INTRODUCTION

The industrial chicken production plays an important role in Brazil's agribusiness, and the country is the world's largest poultry exporter, the second largest producer (ARPTA, 2021). The popularization of chicken meat is possibly due to its sensory and nutritive values, the fact that it can be processed into ready-to-eat meals, as well as its abundant supply of product varieties and low price relative to other animal products (Singh & Cadwallader, 2012; Prejsnar & Ormian, 2004). The quality of meat is influenced by factors such as packaging, storage conditions, gas composition (O₂, CO₂, inert gases) around the tissues, relative humidity (RH), light, and temperature (Singh & Cadwallader, 2004; Angioletti, et al., 2020a). A widely used method to improve the shelf life of chicken meat is cold storage (chilling and freezing) storage (Vorst et al., 2018) because it preserves the quality of meat products by slowing down biochemical and microbiological reactions due to low temperatures (Hoffmann et al., 2021a). Refrigeration extends shelf life by days or weeks (Schleif et al., 2020), while freezing allows for the preservation of food characteristics for even longer periods (O’Jha et al., 2016). However, during freezing, ice crystals are formed, which can cause the rupture of cell structures and significant water loss during thawing (O’Jha et al., 2016; Vieira, 2007). Besides, the size, orientation, and localization of ice crystals can cause malodors in the properties of the protein (Aguilera Barraza, León, and Álvarez, 2015). Additionally, the application of packaging with specific atmospheres (conventional or vacuum) can also be associated with improving the quality and extending the shelf life of foods such as chicken meat (Schmidt & Laurindo, 2014; Ham et al., 2019). Vacuum packaging is a preservation technology that, when associated with temperature control, is capable of inhibiting or reducing the growth of microorganisms responsible for the deterioration of the product (Cortez-Vega et al., 2012). The use of these technologies ensures that the sensory quality of the product (appearance, odour and product composition) is maintained (Lorenzo, & Gómez, 2012).

Despite the different methodologies applied, such as refrigeration (De Souza et al., 2022; Hoffmann et al., 2021a,b), technological packaging (Hoffmann et al., 2019; Angioletti et al., 2020b; Hoffmann et al., 2022), ozonation (Soares et al., 2018), UV led lights (Finardi et al., 2021), edible coating/film (Finardi et al., 2022; Pergentino dos Santos et al., 2022) and oxygen absorbers (Mexis, Chouliara, & Kontominas, 2012), meat and animal food products undergo alterations, mainly due to the action of microorganisms that cause deterioration (Andrade, 2014). Moreover, the susceptibility of meats to undergo lipid and protein oxidation (LipOx and ProtOx, respectively) is highly dependent on the origin of meat, type of muscle, species, and storage conditions, among others (Dominguez et al., 2019; Estévez, 2015). In this regard, several studies have indicated that the oxidation of lipids and proteins could be associated with freeze/thaw procedures (All et al., 2015; Dang et al., 2021).

Chicken meat must be cooked prior to consumption, firstly to guarantee microbiological safety, but also to increase the digestibility of proteins (Sobral et al., 2020) and achieve attractive flavour and texture qualities (Broncano et al., 2009). However, depending on the cooking method applied, considerable changes in the meat’s nutritional and sensory value may occur, as all thermal treatments instigate oxidative processes and water losses (Yu et al., 2017). The cooking method, to which chicken meat is submitted, can influence the content of protein, lipids, total ash and dry matter (Rosa et al., 2006), in addition to impacting the structure of the food and causing cellular changes (García-Arías et al., 2003).

In this regard, research has shown that cooking temperatures above 100 °C can lead to protein carbonylation and aggregation, resulting in a decrease in pepsin enzymatic activity (Echegaray et al., 2020; Traore et al., 2012). The meat texture can be influenced by cooking. Juiciness and tenderness are considered the most important quality attributes of meat products and fresh meat. Cooking can decrease juiciness by reducing water binding capacity and causing the loss of moisture or fat through drip (Wall et al., 2019). Moreover, meat releases flavours during the cooking process due to a series of thermally induced complex reactions that occur between the various non-volatile compounds present in lean and fatty tissues (O’Sullivan, 2016). Therefore, this study evaluated the combined effects of packaging (vacuum and normal pressure, 1 atm), storage temperature (refrigeration and freezing), and cooking methods (household griddle, household oven and industrial oven) on the physical, chemical,
and sensory quality characteristics of chicken hamburgers to meet consumer preferences.

