 72.32 decreased to 68.53 \(L^\ast\) in the control (\(p < 0.05\)), implying that these fries underwent more advanced Maillard reactions during frying when compared with the other treatments.

Conversely, at zero storage time, it was verified that all coated potatoes presented inferior luminosity (\(p < 0.05\)) to the control. Treatments GAH10 and GAH20 have different types of amino acids, as reported by Da Rocha et al. (2018). As mentioned by Garcia-Amezquita et al. (2014), the Maillard reaction is a series of naturally occurring chemical reactions between the amino group of an amino acid, peptide or protein and the carbonyl group of a reducing sugar, resulting in a darkening processes. However, in the present study, the influence of the addition of the hydrolysates on the luminosity of fried potato chips was not verified. Hua et al. (2015) prepared coatings based on pectin and found a luminosity (\(L^\ast\)) of approximately 66.0 for fried potato chips, similar to that found in the present research for coated potatoes.
Table 2 – Color of potatoes strips after frying process

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Days</th>
<th>Control</th>
<th>GAH10</th>
<th>GAH20</th>
<th>GACA</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*</td>
<td>0</td>
<td>72.32 ± 0.33&lt;sup&gt;Ab&lt;/sup&gt;</td>
<td>65.46 ± 1.87&lt;sup&gt;Bb&lt;/sup&gt;</td>
<td>66.08 ± 2.94&lt;sup&gt;Ba&lt;/sup&gt;</td>
<td>68.79 ± 0.94&lt;sup&gt;Ba&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>74.97 ± 0.94&lt;sup&gt;Ac&lt;/sup&gt;</td>
<td>68.05 ± 3.07&lt;sup&gt;Bab&lt;/sup&gt;</td>
<td>69.53 ± 2.78&lt;sup&gt;Ba&lt;/sup&gt;</td>
<td>68.59 ± 1.51&lt;sup&gt;Ba&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>72.50 ± 0.87&lt;sup&gt;Ab&lt;/sup&gt;</td>
<td>66.09 ± 3.23&lt;sup&gt;BA&lt;/sup&gt;</td>
<td>66.22 ± 1.74&lt;sup&gt;Ba&lt;/sup&gt;</td>
<td>69.54 ± 3.40&lt;sup&gt;BA&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>71.11 ± 1.79&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>70.28 ± 1.82&lt;sup&gt;Aa&lt;/sup&gt;</td>
<td>54.77 ± 1.44&lt;sup&gt;BA&lt;/sup&gt;</td>
<td>64.47 ± 1.20&lt;sup&gt;Aa&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>68.53 ± 0.80&lt;sup&gt;Ac&lt;/sup&gt;</td>
<td>70.80 ± 0.39&lt;sup&gt;AA&lt;/sup&gt;</td>
<td>68.63 ± 0.64&lt;sup&gt;BA&lt;/sup&gt;</td>
<td>71.75 ± 2.28&lt;sup&gt;BA&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>-3.10 ± 0.38&lt;sup&gt;Cc&lt;/sup&gt;</td>
<td>-1.53 ± 0.10&lt;sup&gt;Ab&lt;/sup&gt;</td>
<td>-1.02 ± 0.14&lt;sup&gt;AA&lt;/sup&gt;</td>
<td>-1.40 ± 0.44&lt;sup&gt;Ba&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-3.56 ± 0.29&lt;sup&gt;BCC&lt;/sup&gt;</td>
<td>-2.80 ± 0.16&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>-4.61 ± 0.84&lt;sup&gt;CD&lt;/sup&gt;</td>
<td>-0.25 ± 0.00&lt;sup&gt;Ab&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-1.72 ± 0.14&lt;sup&gt;CC&lt;/sup&gt;</td>
<td>-1.78 ± 0.56&lt;sup&gt;Cb&lt;/sup&gt;</td>
<td>0.55 ± 0.30&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>-0.76 ± 0.01&lt;sup&gt;Ba&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Parameter <sup>a</sup>* was significantly higher (<i>p</i> < 0.05) for treatments GAH10 (<sup>a</sup>* = –1.53) and GAH20 (<sup>a</sup>* = –1.02) in relation to the other treatments at zero storage time, implying that the fried potato chips that were coated with the protein hydrolysate formulations were less green. However, throughout the storage time, the fried potato chips coated by these treatments presented an increase in green intensity, resulting in a decrease of the parameter <sup>a</sup>*. The fried potato chips coated by the different treatments (GAH10, GAH20, GACA) had a higher <sup>b</sup>* value than the uncoated potatoes at zero storage time. The golden colour of the surface developed during frying is mainly related to yellowing (Mousa, 2018).

