JMBFS

Journal of Microbiology, Biotechnology and Food Sciences

International peer-reviewed scientific online journal

Published by Faculty of Biotechnology and Food Sciences

INTERACTION OF HEAT TRANSFER METHODS, STORAGE TEMPERATURE AND PACKAGING ATMOSPHERE ON QUALITY OF PROCESSED CHICKEN MEAT

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https://doi.org/10.55251/jmbfs.10251

ARTICLE INFO

Received 6. 1. 2023
Revised 31. 5. 2023
Accepted 5. 6. 2023
Published 1. 10. 2023

Regular article

OPEN ACCESS

ABSTRACT

This research investigated the combined effects of cooking methods (household griddle (C1), household conventional oven (C2), industrial oven (C3), storage temperature (refrigeration /freezing) and packaging system (aerobic and vacuum), on quality of chicken burgers. The results show that refrigeration storage favours the retention of moisture content and the juiciness of chicken burgers, but the application of vacuum (RV) was the best option to maintain the juiciness and moisture content ($p < 0.05$) of the samples prepared in an industrial oven with forced-air convection. The highest protein content was observed in the samples that were frozen in vacuum packaging (FV), and the lipid content was highest in the samples chilled in conventional packaging (RC) at 1 atm. Regardless of the cooking method used and the internal pressure of the packages (≤ 1 atm), refrigerated storage contributed to the best scores ($p < 0.05$) for color and flavor attributes. The treatments that presented the highest sensory acceptance index were the frozen samples in vacuum packaging prepared in the industrial oven, conventional oven, and grill (90%, 82.66%, and 74.33%, respectively).

Keywords: Chicken burger, Cold application, Modified atmosphere, Cooking conditions, Quality parameters

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, and the fourth largest consumer (**ABPA, 2021**). The popularity 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 (**Augustynska-Prejsnar & Ormian, 2019**).The quality of meat is influenced by factors such as packaging, storage conditions, gas composition (O_2, CO_2, inert gases) around the tissues, relative humidity (RH), light, and temperature (**Singh & Cadwallader, 2004; Angioletti, *et al.*,** 2020a). A widely used method to increase 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 (**Schlei *et al.*, 2020**), while freezing allows for the preservation of food characteristics for even longer periods (**Ojha *et al.*, 2016**). However, during freezing, ice crystals are formed, which can cause the rupture of cell structures and significant water loss during thawing (**Ojha *et al.*, 2016; Vieira, 2007**). Besides, the size, orientation, and localization of ice crystals can also cause modifications 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 (**Domínguez *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 (**AlI *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-Arias *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.

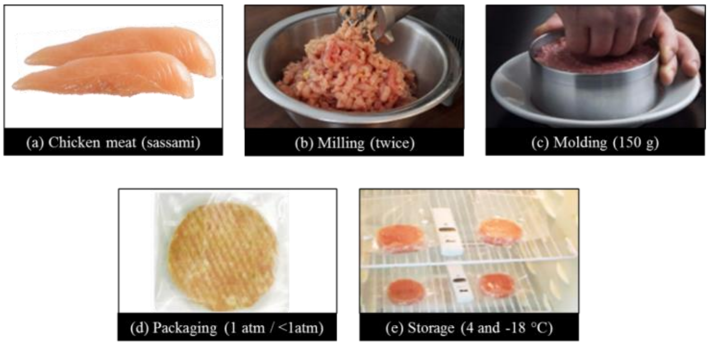

Figure 1 Flowchart of the steps in the process of developing chicken burger samples.

Storage Conditions

The chilled chicken hamburger samples were stored in an Incubator - B.O.D. (Biochemical 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 burger were cooked and flipped in the 3 cooking methods, whose optimal temperatures and times (Table 1) were previously defined in pre-tests (until a well-done burger), so that the inside of the burger (skewer thermometer, Incoterm, AF1506 model) reached a temperature of 75 °C and a "golden" surface colour (**MARTÍNEZ** *et al.*, 2009)
The equipment used for cooking were: household griddle (non-stick), household electric oven (Fischer brand, with natural convection) and industrial gas oven (Pró-Gás brand, with forced convection / hot air flow of 5.5 m s^{-1}).

Table 1 Time and temperature applied in chicken burgers cooking methodologies.

Cooking Methods	Refrigerated Samples (T_0 = 4 °C)		Frozen Samples (T_0= -18 °C)	
	T (°C)	**Time (min)**	**T (°C)**	**Time (min)**
Household Griddle	180	5* + 5	180	10* + 5
Household Oven	150	15* + 5	150	20* + 5
Industrial Oven	120	10* + 5	120	15* + 5

*The first time corresponds to the time that the sample remained on one side and then was turned over. The sum of the times corresponds to the total time. The ovens were preheated for 15 minutes.