MATERIALS AND METHODS

Sample Preparation

The entire experiment was performed in duplicate on different days, with a two-month separation between them. Frozen chicken cuts, specifically fillet type (sassami), were purchased from a supermarket in Blumenau (Santa Catarina, Brazil) and transported in a thermal box to the Food Processing Laboratory (LAPRA) of the Regional University of Blumenau (FURB). There, the chicken cuts were kept chilled (4 ± 1.0 °C) until the preparation of the chicken burger samples on the same day. The chicken meat was cut into small cubes, ground twice using a manual meat grinder, and shaped into burgers weighing 150 g each. The burgers had a diameter of 9 cm and a thickness of 3 cm. The samples were then stored in polyethylene packaging. Half of the samples were placed in conventional packaging with an internal pressure of 1 atm, while the other half were vacuum sealed with an internal pressure lower than 1 atm. For conventional packaging, bags measuring 38 × 16.5 cm were sealed using a Barbi manual hot-sealer, model TCH-320. The vacuum packaging was achieved by using a vacuum pump (Tecnal brand), model TE-058, and transparent polyethylene Zip Lock-N8 bags measuring 24 × 17 cm. Figure 1 provides a flowchart depicting the different stages in the development process of the chicken meat burger.

![Flowchart of the steps in the process of developing chicken burger samples.](image)

Figure 1 Flowchart of the steps in the process of developing chicken burger samples.

Storage Conditions

The chilled chicken hamburger samples were stored in an Incubator - B.O.D. (Biomedical Oxygen Demand), model TE-371 (Tecnal, Piracicaba, Brazil), with monitoring of isothermal conditions (4 ± 1 °C) and relative humidity, using Klima Logg device, for 24 hours. The frozen chicken meat samples were stored in a BOSCH freezer; model KDV47A, for 72 hours at -18 ± 1 °C.

Experimental Set-up

The chicken burgers samples, stored under refrigeration and freezing, were removed and immediately subjected to the three cooking methods: grill (hot plate), household oven and industrial oven. Both sides of the burgers were cooked and removed and immediately subjected to the three cooking methods: grill (hot plate), household oven and industrial oven. Both sides of the burger were cooked and

<table>
<thead>
<tr>
<th>Test</th>
<th>Cooking Method</th>
<th>Packaging (internal pressure)</th>
<th>Storage Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C1 (household Griddle)</td>
<td>&lt;1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>2</td>
<td>C1 (household Griddle)</td>
<td>1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>3</td>
<td>C1 (household Griddle)</td>
<td>&lt;1 atm</td>
<td>4 ± 1.0</td>
</tr>
<tr>
<td>4</td>
<td>C1 (household Griddle)</td>
<td>1 atm</td>
<td>4 ± 1.0</td>
</tr>
<tr>
<td>5</td>
<td>C2 (household oven)</td>
<td>&lt;1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>6</td>
<td>C2/household oven</td>
<td>1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>7</td>
<td>C2 (household oven)</td>
<td>&lt;1 atm</td>
<td>4 ± 1.0</td>
</tr>
<tr>
<td>8</td>
<td>C2 (household oven)</td>
<td>1 atm</td>
<td>4 ± 1.0</td>
</tr>
<tr>
<td>9</td>
<td>C3 (industrial oven)</td>
<td>&lt;1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>10</td>
<td>C3 (industrial oven)</td>
<td>1 atm</td>
<td>-18 ± 1.0</td>
</tr>
<tr>
<td>11</td>
<td>C3 (industrial oven)</td>
<td>&lt;1 atm</td>
<td>4 ± 1.0</td>
</tr>
<tr>
<td>12</td>
<td>C3 (industrial oven)</td>
<td>1 atm</td>
<td>4 ± 1.0</td>
</tr>
</tbody>
</table>

* Internal packaging pressure of 1 atm = Conventional packaging. Internal packaging pressure < 1 atm = Vacuum packaging.

