Effects of the replacement of pork fat by psyllium mucilage in beef hamburgers and display time on chemical-physical characteristics

Efeitos da substituição de gordura suína por mucilagem de psyllium em hamburgueres de carne bovina sobre o tempo de prateleira e características físico-químicas

Efectos de la sustitución de gordura de puerco por mucílago de psyllium en hamburguesas de carne de bovino sobre el tiempo de exposición y las características químico-físicas

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ABSTRACT
Due to the high-fat content of meat products, finding options that make them healthier and that can replace fat is the key to meeting consumer expectations today. In this way, psyllium has been used as an ingredient with potential application in these new products. To assess the effects of including psyllium in beef burgers as a fat substitute, the chemical composition, pH, color, cooking loss, shear force, lipid oxidation, and microstructure characteristics were evaluated. Replacing animal fat with psyllium mucilage in the beef burgers preparation reduced total protein and lipid values and increased moisture and ash values, turn the burgers darker (L* and a* values), and contributed to the reduction of lipid oxidation. Thus, with the inclusion of psyllium mucilage with 15% of fat substituted by mucilage, the overall structure of the burgers was similar and could be used as fat replacer, improving the quality parameters of the meat products without changing the product quality.

Keywords: Dietary Fiber, Fat Replacer, Meat Products, Mucilage.

RESUMO
Devido ao elevado teor de gordura dos produtos cárneos, encontrar opções que os tornem mais saudáveis e que possam substituir a gordura é a chave para satisfazer as expectativas dos consumidores atualmente. Neste sentido, o psyllium tem sido utilizado como um ingrediente com potencial aplicação nestes novos produtos. Para avaliar os efeitos da inclusão de psyllium em hambúrgueres de carne bovina como substituto de gordura, foram avaliadas as características de composição química, pH, cor, perda por cocção, força de cisalhamento, oxidação lipídica e microestrutura. A substituição da gordura animal pela mucilagem de psyllium na preparação de hambúrgueres de carne bovina reduziu os valores de proteínas totais e lípidos e aumentou os valores de humidade e cinzas, tornando os hambúrgueres mais escuros (valores L* e a*) e contribuindo para a
INTRODUCTION

Meat plays a crucial role as a significant provider of high-quality proteins and essential nutrients for human consumers. Its derivatives are a key component of everyday meals, serving as excellent sources of vital nutrients (Olmedilla-Alonso et al., 2013).

Consumers, particularly the younger generation, have a strong preference for various meat products (Carvalho et al., 2020; Carvalho et al., 2017). Nevertheless, the rising issues associated with the overconsumption of high-fat and high-sugar foods, coupled with the increasing public concern for health improvements through diet, have prompted a quest for healthier alternatives. To achieve this goal, diverse strategies can be employed, such as reducing harmful compounds and enhancing beneficial ones in meat products (Monteschio et al., 2020; Vital et al., 2016).
To create low-calorie products that match the quality of traditional ones, researchers have investigated fat substitutes to produce foods with fats' sensory and functional characteristics but without their high caloric value. The goal is to offer to consumers a tasty and visually appealing products focused on well-being and health. Functional foods, which are known for their proven clinical or health benefits alongside their nutritional effects, fall into this category (Biesalski et al., 2009; Olmedilla-Alonso et al., 2013).

Fat plays a crucial role in meat products, enhancing their texture, flavor, and juiciness (Pethick et al., 2011). Nevertheless, excess fat can be detrimental to human health. Despite this, reducing fat content can pose challenges during product manufacturing, altering texture and sensory attributes (Choi et al., 2013). A suitable fat substitute for meat should mimic fats in structure, texture, and juiciness. Using dietary fiber as a fat alternative not only boosts the product's nutritional profile but also lowers its caloric value (Han & Bertram, 2017). Additionally, dietary fibers like psyllium have been utilized as thickeners in meat products due to their gel-forming properties. Psyllium, a rich source of soluble and insoluble fiber, has gained attention for its potential health advantages and applications in various food products (Franco et al., 2020; Guo et al., 2009).