Experimental Design and Statistical Analysis

Statistical analyses were performed using the software Statistica (version 7.0, StatSoft Inc., Oklahoma, USA, 2004). Normal distribution and variance homogeneity had been previously tested (Shapiro-Wilk). The experimental data were analysed by ANOVA, with the mean comparison (Tukey's test). The difference was considered significant if $p < 0.05$. The experimental matrix, used for the execution of the tests, is shown in Table 2.

Table 2 Experimental design matrix.

Test	Cooking Method	Packaging (internal pressure*)	Storage Temperature (°C)
1	C1 (household Griddle)	<1 atm	-18 ± 1.0
2	C1 (household Griddle)	1 atm	-18 ± 1.0
3	C1 (household Griddle)	<1 atm	4 ± 1.0
4	C1 (household Griddle)	1 atm	4 ± 1.0
5	C2 (household oven)	<1 atm	-18 ± 1.0
6	C2(household oven)	1 atm	-18 ± 1.0
7	C2 (household oven)	<1 atm	4 ± 1.0
8	C2 (household oven)	1 atm	4 ± 1.0
9	C3 (industrial oven)	<1 atm	-18 ± 1.0
10	C3 (industrial oven)	1 atm	-18 ± 1.0
11	C3 (industrial oven)	<1 atm	4 ± 1.0
12	C3 (industrial oven)	1 atm	4 ± 1.0

* 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:

$$\text{Moisture content (\%)} = \frac{(\text{cooked weight} - \text{initial raw weight})}{(\text{initial raw weight})} \; x\,100$$

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).

Sensorial 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 (**Meilgaard *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).

Figure 2 Diagram showing the main information referring to the sensory tests.

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:

$$AI\ (\%) = (M * 100)\ K^{-1}$$

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).

Samples	AS (%)	C1 (%)	C2 (%)	C3 (%)
RC	$75.46\pm0.07^{a}_{A}$	$69.59\pm0.62^{ab}_{A}$	$66.86\pm1.01^{bc}_{AC}$	$62.33\pm3.83^{cd}_{A}$
RV	$75.55\pm0.12^{a}_{A}$	$67.79\pm1.03^{b}_{A}$	$65.65\pm1.17^{b}_{A}$	$64.31\pm1.21^{b}_{A}$
FC	$75.99\pm0.22^{a}_{A}$	$54.59\pm0.37^{b}_{B}$	$61.10\pm1.81^{b}_{B}$	$56.21\pm1.81^{b}_{B}$
FV	$70.94\pm6.15^{a}_{A}$	$58.20\pm2.91^{bcd}_{B}$	$68.59\pm0.55^{c}_{C}$	$60.93\pm1.59^{cd}_{AB}$

[a-d] Different lowercase letters in the same row indicate a significant difference ($p < 0.05$) by Tukey's test. [A-C] 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.

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 **Echegaray *et al.* (2020)** in the moisture contents of *Longissimus thoracis et lumborum* 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 (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 meat 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 griddle showed the lowest value of final moisture (54.59%), while those baked in a conventional household oven showed the highest value (61.10%). Regarding the samples frozen under vacuum packing (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 (69.59%) of the chicken meat samples. 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 the meat can form a crust that impairs the transfer of heat and energy through water 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 acceptance. 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).

Samples	AS (%)	C1 (%)	C2 (%)	C3 (%)
RC	$0.72\pm0.00^{b}_{A}$	$1.88\pm0.46^{a}_{A}$	$1.42\pm0.47^{a}_{A}$	$1.28\pm0.21^{a}_{A}$
RV	$0.71\pm0.09^{b}_{A}$	$1.10\pm0.13^{a}_{B}$	$0.76\pm0.17^{b}_{B}$	$1.06\pm0.32^{ab}_{A}$
FC	$0.66\pm0.08^{b}_{A}$	$1.07\pm0.18^{a}_{B}$	$0.66\pm0.28^{ab}_{B}$	$0.57\pm0.19^{b}_{B}$
FV	$0.52\pm0.04^{b}_{A}$	$1.65\pm0.23^{a}_{A}$	$0.84\pm0.14^{b}_{B}$	$0.52\pm0.15^{b}_{B}$

[a-d] Different lowercase letters in the same row indicate a significant difference ($p < 0.05$) by Tukey's test.
[A-B] 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.

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 was 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, conventional 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 a*l., 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 roasting, grilling, microwaving, 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/freezing, 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).