### 3.3 FIRMNESS

Cutting strength and crispness are important texture parameters for fried potato chips (Mousa, 2018). Table 3 reports the texture values for fried potato chips. At the zero storage time, the potatoes of treatments GAH10 (12.21 N), GAH20 (17.52 N) and GACA (15.52 N) presented greater firmness (<i>p</i> < 0.05) than the control (8.91 N), which could
result from the formation of a crust, due to the presence of the coatings. The same behaviour was observed in the study by Mousa (2018).

Table 3 - Firmness of fried potato strips with or without coatings

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Days</th>
<th>Control</th>
<th>GAH10</th>
<th>GAH20</th>
<th>GACA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firmness (N)</td>
<td>0</td>
<td>8.91 ± 2.13&lt;sup&gt;CD&lt;/sup&gt;</td>
<td>12.51 ± 1.48&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>17.52 ± 1.68&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>15.53 ± 1.26</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11.94 ± 0.97&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>21.87 ± 1.95&lt;sup&gt;BB&lt;/sup&gt;</td>
<td>16.11 ± 0.46&lt;sup&gt;BC&lt;/sup&gt;</td>
<td>30.95 ± 2.34</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>16.30 ± 3.36&lt;sup&gt;CC&lt;/sup&gt;</td>
<td>30.18 ± 0.82&lt;sup&gt;Aa&lt;/sup&gt;</td>
<td>22.20 ± 1.82&lt;sup&gt;BB&lt;/sup&gt;</td>
<td>23.77 ± 1.52</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>20.70 ± 0.54&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>20.74 ± 2.30&lt;sup&gt;ABB&lt;/sup&gt;</td>
<td>26.97 ± 1.96&lt;sup&gt;AA&lt;/sup&gt;</td>
<td>24.79 ± 1.52</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>25.15 ± 1.19&lt;sup&gt;Aa&lt;/sup&gt;</td>
<td>20.12 ± 0.89&lt;sup&gt;Bb&lt;/sup&gt;</td>
<td>20.27 ± 1.57&lt;sup&gt;BB&lt;/sup&gt;</td>
<td>26.05 ± 1.52</td>
</tr>
</tbody>
</table>

Control (no coating); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) protein hydrolysate with 10% DH (GAH10); 5% (w/v) gum Arabic, glycerol (8%, w/v)n and 2% (w/v) protein hydrolysate with 20% DH (GAH20); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) citric acid (GACA). Equal capital letters on the same line indicate that there is no significant difference (p> 0.05) for the same storage day between the different samples. Equal lowercase letters in the same column indicate that there is no significant difference (p> 0.05) for the same treatment between the different storage days.

Source: Authors.

The bleaching temperature influences the softening and tissue texture, due to gelatinisation of potato starch (Amaral et al., 2017). In the present study, the control at zero storage time, exhibited greater firmness (8.91 N) than that verified by Amaral et al. (2017) for fried Asterix potatoes, bleached and vacuum-packed (1.1 N).