The potent gelling ability of its polysaccharides is strongly linked to its health advantages and its role as a binder in the food industry. When dissolved in water, it can create a gel and serves as a robust gelling agent and enhances viscosity in meat product development (Talukder, 2015). Researchers have also investigated the nutraceutical, pharmaceutical, and medicinal properties of psyllium in order to treat conditions like irritable bowel syndrome, obesity, colon cancer, constipation, diabetes, high cholesterol, ulcerative colitis, and atherosclerosis (Mishra et al., 2014; Wahid et al., 2020).

It's a well-known fact that including fiber-rich foods in human diet brings numerous health advantages, aiding in both the avoidance and management of chronic illnesses. Psyllium, a soluble fiber derived from the seed husks of plants belonging to the Plantago genus, stands out as a popular supplemental fiber, especially abundant in specific subtropical areas. Initially explored for its possible health-promoting properties,
research has expanded to examine its potential applications in various consumer goods, ranging from dietary supplements to skincare products and medications (Guo et al., 2008).

The seed of Plantago contains a polysaccharide of high added value called psyllium husk mucilage. This mucilage is predominantly made up of arabinoxylans, with 22.6% arabinose and 74.6% xylose. Throughout history, it has been utilized to treat various conditions like constipation, irritable bowel syndrome, colon cancer, and diarrhea. Furthermore, it has been shown to have beneficial effects such as reducing cholesterol levels, decreasing the risk of colon cancer and hyperglycemia, as well as aiding in weight control (Wahid et al., 2020). Moreover, it presents promising applications in the food industry as a stabilizing and gelling agent (Franco et al., 2020).

Numerous research endeavors have been undertaken to broaden the psyllium application across various industries (Kumar et al., 2019), including biodegradable films (Tóth & Halász, 2019), the development of gluten-free products (Fradinho et al., 2020), and the enhancement of meat products (Osheba et al., 2013).

This work was realized to evaluate the effects of including psyllium in beef hamburgers as a fat substitute on pH, chemical composition, color, weight losses, shear force lipid oxidation and microstructure.

2 MATERIAL AND METHODS

2.1 MEAT SAMPLES

The meat used for this study was the Biceps femoris muscle from a Nellore steer weighting 500 kg and slaughtered at 24-months old, obtained from marked of Maringá, Paraná, Brazil. The average weight of the Biceps femoris sample was 8.5 kg.
2.2 PSYLLIUM MUCILAGE EXTRACTION

For the psyllium mucilage extraction, there was used the methodology described by Guo et al. (2008), with modifications. After several tests for standardization and better use of the mucilage, the use of a 4:100 ratio was determined, that is, the addition of 4 grams of psyllium for each 100 ml of distilled water, with heating at 80º C for 30 min in constant agitation, until the mixture becomes a homogeneous gel.

2.3 HAMBURGER PREPARATION AND TREATMENTS

The hamburgers were prepared at the Laboratory of Technology for Products of Animal Origin, belonging to the State University of Maringá and formulated according to Carvalho et al. (2017) to evaluate the effect of gradual replacement of pork fat by psyllium mucilage. Four treatments were compared: P00 (without psyllium mucilage and 20% pork fat), P05 (replacement of 5% of pork fat by psyllium mucilage), P10 (replacement of 10% of pork fat by psyllium mucilage) and P15 (replacement of 15% of pork fat by psyllium mucilage). Each hamburger was stored in polystyrene trays, covered with retractile film and stored with an illuminated display (2ºC) and the samples were analyzed at 1, 3 and 7 days of display.

2.4 CHEMICAL COMPOSITION

The beef hamburger samples were minced, homogenized and analyzed in triplicate on day one. Beef hamburger moisture, ash and crude protein content were determined according to AOAC (2005).

2.5 pH MEASUREMENTS

The pH was measured at 1, 3 and 7 days of storage time, using a pH meter text model (Tradelab, Contagem, MG, Brazil), as describe by Vital et al. (2016).
2.6 WATER LOSSES

The individual weights of hamburgers were recorded each day of analyses. Results were expressed as a percentage relative to hamburger’s initial weight (day 0).

2.7 SHEAR FORCE

Shear force (N) was analyzed using TA.XT Plus (texturometer - Texture Technologies 15 Corp., UK) with a Warner-Bratzler blade. The parameters used were a 5 kg load cell and a speed of 1 mm/s. Four samples were grilled at 200 °C on an electric grill (Grill Philco Jumbo Inox, Philco SA, Brazil) until 72 °C. Then, samples were cooled (25 °C), cut and analyzed in the center.