Nutritional Analysis

The nutritional analysis of the samples (moisture, total protein, total lipid, and total ash contents) was performed in the Product Development, Sensory Analysis and Chemical Testing Laboratories on Campus 2, at the Regional University of Blumenau. These analyses were made in three moments: 1) Day 0: Before the samples were submitted to storage (4 °C and -18 °C) and packed (atmospheric pressure and vacuum); 2) After 24 h and 72 h of storage, 4 °C and -18 °C, respectively, packed in the different conditions of the internal atmosphere of the package (before being submitted to cooking) and 3) After cooking (until the temperature reaches 75 °C in the center of the food). The results obtained were measured by proximal composition and all tests were done in triplicate.

Moisture Content

Moisture content was determined using the gravimetric method using heat, which is based on the loss in mass of the product subjected to heating to 105 °C, until it reaches a constant value (AOAC, 2019). After thermal treatment, the samples were dried with absorbent paper to remove the surface water. After cooking, the samples were re-weighed for the following calculation:

\[
\text{Moisture content (\%)} = \frac{(\text{cooked weight} - \text{initial raw weight})}{\text{initial raw weight}} \times 100
\]

Total Lipids

The analysis of total lipid content (%) was performed by the Soxhlet method through the gravimetric process, which is based on the material mass loss, submitted to the ethyl ether extraction, or on the amount of material solubilized by the solvent (AOAC, 2019).

Total Proteins

The quantification of the protein content (%) was performed by applying the Kjeldahl method, where the total nitrogenous matter in the sample is determined (AOAC, 2019).

Total Ash

The percentage of ash was determined by incinerating the sample, in a muffle furnace, at 550 °C (AOAC, 2019).

Sensory Evaluation

The samples were examined by a sensory panel composed of 12 trained judges, in individual sensory booths with control of the lighting and temperature, and the absence of noise (Melingard et al., 2016). The panelists were recruited from students at the University of Blumenau and chosen based on their experience in the sensory analysis of meat products and on their availability. The execution of this project, which contemplates the participation of human beings (Figure 2), was approved by the Ethics Committee on Research with Human Beings at the Regional University of Blumenau (CAAE: 93420818.4.0000.5370).
Sensorial evaluations were carried out immediately after removing the sample from cooking. The sensory analysis was based on a quantitative descriptive test, considering the sensory attributes (colour, texture, flavour, juiciness, tenderness and overall sensory acceptability) as perceived by the judges. Samples were labelled with a three-digit random number and served warm (± 50 °C) on labelled glass plates to quantify the quantitative descriptive test results, an unstructured hedonic scale with 9 points was applied, considering the score of 6 as the minimum acceptability limit (Camo et al., 2011).

The tested attributes were: Liking of colour (1 = extremely dislike, 9 = extremely like), liking of texture (1 = extremely dislike, 9 = extremely like), liking of flavour (1 = extremely dislike, 9 = extremely like), liking of Juiciness (1 = very dry, 9 = very juicy), liking of tenderness (1 = extremely tough, 9 = extremely tender) and overall sensory acceptability (1 = extremely dislike, 9 = extremely like) (Lago et al., 2017). The acceptance index (AI %) of the samples was analysed following the equation shown below:

\[ AI(\%) = (M * 100) / K \]

Where, M is the average of the scores given to the overall sensory acceptability and K is the maximum score on the hedonic scale used (9).

RESULTS AND DISCUSSION

Moisture Content

The moisture content found in the raw samples, before the application of cold and the use of packaging, was 70.28 ± 1.09%. The results for the moisture content in the refrigerated/frozen samples, in conventional/vacuum packages, and after each cooking are presented in Table 3. After cold storage (refrigeration and freezing), some samples (RC, RV and FC) showed an increase (5%) in moisture content. These fluctuations in temperature may occur during storage due to the transfer of water from the surface to the interior of the product, even when the food was already packed (Guitiérrez, 2017).

Moreover, the moisture content of chicken burger samples after storage (AS) and cooking (C1, C2 and C3) showed significant differences (p < 0.05) in most samples. The refrigerated samples (RC and RV), after cooking in household (C2) and industrial (C3) ovens, showed a significant reduction in moisture content (p < 0.05). In this regard, previous research confirmed a significant decrease in the moisture contents of lamb cuts submitted to two cooking methods (microwave, followed by grilling and roasting in a household conventional oven) when those were compared to raw samples (Maranesi et al., 2005).

Table 3 Moisture content of chicken meat burger samples, after storage (AS) and after cooking with the different methods (C1, C2 and C3).