Yu et al. (2016) found that a coating of guar gum and glycerol enhanced the firmness of fried potatoes coated, possibly related to the adhesion of guar gum and glycerol. Some hydrocolloids and/or hydrophilic polymers are widely used as coating-forming solutions for controlling and preserving the texture, among other properties (Varela; Fiszman, 2011). At the end of the 10th day of storage, it can be verified that the fries coated with protein hydrolysates were less firm than those without coating (control) and GACA ($p < 0.05$), which may be due to the characteristics of the added hydrolysates.

Nuanmano, Prodpran, and Benjakul (2015) mentioned that short-chain peptides could act as plasticisers in filmogenic solutions, reducing the interaction between the polymers by increasing the free volume between them. Consequently, the incorporation of protein hydrolysates may have contributed to the greater flexibility of the coating by reducing the firmness of the chips coated by these treatments.

3.4 ASSESSMENT OF LIPID AND MOISTURE CONTENTS

During the frying process, the moisture content of the potatoes can decrease with the consequent absorption of the oil. Furthermore, the evaporation of water will also lead
to the development of shrinkage and surface roughness of the fried potato chips (Hua et al., 2015; Yan et al., 2015). Table 4 displays the lipid and moisture contents of the coated and uncoated fried potato chips.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Days</th>
<th>Control</th>
<th>GAH10</th>
<th>GAH20</th>
<th>GACA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>0</td>
<td>55.5 ± 1.1bAa</td>
<td>59.1 ± 2.1Aa</td>
<td>57.0 ± 2.0bBb</td>
<td>55.2 ± 2.2Baa</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>53.7 ± 3.1Aa</td>
<td>55.8 ± 0.5Ab</td>
<td>48.7 ± 1.3bBb</td>
<td>52.0 ± 2.3Aba</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>51.49 ± 0.8Aa</td>
<td>49.2 ± 0.9Abc</td>
<td>51.52 ± 1.6Ab</td>
<td>47.9 ± 1.7Bb</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>50.3 ± 1.9BCa</td>
<td>55.9 ± 0.5Ab</td>
<td>47.9 ± 1.2Cb</td>
<td>51.4 ± 0.5Bb</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>51.1 ± 3.7Aa</td>
<td>51.6 ± 1.15Ac</td>
<td>50.9 ± 2.5Ab</td>
<td>53.9 ± 1.7Ab</td>
</tr>
<tr>
<td>Lipids (%)</td>
<td>0</td>
<td>20.8 ± 0.8Aab</td>
<td>19.6 ± 0.8Aa</td>
<td>12.4 ± 0.3Bb</td>
<td>14.1 ± 0.2Bb</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11.1 ± 1.5Ac</td>
<td>9.4 ± 0.4Ad</td>
<td>9.9 ± 0.7Abc</td>
<td>10.9 ± 0.9Ac</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>9.5 ± 0.3Ac</td>
<td>9.7 ± 0.9Ad</td>
<td>9.8 ± 0.5Ac</td>
<td>10.1 ± 0.9Ac</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>17.4 ± 0.8Ab</td>
<td>17.1 ± 1.2Ab</td>
<td>10.5 ± 0.2Bbc</td>
<td>10.7 ± 0.5Bc</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>21.9 ± 1.4Aa</td>
<td>12.4 ± 1.1Bcd</td>
<td>11.4 ± 0.2Bbc</td>
<td>20.4 ± 0.9Ab</td>
</tr>
</tbody>
</table>

Control (without coating); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) protein hydrolysate with 10% DH (GAH10); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) protein hydrolysate with 20% DH (GAH20); 5% (w/v) gum Arabic, glycerol (8%, w/v) and 2% (w/v) citric acid (GACA).

Equal capital letters on the same line indicate that there is no significant difference (p > 0.05) for the same storage day between the different samples. Equal lowercase letters in the same column indicate that there is no significant difference (p > 0.05) for the same treatment between the different storage days.

Source: Authors.