Samples	AS (%)	C1 (%)	C2 (%)	C3 (%)
RC	$23.56\pm1.22^{a}_{A}$	$29.98\pm0.63^{b}_{A}$	$31.55\pm1.93^{bc}_{AB}$	$34.43\pm0.52^{c}_{A}$
RV	$23.63\pm0.30^{a}_{A}$	$29.20\pm0.24^{b}_{A}$	$32.23\pm0.63^{c}_{AB}$	$33.55\pm0.81^{c}_{A}$
FC	$22.07\pm0.57^{a}_{A}$	$38.40\pm0.45^{b}_{B}$	$33.59\pm1.19^{c}_{A}$	$39.50\pm1.30^{bc}_{B}$
FV	$23.14\pm0.93^{a}_{A}$	$40.99\pm3.92^{c}_{B}$	$30.80\pm1.09^{b}_{B}$	$35.71\pm1.35^{bc}_{A}$

[a-d] Different lowercase letters in the same row indicate a significant difference ($p < 0.05$) by Tukey's test.
[A-B] 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.

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 in the literature (**Juárez *et al*., 2010**).

Regarding storage temperature effect, chicken burger samples showed higher protein contents when they were stored under freezing conditions (39.50% *vs.* 34.43%), except for the vacuum frozen (FV) sample prepared in the home oven (33.59 *vs.* 30.80%). This is could be due to frozen samples required a longer cooking time, resulting in a product with lower moisture content. On the other hand, in the refrigerated (conventional and vacuum packed) and conventional frozen (FC) samples, those prepared in an industrial oven showed higher protein content. Samples stored under refrigeration showed no statistically significant change, while FC displayed significantly higher values (39.50% *vs.* 34.43% and 33.55% for FC, RC and RV, respectively). In the case of vacuum-frozen samples (FV), those prepared on the griddle (C1) showed a higher percentage of protein compared to the other cooking methods (40.99% *vs.* 35.71% and 30.80% for griddle cooking, industrial oven and household oven, respectively).

In general, samples cooked in the oven had higher values than those obtained from the griddle. This is in agreement with the results found by other authors in pork (**Echegaray *et al*., 2020; Echegaray *et al*., 2020a**) and in chicken breast and thigh (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 griddle), 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 (**Chiavaro *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 application of storage conditions, was 1.97 ± 0.40%. The results of the ash content, found in the refrigerated/frozen samples, in conventional/vacuum packaged 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/freezing) samples (0.71-1.03%). Samples displayed higher percentages of ash after cooking in all methods, which would be related to the reduction of moisture contents and the nutrients concentration. the same trend was previously observed by other authors in buffalo and chicken meat **(juárez *et al*., 2010; hussain *et al*., 2013**).

Regarding conventional packaging, grilled samples were those that showed the highest contents both in chilled and frozen samples. This did not coincide with the results found by other authors in cooked pork meat, where roasted meat showed higher contents than those obtained in grilled samples (1.95% *vs.* 1.76%) (**Echegaray *et al*., 2020**). On the contrary, **Hussain *et al.* (2013)** did not find significant differences between grilled and microwaved samples (3.1% *vs.* 3.6%), showing higher values than those obtained in the present study. The same behaviour was found in chicken breasts, which displayed higher ash contents when they were roasted in microwave, grilled or fried (1.42%, 1.25% and 1.35%, respectively) (**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).

Samples	AS (%)	C1 (%)	C2 (%)	C3 (%)
RC	$0.71\pm0.07^{a}_{A}$	$1.69\pm0.04^{b}_{A}$	$1.49\pm0.06^{b}_{A}$	$1.57\pm0.05^{b}_{A}$
RV	$0.78\pm0.07^{a}_{A}$	$0.83\pm0.33^{a}_{B}$	$1.41\pm0.22^{b}_{A}$	$1.41\pm0.56^{b}_{A}$
FC	$1.03\pm0.20^{a}_{A}$	$1.71\pm0.38^{a}_{A}$	$1.23\pm0.08^{ab}_{A}$	$1.51\pm0.03^{b}_{A}$
FV	$0.88\pm0.25^{a}_{A}$	$1.63\pm0.32^{ab}_{A}$	$1.18\pm0.18^{a}_{A}$	$1.94\pm0.39^{b}_{A}$

[a-d] Different lowercase letters in the same row indicate a significant difference ($p < 0.05$) by Tukey's test.
[A-B] 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 ovens. Only in the RV samples, the contents found were practically the same (1.41% for C2 and C3).

Sensorial 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).