2.8 COLOR

Color was evaluated using a Minolta CR-400 Chroma meter (Japan) (with a 10° view angle, D65 illuminant, and 8 mm aperture with a closed cone) as describe by Vital et. al (2016). Six measurements selected at random points were recorded per sample, obtaining values for lightness (L*), redness (a*), and yellowness (b*).

2.9 LIPID OXIDATION

Lipid oxidation was assessed as the malanaldehyde (MDA) content in the hamburger. It was quantified using the thiobarbituric acid reactive substances (TBARS) assay according to Vital et al. (2016). A total of 5 g of each hamburger was mixed with TCA solution (7.5% TCA, 0.1% EDTA and 0.1% gallic acid), homogenized using an Ultra Turrax, then centrifuged at 4 °C for 15 min and 4.000 rpm. The supernatant was filtered and mixed with the TBARS reagent (1% thiobarbituric acid, 562.5 μM, HCl, 15% TCA) (1:1 v/v). The mixture was boiled (100° C) for 15 min, cooled, then the absorbance
measured at 540 nm against an MDA standard. Results were expressed as mg MDA kg\(^{-1}\) of hamburger.

2.10 SCANNING ELECTRON MICROSCOPY

The microstructure analysis was performed according to Matumoto-Pintro et al. (2011), using a scanning electron microscope (SEM) (Superscan, Shimadzu SS-550) at 15 kV. Hamburgers samples at 1 day of display were frozen-fixed in liquid nitrogen and lyophilized. Samples were mounted on aluminum stubs and coated with a gold layer (sputter coater, Bal-Tec, SCD 050).

2.11 STATISTICAL ANALYSES

All data were tested for normality (Shapiro-Wilk test) and showed normal distribution. Hamburger’s data were evaluated by analysis of variance with the general linear model (GLM) with SPSS (v.27.0) (IBM SPSS Statistics). Means and standard error mean were determined. Treatments (replacement levels of pork fat by psyllium mucilage) and display or storage (pH, color, dripping and cooking losses, texture, and lipid oxidation) were considered as fixed factors in a factorial design, with three replications per treatment for each analysis. When differences were observed, Tukey’s test was used with statistical differences (P < 0.05).

3 RESULTS AND DISCUSSIONS

3.1 CHEMICAL COMPOSITION

The hamburger's moisture and ashes percentage increased linearly (P < 0.001) with the replacement of pork fat by psyllium mucilage (Table 1). This result is attributed directly to the higher moisture percentage (11 to 15%) and the greater amount of fiber present in psyllium mucilage, which ranges from 4 to 5% (Antigo et al., 2020).
On the contrary, the hamburger's protein and lipids percentage decreased linearly (P < 0.001) with the replacement of pork fat by psyllium mucilage (Table 1). This reduction is due to the lower protein and total lipid percentage in the psyllium mucilage. The total lipid content in psyllium mucilage can range from 0.5 to 1.1% (Antigo et al., 2020).

Table 1. Effect of pork fat replacement levels by psyllium extract on chemical composition of beef hamburgers

<table>
<thead>
<tr>
<th>Composition</th>
<th>Treatments</th>
<th>SEM</th>
<th>P &lt; Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>P00¹</td>
<td>60.37d</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>62.44c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>64.53b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>72.37a</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>P00¹</td>
<td>19.43a</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>19.33a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>17.32b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>15.69c</td>
<td></td>
</tr>
<tr>
<td>Total fat</td>
<td>P00¹</td>
<td>38.09a</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>37.45a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>35.10b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>33.45c</td>
<td></td>
</tr>
<tr>
<td>Ashes</td>
<td>P00¹</td>
<td>3.63a</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>4.28b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>4.31b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>5.97a</td>
<td></td>
</tr>
</tbody>
</table>

¹P00: No addition of psyllium, ²P05: Replacement of 5% psyllium by pork fat, ³P10: Replacement of 10% psyllium by pork fat, ⁴P15: Replacement 15% psyllium by pork fat. Results are expressed as mean and standard error of mean. Means followed by different letters, in the same line, are different (P < 0.05).

⁵SEM – Standard error mean.