<table>
<thead>
<tr>
<th>Samples</th>
<th>AS (%)</th>
<th>C1 (%)</th>
<th>C2 (%)</th>
<th>C3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>75.46±0.07a</td>
<td>69.59±0.62ab</td>
<td>66.81±1.01bc</td>
<td>62.33±3.83acd</td>
</tr>
<tr>
<td>RV</td>
<td>75.55±0.12a</td>
<td>67.79±1.03ab</td>
<td>65.65±1.17ac</td>
<td>63.41±1.21ac</td>
</tr>
<tr>
<td>FC</td>
<td>75.99±0.22a</td>
<td>54.59±3.07ab</td>
<td>61.10±1.81ab</td>
<td>56.21±1.81ab</td>
</tr>
<tr>
<td>FV</td>
<td>70.94±6.15a</td>
<td>58.20±2.91bc</td>
<td>68.59±0.55bc</td>
<td>60.93±1.59ab</td>
</tr>
</tbody>
</table>

aDifferent lowercase letters in the same row indicate a significant difference (p < 0.05) by Tukey's test.  
a,bDifferent capital letters in the same column indicate a significant difference (p < 0.05) by Tukey's test.

Among the cooking methods for chilled samples (RC and RV), the industrial oven was the one that most reduced moisture content (62.33%), while the household griddle caused the least reduction (69.59%), although the differences were not significant (p > 0.05). A similar behaviour was observed by Echeagaray et al. (2020) in the moisture contents of Longissimus thoracis et lumbrorum Celta pig muscle cooked by frying, microwaving, roasting, and grilling (51.68%, 52.90%, 58.61% and 61.22%, respectively). Similar results were observed by Vieira et al. (2007) who evaluated the effect of cooking methods on the nutritional composition of chicken breast from different chicken breeds. In this case, the microwave-baked meal was also the one that reduced the moisture content the most, following by conventional oven-baked and oil-fried (56.18%, 63.18% and 63.73% vs. 74.08% for microwave-baked meat, conventional oven-baked and oil-fried vs. raw samples, respectively). The same outcomes were observed in breast and thigh cuts submitted to five cooking methods (boiled in water, baked in a conventional oven, microwave, grilled and fried in oil) (Rosa, 2003). Thus, the lowest percentages of moisture were found in the thigh and breast cuts submitted to frying (64.52% and 63.41%, respectively) and roasted in the microwave (64.17% and 64.78%, respectively).

As expected, cooking modifies the chemical composition of the meat with the consequent change in nutritional value. Water in chicken tissue exists in both forms, relatively freely moving and tightly bound to proteins. Upon heating, the tissue loses the ability to hold water due disruption of the cell structure and to the unfolding of protein. The increased water loss and more extensive destruction of cell structure led to substantial cooking loss at higher temperature (Qu et al., 2021). Therefore, the cooking loss in cooked chicken is mainly caused by the loss of moisture, melting of fat, and denaturation of protein (Xiong et al., 2020). Most of the cooking loss constitutes water, along with a small number of vitamins and solubilized proteins (Tornberg, 2005). This decrease was significant (p < 0.05) in the samples stored at -18 °C (FC and FV), after being submitted to the different preparation procedures (longer cooking time). During freezing, the quality of the meat can be reduced due to the destruction of the cells, caused by ice crystals that negatively change the sensory and nutritional characteristics of the food (Ciobanu et al., 2018). Once cooked, the samples frozen in conventional packaging (FC), showed no significant differences (p > 0.05) between cooking methods. However, samples prepared on the grill showed the lowest value of final moisture (54.59%), while those baked in a conventional oven showed the highest value (61.10%). Regarding frozen samples, oven baked using vacuum packaging (FV), similar moisture contents were observed in burgers cooked on a griddle and in a conventional domestic oven. In this case, griddle was the method that resulted in the greatest moisture reduction (57.62%), while domestic oven was the one that best maintained the moisture (60.93% and 62.33% in the thigh and breast cuts, respectively) in view of the previous results, there was a significant difference between chilled and frozen samples. The refrigeration temperature contributed to maintaining the moisture content (75.5%), while the freezing temperature resulted in samples with lower moisture content (73.5%). Among the cooking methods (griddle, household oven and industrial oven), the samples that presented the lowest moisture content were those frozen in conventional packaging (54.59%, 61.10% and 56.21%, respectively). It is very important to know these effects of cooking on moisture content since is related to attributes highly valued by consumers such as juiciness and palatability (Ciobanu et al., 2018). In this regard, the application of higher temperatures on the surface of meat samples generates a more rapid transfer of heat and energy through the exchange. According to the literature, tenderness and juiciness of steaks of greater thicknesses, grilled at greater surface temperatures are liked less than those grilled at lesser surface temperatures (Kerth & Miller, 2015b).