At zero storage time, the control and GAH10 were found to have a significantly higher moisture content (p < 0.05) than GAH20 and GACA. However, at the end of the 10th day of storage, the moisture contents were similar among all treatments (p > 0.05). In addition, all treatments, except for GACA, had reduced moisture content (p < 0.05). Polysaccharides used as coatings act as a barrier to water evaporation (Archana et al., 2016), because of their hydrophilicity, and thereby are capable of binding to water, increasing the water content of the product.

As mentioned above, at the end of the 10th day of storage, the protein hydrolysate treatments (GAH10 and GAH20) were found to have a reduction in moisture content (p < 0.05). According to Rocha et al. (2018), protein hydrolysates have a high content of hydrophobic amino acids, which may have contributed to this effect over time (storage). Many studies (Ajo, 2017; Hua et al., 2015; Mousa, 2018; Yu et al., 2016) noted that the use of polysaccharides contributed to the maintenance of water content in fried potato chips, due to their hydrophilic nature.

Angor (2016) suggested that the decrease in oil absorption may be related to the formation of covalent bonds in the coating during heating (frying). In the present study, as observed in Table 4, from time zero to day 7, there was a significant (p < 0.05) decrease
in lipid content of the coated fried potato chips, but this behaviour was not verified for the treatment. Hence, the coatings seemed to contribute to this behaviour during storage. Yu et al. (2016) confirmed a reduction of 51.8% in the lipid content of potato chips at the end of storage time, afforded by applying coatings of guar gum and glycerol blend compared with the uncoated and guar gum-coated potato chips.

In the present study, treatments GAH10 and GAH20 exhibited a significant reduction \((p < 0.05)\) in lipid content in relation to the control and GACA, as they presented a lipid content of 12.4% and 11.4%, respectively. Protein hydrolysates may vary in the composition and content of amino acids (Najafian, Najafian, and Babji, 2012). Da Rocha et al. (2018) prepared protein hydrolysates with 10 and 20% DH, by Alcalase hydrolysis of MFP, and detected 361.87 and 364.24 mg amino acids/g protein, respectively. In spite of having an important content of hydrophobic amino acids, hydrolysates are generally low-molecular-weight peptides, and as stated by Chalamaiah et al. (2012), the greater the extent of hydrolysis, the greater the solubility of the proteins, that is, they have an affinity with water. This fact can explain the lipid content at the end of the 10th day of storage for these samples.

The other samples (control and GACA) demonstrated an increase in lipid content at the end of the 10th day of storage, which can be explained by the increase in their firmness in relation to the other treatments, as verified in Table 3, and can be explained by a possible loss of water from the potatoes throughout storage. Coatings can create a thin layer of film, which prevents the oil from entering the alternative passages that originate in the frying process (Yu et al., 2016). Conversely, the coating can make the surface of the potato chips more homogeneous and lead to the formation of fewer passages to the oil, thereby reducing water evaporation, resulting in less oil absorption than uncoated products. This phenomenon may have occurred with the coatings of gum arabic and glycerol added with protein hydrolysates, because of a plasticising effect of the hydrolysate, forming a flexible, but cohesive coating (Nuanmano et al., 2015; Rocha et al., 2018).

4 CONCLUSION

The use of active gum arabic coatings incorporated with bioactive compounds is an alternative to reduce oil absorption by potato chips. The evaluated samples did not present thermotolerant coliforms \((<0.03 \text{ MPN/g})\), indicating that hygienic-sanitary
procedures were effective. Furthermore, the addition of citric acid inhibited moulds and yeasts and delayed the multiplication of total aerobic mesophiles in relation to the other treatments. In the present study, a significant reduction in luminosity ($L^*$) occurred for the control treatment compared with the other samples. The parameters $a^*$ and $b^*$ were higher for the treatments containing protein hydrolysates than in the control. At the end of the 10th day of storage, potato chips coated with films incorporated with protein hydrolysates showed lower firmness, and reduced moisture and lipid contents compared with the other treatments examined. The coatings with added protein hydrolysates represent a promising alternative as an active coating to reduce the oil content in fried potato chips.

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