Source: Authors

Therefore, the use of psyllium into hamburgers as a replacement for animal fat demonstrated a favorable outcome in reducing total lipid content. This subsequent reduction in fat percentage is beneficial for human health (Toldrã & Reig, 2011). It stands as a crucial finding as modern consumers are increasingly health-conscious, seeking healthier dietary options that cut down on fat without sacrificing product quality (Biesalski et al., 2009).

3.2 pH

The pH results of the hamburgers are shown in Table 1. On days 1 and 3, treatments did not affect (P > 0.05) the pH values of hamburgers (Table 2), that varied within the pH range observed for hamburgers (Cardoso et al., 2023; Nascimento et al., 2020). At day 7, pH values for treatments with the replacement of pork fat by psyllium mucilage were higher (P < 0.001) compared to treatments with no addition of mucilage (Table 2). This difference may be due to the higher moisture content of psyllium mucilage compared to pork fat.
The pH values increased significantly (P < 0.05) over the days of storage (Table 2), going from 5.68 to 6.42. In general, the pH of meat and hamburgers increases with storage time (Cardoso et al., 2023; Nascimento et al., 2020). As stated by Zarei and colleagues (2015), the rise in hamburger pH throughout the storage period is associated with deterioration caused by changes in glycolytic activity, leading to the breakdown of amino acids through microbial metabolism, resulting in the formation of ammonia and trimethylamine by either endogenous or microbial enzymes.

Table 2. Effect of pork fat replacement levels by psyllium extract and display time on pH values of beef hamburgers

<table>
<thead>
<tr>
<th>Days</th>
<th>Treatments</th>
<th>SEM</th>
<th>P &lt; Value⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P00¹</td>
<td>P05²</td>
<td>P10³</td>
</tr>
<tr>
<td>1</td>
<td>5.68B</td>
<td>5.77B</td>
<td>5.69B</td>
</tr>
<tr>
<td>3</td>
<td>5.75B</td>
<td>5.85B</td>
<td>5.79B</td>
</tr>
<tr>
<td>7</td>
<td>6.00cA</td>
<td>6.42aA</td>
<td>6.19bA</td>
</tr>
<tr>
<td>SEM</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>P &lt; Value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

¹P00: No addition of psyllium, ²P05: Replacement of 5% psyllium by pork fat, ³P10: Replacement of 10% psyllium by pork fat, ⁴P15: Replacement 15% psyllium by pork fat. Results are expressed as mean and standard error of mean. Means followed by different lowercase letters, in the same line, are different (P < 0.05). Means followed by different capital letters, in the same column, are different (P < 0.05). ⁵SEM – Standard error mean.

3.3 COLOR

The color parameters of the hamburgers (L*, a*, and b*) are shown in Table 3. The L* values were lower as the levels of substitution of pork fat for psyllium mucilage were increased (P > 0.05). These values show that the more psyllium mucilage included, the darker the burgers became. The weightlessness of hamburgers is influenced by their ingredients and how they are made, as these elements can differ significantly. Therefore, in most cases, the duration of exposure either decreases the L* value of beef products (Nascimento et al., 2020) or keeps it the same (Cardoso et al., 2023).
Table 3. Effect of pork fat replacement levels by psyllium extract and display time on colour of beef hamburgers.

<table>
<thead>
<tr>
<th>Days</th>
<th>Treatments</th>
<th>SEM</th>
<th>P &lt; Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>46.43</td>
<td>2.33</td>
<td>0.683</td>
</tr>
<tr>
<td>3</td>
<td>49.89a</td>
<td>2.00</td>
<td>0.001</td>
</tr>
<tr>
<td>7</td>
<td>46.54a</td>
<td>1.66</td>
<td>0.001</td>
</tr>
<tr>
<td>SEM</td>
<td>1.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P &lt; Value</td>
<td>0.381</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P00: No addition of psyllium, P05: Replacement of 5% psyllium by pork fat, P10: Replacement of 10% psyllium by pork fat, P15: Replacement 15% psyllium by pork fat. Results are expressed as mean and standard error of mean. Means followed by different lowercase letters, in the same line, are different (P < 0.05). Means followed by different capital letters, in the same column, are different (P < 0.05).