Total Lipids

Lipids also have a determining role in meat acceptability. The lipid content found in the raw samples, before the application of cold and the use of packaging, was 0.37 ± 0.34%. The values of total lipids in the chilled/frozen samples in conventional/vacuum packs and after each cooking method are presented in Table 4.

Table 4 Lipid content (%) in chicken burger samples after storage (AS) and cooking in different methods (C1, C2 and C3).

<table>
<thead>
<tr>
<th>Samples</th>
<th>AS (%)</th>
<th>C1 (%)</th>
<th>C2 (%)</th>
<th>C3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>0.72±0.03a</td>
<td>1.88±0.46ab</td>
<td>1.42±0.47ab</td>
<td>1.28±0.23ab</td>
</tr>
<tr>
<td>RV</td>
<td>0.71±0.09a</td>
<td>1.10±0.13ac</td>
<td>0.76±0.17bc</td>
<td>1.06±0.32ac</td>
</tr>
<tr>
<td>FC</td>
<td>0.66±0.08ab</td>
<td>1.07±0.18bc</td>
<td>0.66±0.28ab</td>
<td>0.57±0.19ab</td>
</tr>
<tr>
<td>FV</td>
<td>0.52±0.04ab</td>
<td>1.65±0.23ac</td>
<td>0.84±0.14ab</td>
<td>0.52±0.15ab</td>
</tr>
</tbody>
</table>

a Different lowercase letters in the same row indicate a significant difference (p < 0.05) by Tukey's test.  
abDifferent capital letters in the same column indicate a significant difference (p < 0.05) by Tukey's test.  
bcDifferent capital letters in the same column indicate a significant difference (p < 0.05) by Tukey's test.

In general, raw samples presented lower lipid content (0.37%) than those stored in the refrigerator/freezer without the application of cooking. Concerning these samples, there were no significant changes between them, being samples frozen in vacuum those that showed the lowest percentage of lipids (0.52%), while chicken burgers refrigerated in conventional packaging displayed the highest percentage of lipids (0.72%). These were also reflected in all cooking methods, since the samples refrigerated in conventional packaging had significantly higher lipid contents than conventional frozen samples. Cooking resulted in an increase in fat contents compared to the values observed before the thermal treatment. This is in agreement with the results found by other
researchers, who observed an increase in fat contents of beef cuts after cooking methods (roasted, grilled, fried and microwave) (Domínguez, Borrajo, and Lorenzo, 2015). In contrast, Gokoglu et al. (2004) only observed an increase in rainbow trout fillets subjected to frying compared to those obtained by water-boiled, grilled, roasted and microwave roasted. The incorporation of lipids from the oil used could be responsible for these higher values (Echegaray et al., 2020).

However, when the three cooking methods (griddle, household oven cooking and industrial oven cooking) were compared, a significant effect were observed except for samples refrigerated in conventional packaging (1.88%, 1.42% and 1.28% for C1, C2 and C3, respectively). On the contrary, there are several studies that barely found differences between the studied methods (Broncano et al., 2009). Moreover, grilled samples showed significantly higher values than those observed in oven-cooked samples, despite the fact that the cooking was carried out without adding oil or fat. These results are also unrelated to those obtained previously, since cooking on the grill showed the lowest fat values (Echegaray et al., 2020).

Regarding oven cooking, the use of the household oven resulted in higher fat content, which could be related to the temperature reached and the time of treatment. In this regard, the higher temperatures and cooking times reached in this type of oven would induce water loss during cooking, resulting in higher fat contents (0.66% vs. 0.57% for FC samples cooked in home and industrial oven, respectively).

To sum up, lipid content varied depending on the cooking method. In addition, it is important to note that thermal treatments instigate oxidative processes (Yu et al., 2017; Traore et al., 2012) emphasizing on the home-cooking methods as responsible for the fat formation, among others (Traore et al., 2012; Hu et al., 2017). Therefore, selecting a suitable cooking method would allow to reduce the loss of essential fatty acids and vitamins that would result in changes in nutritional and organoleptic properties (Guyon, Meynier, and Lamballerie, 2016).