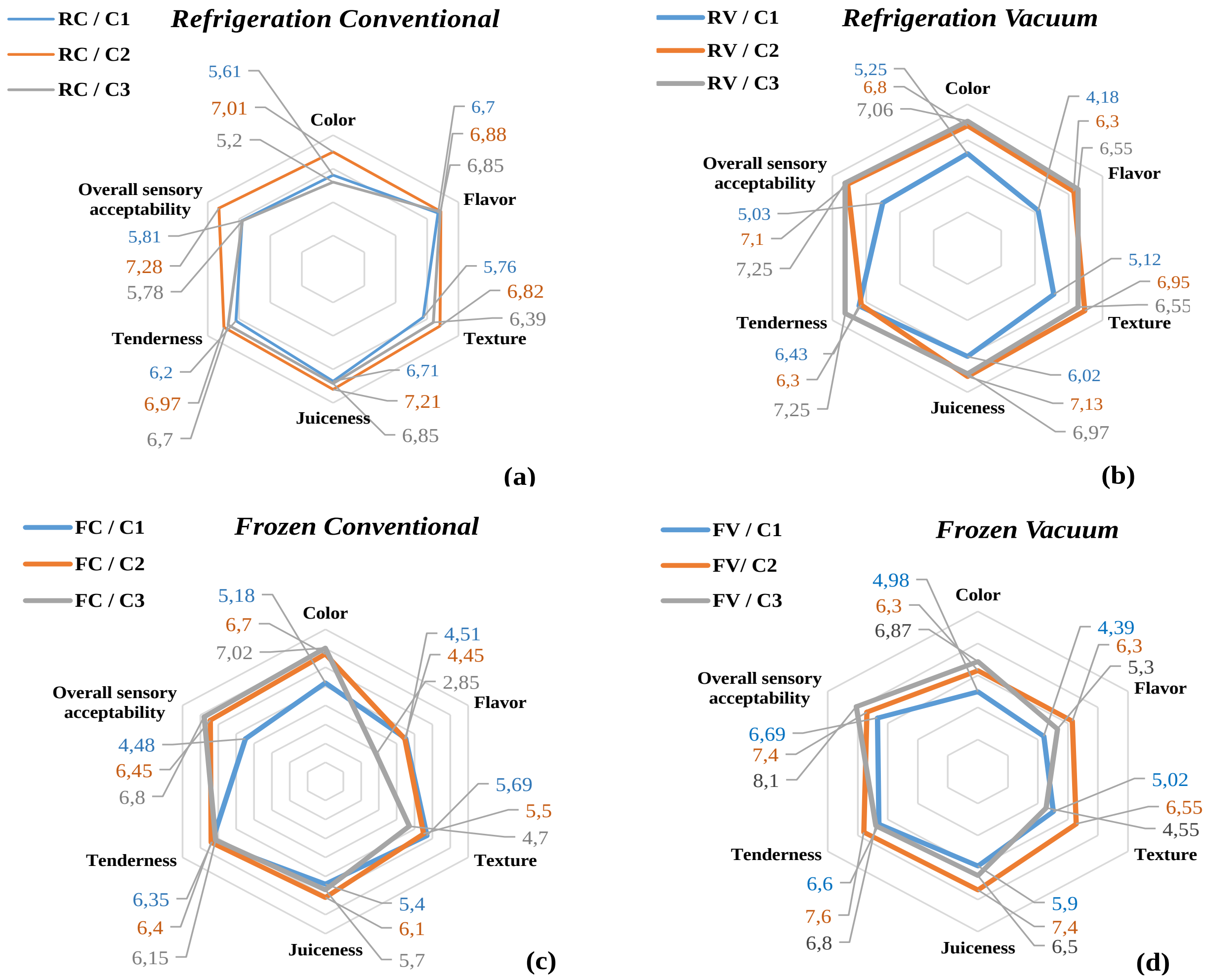

Figure 3 Average scores assigned to the sensory attributes (colour, flavour, texture, juiciness, tenderness and overall sensory acceptability), of the different chicken burger samples, stored (a) under refrigeration and packed at atmospheric pressure, (b) under refrigeration and vacuum-packed, (c) under 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.

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 (**Sañudo *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 **Ángel-Rendón *et al.* (2020)**, who associate vacuum cooked meats as paler meats. The tenderness of the vacuum-packed samples (FV/C1, FV/C2 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 that observed that samples FV remained sensorially acceptable even at the end of the storage period.

Table 7 Information about the storage parameters (temperature and atmospheric pressure) and cooking methods (C1, C2 and C3) and their respective acceptance index (AI).

Samples	Cooking Method	AI (%)
RC	C1	64.55^{c}
RV	C1	55.88^{b}
FC	C1	49.77^{a}
FV	C1	74.33^{d}
RC	C2	80.88^{e}
RV	C2	79.88^{e}
FC	C2	71.66^{d}
FV	C2	82.66^{f}
RC	C3	64.22^{c}
RV	C3	80.55^{e}
FC	C3	75.55^{d}
FV	C3	90.00^{g}

$^{a\text{-}g}$ 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 (FV), prepared in the industrial oven, received the highest sensory acceptance index (90%). On the other hand, the samples stored in conventional packaging (FC/C1 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 (FURB). The authors gratefully acknowledge Regional University of Blumenau (FURB). 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 HealthyMeat network, funded by CYTED (Ref.119RT0568).

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