The a* values present a significative difference (P > 0.05) at the 3 and 7 days of display in the hamburgers of all treatments (Table 3). Thus, the treatments with higher levels of replacement of pork fat for psyllium mucilage present higher values of a*. Thus, the a* values in hamburgers ranged from 7.5 to 14.2 points, as observed in other studies (Cardoso et al., 2023). Display time had an effect (P < 0.001) on the evolution of a* values of hamburgers in all treatments (Table 3). The storage days linearly reduced (P < 0.05) a* values in all treatments. Therefore, the psyllium mucilage made the hamburgers redder (dark).

Both the L* and a* values indicated that the burgers had a darker color with the inclusion of psyllium mucilage. According to Jovanovki et al. (2018), Psyllium mucilage is obtained from the grinding of Plantago seeds, which are light brown, hence contributing to a slight darkening of the hamburgers.
The replacement levels of pork fat by psyllium mucilage and display time had no effect (P > 0.05) on \( b^* \) (yellowness) values of hamburgers (Table 3). The \( b^* \) values varied from 14.17 to 17.61 without considering treatment and display time.

### 3.4 WEIGHT LOSSES AND COOKING LOSSES

The replacement of pork fat by psyllium mucilage and the display time had no influence (P > 0.05) on the dripping loss of the hamburgers in the three display times (1, 3, or 7 days) (Table 4). Dripping losses were low and ranged from 1.54 to 1.63%, within the average found in studies on hamburgers (1.0 to 3.0%) (Vital et al., 2021; Cardoso et al., 2023).

Cooking losses present a significative difference (P < 0.05) between the treatments on days 3 and 7 of display (Table 4), where the treatments with the highest levels of fat substitution with psyllium mucilage showed the highest losses. The reason behind this outcome can be attributed to the elevated water content found in psyllium mucilage in contrast to pork fat, resulting in increased water evaporation while cooking, as highlighted by Antigo et al. (2020).

The display time had no effect (P > 0.05) on cooking losses in the CONT, P05, and P10 treatments, however, it increased with display time (P < 0.001) with the addition of 15% of pork fat replacement by psyllium mucilage. However, cooking losses were around 20-25%, with is accepted for hamburgers (Vital et al., 2021; Cardoso et al., 2023).

### 3.5 TEXTURE

The replacement of pork fat by psyllium mucilage improved linearly (P < 0.001) the texture of the hamburgers (lower shear force) (Table 4). Thus, shear force decreased from an average of 1.44 kg in the treatment without psyllium inclusion to 0.56 kg in the hamburgers with 15% replacement of animal fat by psyllium mucilage. The difference in hamburger texture is also related to the texture of psyllium mucilage compared to animal fat, directly influencing the result.
Table 4. Effect of pork fat replacement levels by psyllium extract and display time on weight losses and shear force (kg) of beef hamburgers

<table>
<thead>
<tr>
<th>Days</th>
<th>Treatments</th>
<th>SEM</th>
<th>P &lt; Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>P001</td>
<td>1.55</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>P052</td>
<td>1.56</td>
<td>0.01</td>
</tr>
<tr>
<td>7</td>
<td>P103</td>
<td>1.59</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>P154</td>
<td></td>
<td>0.334</td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P &lt; Value</td>
<td>0.336</td>
<td></td>
</tr>
</tbody>
</table>

![Table 4](image-url)

On the other hand, the replacement of pork fat by psyllium mucilage over the display time (1, 3, or 7 days) had no effect (P > 0.05) on the texture of the hamburgers, with the shear force being similar in all cases (Table 5). Thus, as can be seen with the reduction of sodium content or protection with active packaging that did not show these effects in beef hamburgers (Carvalho et al., 2020).

3.6 LIPID OXIDATION

Tbars values were lower (P < 0.001) in the treatments with psyllium mucilage inclusion compared to the control treatment (Table 5). Furthermore, this reduction was higher (P < 0.01) with the replacement of 10 and 15% of the fat by psyllium mucilage. In general, malondialdehyde levels exceeding 2.0 mg/100 grams per kg of meat are deemed unacceptable for consumption, according to Campo et al. (2006) and hamburgers, given their greater processing compared to fresh meat, may exhibit even higher oxidation levels.
In this study, only hamburgers prepared without the inclusion of psyllium and after seven days of display can be considered unsuitable for human consumption.