Moreover, lipids have an important role in texture since they contribute to improve tenderness and juiciness, which are attributes highly valued by consumers (Amaral, Silva, and Lannes, 2018).

## Total Proteins

The total protein content found in the raw samples, before being subjected to the storage parameters, was 24.82 ± 0.46%. Table 5 shows the total protein values of the samples stored under refrigeration/freezezing, in conventional/vacuum packaging, before (AS) and after cooking (C1, C2 and C3).

### Table 5 Protein content in chicken meat samples after storage (AS) and submission to different cooking methods (C1, C2 and C3).

<table>
<thead>
<tr>
<th>Samples</th>
<th>AS (%)</th>
<th>C1 (%)</th>
<th>C2 (%)</th>
<th>C3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>23.56±1.22a</td>
<td>29.98±0.63a</td>
<td>31.55±1.93ab</td>
<td>34.43±0.52a</td>
</tr>
<tr>
<td>RV</td>
<td>23.63±3.00b</td>
<td>29.20±0.24a</td>
<td>23.22±0.63ab</td>
<td>33.55±0.81a</td>
</tr>
<tr>
<td>FC</td>
<td>22.07±0.57a</td>
<td>38.40±0.45a</td>
<td>35.59±1.19a</td>
<td>39.50±1.30a</td>
</tr>
<tr>
<td>FV</td>
<td>23.14±0.93b</td>
<td>40.99±3.92a</td>
<td>32.80±1.09a</td>
<td>35.71±1.35a</td>
</tr>
</tbody>
</table>

*ab Different lowercase letters in the same row indicate a significant difference (p < 0.05) by Tukey's test.

** Different capital letters in the same column indicate a significant difference (p < 0.05) by Tukey test. RC - Refrigeration in conventional packaging; RV - Refrigeration in vacuum packaging; FC - Frozen in conventional packaging; FV - Frozen in vacuum packaging.

Before storage, raw samples showed a higher percentage of protein (24.82%) compared to those observed in the post-storage cold storage (average of 23.60% and 22.60 in chilled and frozen samples, respectively), although the difference was not significant (p > 0.05). However, protein concentration increased considerably after cooking (p < 0.05), probably due to the loss of water causes the concentration of the rest of the components (Echegaray et al., 2020). This is in agreement with the results found by other authors (Rosa, 2006). The authors confirmed that meat obtained from microwave and oven with forced convection presented higher protein percentages, what it would be related to the lower moisture contents obtained in these treatments, favouring the increase in protein concentration. In this regard, samples in the oven were subjected to longer cooking (15-25 min in the oven vs. times less than 15 min in the grill), which promoted cooking loss (Lorenzo et al., 2015), while the high temperatures reached in the grill (180 °C vs. 120-150 °C), cause the formation of a crust on the surface of the product that allows the water to remain inside the product (Vittadini et al., 2005).

Moreover, as mentioned previously, meats are susceptibility to ProtOx (Estévez, 2015). During cooking, heat induced protein denaturation, which causes less water to be entrapped within the protein structures (Aaslyng et al., 2003). Therefore, texture profile can be affected due to modifications in the structure of myofibrillar proteins (Chiavarro et al., 2009). The extent and rate of these changes are related to heating temperature and time. In this regard, isothermal heating tests can be used to predict, understand and control quality changes during heating (Ling et al., 2015). In addition, freezing and thawing can change the water content in meat proteins. Consequently, freezing may adversely affect the raw meat quality and nutritional qualities after cooking, which are correlated with proteins thermal changes (Tornberg, 2005). These processes result in losses of essential amino acids leading to an overall decrease in protein quality (Sobral et al., 2020).

### Total Ashes

The total ash content, observed in the raw samples, before packaging and storage, was 1.97 ± 0.40%. The results of the ash content, found in the refrigerated/frozen samples, in conventional/vacuum packed samples, and after cooking, are presented in Table 6. The total ash content in raw samples (1.97%) was higher than the contents found in the post-storage (chilling/freezezing) samples (0.71-1.03%). Samples displayed higher percentages of ash content, increasing in all cooking methods, which would bring good nutritional benefits. Ash contents varied between the five studied methods. Moreover, significant differences were observed between the studied methods, as less water was added to the raw samples, regardless of cooking methods (Rosa, 2003). In the vacuum-packed samples, the lowest values were found in the samples cooked in household oven.

### Table 6 Total ash content (%) in chicken burger samples after storage (AS) and preparation with different cooking methods (C1, C2 and C3).

<table>
<thead>
<tr>
<th>Samples</th>
<th>AS (%)</th>
<th>C1 (%)</th>
<th>C2 (%)</th>
<th>C3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC</td>
<td>0.71±0.07a</td>
<td>1.69±0.04a</td>
<td>1.49±0.06a</td>
<td>1.57±0.05a</td>
</tr>
<tr>
<td>RV</td>
<td>0.78±0.07a</td>
<td>0.83±0.33a</td>
<td>1.41±0.22a</td>
<td>1.41±0.56a</td>
</tr>
<tr>
<td>FC</td>
<td>1.03±0.20b</td>
<td>1.71±0.38a</td>
<td>1.23±0.08a</td>
<td>1.51±0.03a</td>
</tr>
<tr>
<td>FV</td>
<td>0.88±0.25b</td>
<td>1.63±0.32a</td>
<td>1.18±0.18a</td>
<td>1.94±0.39a</td>
</tr>
</tbody>
</table>

** Different lowercase letters in the same row indicate a significant difference (p < 0.05) by Tukey's test.

** Different capital letters in the same column indicate a significant difference (p < 0.05) by Tukey test. RC - Refrigeration in conventional packaging; RV - Refrigeration in vacuum packaging; FC - Frozen in conventional packaging; FV - Frozen in vacuum packaging; AS - after storage / before applying the cooking method; C1 - Griddle cooking; C2 - Household oven cooking; C3 - Industrial oven cooking. Means and standard deviations in triplicates.

Within storage temperature effect, freezing the samples before cooking on the grill or in the industrial oven resulted in higher contents than those obtained in the refrigerated burgers. An opposite behaviour was observed when the samples were cooked in a household oven (1.45% vs. 1.21% for samples previously chilled and frozen, respectively). Moreover, significant differences were observed between the samples cooked in the oven, since the speed of the air, temperature reached and time of treatment were different between both types of oven. Only in the RV samples, the contents found were practically the same (1.41% for C2 and C3).

### Sensory Evaluation

Chicken is characterized by its pleasant flavours and can be prepared using several cooking methods, which ensure its safety (Langsrud et al., 2020). During these processes, the chicken is subjected to high temperatures, depending on the desired characteristics of the final product. Changes in sensory characteristics are accompanied by the re-lease of distinctive smells, changes in texture, and transformations in appearance due to complex chemical changes that occur in the
chicken during cooking (Fedorov et al., 2021). The chicken burger samples were sensory evaluated for colour, flavour, texture, juiciness, tenderness and overall sensory acceptability (Figure 3).

The treatments that received the lowest scores (Figure 3c) for juiciness were the samples stored at freezing temperature (FC). This reflected that although freezing is characterized by its efficiency in inhibiting microbial proliferation, it does not completely prevent the chemical and biochemical reactions, and physico-chemical and sensory changes can still occur in the frozen product during storage (Salgado et al., 2013). The results show that refrigeration storage (Figure 3a) favoured the juiciness of chicken burgers (C1, C2 and C3), but the application of vacuum (RV) was the best option to maintain the juiciness (p < 0.05) in the samples prepared in an industrial oven, with forced-air convection (Figure 3b). The vacuum packaging of meat (refrigerated/frozen) can help to minimize some of physico-chemical changes, reducing or avoiding the occurrence of dehydration, oxidation and freeze burn (Muela et al., 2010). In addition, regardless of the cooking method used (C1, C2 and C3) and the internal pressure of the packages (≤ 1 atm), refrigerated storage (4 °C) contributed to the best scores (p < 0.05) for colour, flavour and texture attributes (Figure 3b). Similar results were observed by Angel-Rendon et al. (2020), who associate vacuum cooked meats as paler meats. The tenderness of the vacuum-packed samples (FVC1, FVC2 and RV/C3) received the best scores (p < 0.05) by the sensory panel (Figure 3c and 3d).