Table 5. Effect of pork fat replacement levels by psyllium extract and display time on lipid oxidation (tbars) of beef hamburgers

<table>
<thead>
<tr>
<th>Days</th>
<th>Treatments</th>
<th>SEM</th>
<th>P &lt; Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P00¹</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>3</td>
<td>P00¹</td>
<td>1.07</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>0.08</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>0.07</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>0.07</td>
<td>0.001</td>
</tr>
<tr>
<td>7</td>
<td>P00¹</td>
<td>1.57</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P05²</td>
<td>1.26</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P10³</td>
<td>1.26</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>P15⁴</td>
<td>1.26</td>
<td>0.001</td>
</tr>
</tbody>
</table>

¹P00: No addition of psyllium, ²P05: Replacement of 5% psyllium by pork fat, ³P10: Replacement of 10% psyllium by pork fat, ⁴P15: Replacement 15% psyllium by pork fat. Results are expressed as mean and standard error of mean. Means followed by different lowercase letters, in the same line, are different (P < 0.05). Means followed by different capital letters, in the same column, are different (P < 0.05). ⁵SEM – Standard error mean.

With the psyllium addition, the TBARS values were all below 2.0. The lowest values of TBARS were always observed in hamburgers prepared with the psyllium inclusion. These results can be attributed to the fat content reduction in these treatments, and as psyllium mucilage has a low total lipid content, consequently, lipid oxidation in these treatments will be lower compared to the control treatment.

On the other hand, lipid oxidation increased with display time, with the lowest values (P < 0.001) being observed before the display and the highest 7 days post-display (Table 5). In this way, the display time increases lipid oxidation (higher TBARS values) as generally observed in the literature for hamburgers. The lipids oxidation is a significant element that has the potential to impact the meat quality and is linked to meat deterioration (Carvalho et al., 2020).

3.7 SCANNING ELECTRON MICROSCOPY (SEM)

To investigate the behavior of psyllium mucilage as a fat substitute, scanning electron microscopy (SEM) was used (Figure 1). In the treatment without the psyllium addition, a protein matrix with a very homogeneous distribution of pore size is observed. In
the image with the highest magnification (2000x) it is possible to observe some fat particles, but it turns out to be difficult to differentiate them because they are trapped in the protein matrix.

In their study, Liu & Lanier (2015) highlighted a similar finding when examining various electron microscopy techniques for assessing mechanically processed meat. The authors pointed out that traditional microscopy methods may obscure crucial details about how the protein matrix pores interact with fat globules, making visualization challenging. They also suggested that this phenomenon could be attributed to the melting and spreading of fat within the microscopic mesh, both during hamburger preparation and image capturing at room temperature.

With the psyllium mucilage inclusion throughout the treatments there is a noticeable alteration in the protein matrix, leading to a more diverse distribution of pore sizes and the absence of visible fat particles. This suggests that the mucilage addition alters the microstructure of hamburgers. In comparison to the treatment without psyllium, the matrix network becomes less porous when psyllium is included. This can be attributed to the texture of mucilage, which has a higher water content and interacts differently with the protein matrix than fat, ultimately changing its structure and decreasing the number of pores. This impact of using fat substitutes like mucilage is apparent in various food products (Calderón-Domínguez, 2017; Ferraro et al., 2022).
Figure 1. Scanning electron microscopy of hamburger samples: P00 - No psyllium added; P05 - Addition of 5% psyllium to replace animal fat; P10 - Addition of 10% psyllium in substitution of animal fat and P15 - Addition of 15% of psyllium in substitution of animal fat. With magnification of 1000x and 2000x, respectively.

Source: Authors
When comparing the treatment without psyllium mucilage to the one with 15% fat replaced by mucilage, similarities in the overall structure of the hamburgers are observed.

5 CONCLUSION

The replacement of pork fat with psyllium mucilage in the preparation of beef hamburgers reduced the values of total proteins and lipids and increased the values of moisture and ash. The replacement also made the burgers darker (L* and a* values) and contributed to the reduction of lipid oxidation. Regarding the microstructure, a similarity was observed concerning the general structure of the hamburgers between the treatments. In this way, psyllium mucilage can be used in the preparation of beef burgers as a fat replacer, improving the quality parameters of the meat products without changing the product quality and improving its functional properties.

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