The samples that presented the best acceptance index (Table 7) were the vacuum frozen (FV) samples prepared in the industrial oven, conventional oven and griddle (90%, 82.66% and 74.33%, respectively). It is in agreement with the results found by Fernandes et al. (2012), who observed that samples FV remained sensorially acceptable even at the end of the storage period.

![Figure 3](https://example.com/figure3.png)

**Figure 3** Average scores assigned to the sensory attributes (colour, flavour, texture, juiciness, tenderness and overall sensory acceptability), of the different chicken burger samples, stored (a) under refrigeration and packed at atmospheric pressure, (b) under refrigeration and vacuum-packed, (c) under frozen and packed at atmospheric pressure and (d) under frozen and vacuum-packed, after cooking (C1, C2 and C3). RC - Refrigeration in conventional packaging; RV - Refrigeration in vacuum packaging; FC - Frozen in conventional packaging; FV - Frozen in vacuum packaging; C1 - Griddle cooking; C2 - Household oven cooking; C3 - Industrial oven cooking.

| Table 7 Information about the storage parameters (temperature and atmospheric pressure) and cooking methods (C1, C2 and C3) and their respective acceptability index (AI). |
|---------------------------------|-------|--------|
| **Samples** | **Cooking Method** | **AI (%)** |
| RC | C1 | 64.55\(^\text{a}\) |
| RV | C1 | 55.88\(^\text{a}\) |
| FC | C1 | 49.77\(^\text{a}\) |
| FV | C1 | 74.33\(^\text{a}\) |
| RC | C2 | 80.88\(^\text{a}\) |
| RV | C2 | 79.88\(^\text{a}\) |
| FC | C2 | 82.66\(^\text{a}\) |
| FV | C2 | 64.22\(^\text{a}\) |
| RC | C3 | 80.55\(^\text{a}\) |
| RV | C3 | 75.55\(^\text{a}\) |
| FC | C3 | 90.00\(^\text{a}\) |

\(^{a}\) Different lowercase letters in the same column indicate a significant difference (p < 0.05) by Tukey test.

The worst acceptance index of the samples prepared with cooking methods C1, C2 and C3 (49.77%, 71.66% and 64.22%), were for samples stored in conventional packaging (FC/C1 and C2, RC/C3).

**CONCLUSION**

Cooking conditions, including equipment, temperature, and time, influence the nutritional characteristics and sensory quality of chicken meat burgers. The results of the study demonstrated that refrigeration storage positively impacted the moisture content and juiciness of the chicken burgers (C1, C2, and C3), while the use of vacuum packaging (RV) was found to be the most effective method for...
maintaining juiciness in the samples prepared in an industrial oven. The samples stored at freezing temperature under 1 atm pressure (FC) received the lowest scores for juiciness. Furthermore, irrespective of the cooking method employed (C1, C2, and C3) and the internal pressure of the packages (≤ 1 atm), refrigerated storage yielded the highest scores for color and flavor attributes. The refrigerated samples in vacuum packaging (FVC1 and C2, RC/C3) exhibited the lowest acceptance index, showing a statistically significant difference among the cooking methods.

Acknowledgments: This research was supported and funded by the Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina- FAPESC, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES [finance code 001] and Regional University of Blumenau (PURB). The authors gratefully acknowledge the contribution of the University of Blumenau (PURB). Thanks to GAIN (Axencia Galega de Innovación) for supporting this study, (grant number IN607A2019/01). Jose M. Lorenzo and Mirian Pateiro are members of the HealthyMeal network, funded by CYTED (Ref:119RT0568).

REFERENCES


Andrade, M. C. G., (2014). Avaliação da qualidade microbiológica de carnes de peito de frangos de corte submetidas a diferentes temperaturas do ambiente de processamento. 57ª Dissertação (Mestrado em Tecnologia e Inspeção de Produtos de Origem Animal) – Universidade Federal de Minas Gerais, Belo Horizonte, Brazil.


Andrade, M. C. G., (2014). Avaliação da qualidade microbiológica de carnes de peito de frangos de corte submetidas a diferentes temperaturas do ambiente de processamento. 57ª Dissertação (Mestrado em Tecnologia e Inspeção de Produtos de Origem Animal) – Universidade Federal de Minas Gerais, Belo Horizonte, Brazil.


fruits and vegetables under refrigerated conditions. Chemical Engineering Transactions, 87, 115-120. https://doi.org/10.3303/CET1827020