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Wooden Breast Chicken Fillets: Viability in the Preparation of Hamburgers and Bologna

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HIGHLIGHTS

- Hamburgers and bologna with WB did not show changes quality parameters.
- Chicken meat products are a suitable purpose for WB fillets.
- Use in chicken meat products can minimize the negative effects of WB anomaly.

Abstract: This study aimed to evaluate the viability of using wooden breast (WB) chicken fillets in the production of hamburgers and bologna. Fillets (*pectoralis major*) were collected from a commercial slaughterhouse and classified as normal (no visible alteration) or WB (with characteristic visual alterations) by a trained specialist. The quality parameters and physical, chemical, and technological stability of the resulting meat products during the storage period, at 1, 30, 60, and 90 days from production were evaluated. Hamburgers with WB showed a significant increase of 2.38% in moisture content and a reduction of 17% in protein content, whereas bologna showed an increase of 1.15% in moisture content. The inclusion of WB meat did not influence the yield and stability of these products, but resulted in higher pH and softer hamburgers with greater lipid oxidation. The results suggest that the manufacture of meat products with a lower percentage of WB meat in their formulation is a viable alternative to minimize costs and reduce economic losses generated by the incidence of the anomaly.

Keywords: broilers; degeneration; meat products; myopathy; texture profile analysis.

INTRODUCTION

In recent years, chicken meat has stood out among the animal-source proteins offered on the market and is one of the most consumed animal protein in the world [1]. Factors associated with low cost, ease and diversity of preparation, nutritional and sensory properties, and consumption free of religious or cultural

restrictions are responsible for the growing increase in consumption and interest in chicken meat [1,2].

The poultry industry is driven to perform intense genetic selection to obtain chickens with a shorter slaughter time (5-8 weeks) and higher growth rates and carcass yield [1]. The rapid growth of these birds, mainly induced by chicken breast hypertrophy, results in cardiovascular diseases, fibers with less capillarization, and inadequate supply of nutrients and oxygen, with consequent ischemia and hypoxia, leading to the incidence of abnormalities such as wooden breast (WB) [3,4].

Chicken fillets compromised by WB anomaly are mainly characterized by increased palpable hardness, pale color, a bulge in the caudal and cranial regions, presence of exudate, and small hemorrhages [5,6]. Histologically, the muscle fibers of WB present lesions resulting from inflammatory processes, which can be observed in the presence of T lymphocytes and high levels of histamine in the muscle [7,8]. Furthermore, WB contains muscle fibers with moderate to severe degeneration, variation in fiber diameter and size, and accumulation of connective tissue (fibrosis), with a consequent increase in collagen deposition and intramuscular fat accumulation (lipidosis) [5]. This increase in collagen deposition may be directly related to the increased hardness of these fillets [5,9,10]. Degeneration of muscle fibers causes structural changes, such as increased moisture content and reduced protein content [9,11].

Depending on the severity of the anomaly, its incidence directly and significantly reflects low acceptance and purchase intention [10]; therefore, WB meat if often designated for the manufacture of meat products [12]. The use of meat with less acceptance in meat products enables its use in partial or total replacement of normal meat, generally used in crushed and emulsified products [13,14]. WB is sometimes accompanied by striping (WS), characterized by the presence of white striations on the surface [12]. Bordignon and coauthors [14] reported that the production of chicken nuggets and hamburgers is a suitable purpose for WS fillets. Thus, the use of WB fillets in the preparation of meat products could be a suitable alternative to add value to these cuts. In this context, this study aimed to evaluate the viability of WB fillets in the preparation of hamburgers and bologna.

MATERIAL AND METHODS

Sample collection

This research project was approved by the Animal Use Ethics Committee of the State University of Londrina (CEUA Protocol no. 10861.2018.12). For the experiment, 80 chicken fillets (*pectoralis major*) from broilers of mixed sex, same flock (Ross 308), aged 47 days with an average weight of approximately 3.51 kg were collected from a commercial poultry slaughterhouse located in the state of Paraná, Brazil. Chickens were slaughtered according to standard procedures. The classification of chicken fillets was performed by a trained specialist based on tactile and visual inspection, as described previously [5] WB fillets (n=40) were identified by palpable hardness, presence of pale areas and small hemorrhages, exudates, and bulges in the caudal and cranial regions. Normal fillets (n=40) were identified in the absence of any visual anomalies.

Preparation of meat products

Two types of meat products, bologna and hamburger, were produced to assess the viability of using chicken fillets affected by WB anomalies. The products were evaluated for their approximate chemical composition, stability of quality, and technological parameters during the storage period (1, 30, 60, and 90 days after manufacture). The hamburgers and bologna were stored at −18 °C and 4 °C, respectively, according to commercial practices.

Hamburgers were prepared using the following formulation:68.49% chicken fillet (normal or WB), 15.0% animal fat, 4.0% isolated soy protein, 10.0% water, 1.7% salt, 0.15% sodium glutamate, 0.25% sodium erythorbate, 0.20% garlic powder, 0.06% onion powder, and 0.15% white pepper powder. The chicken fillets were crushed and homogenized with water and animal fat, and other ingredients were added and mixed. The hamburgers were molded to weigh approximately 110.0 g (± 10.0 g) and stored at −18 °C until further analysis. In total, 64 hamburgers were prepared, with 32 hamburgers of each meat type.

Bologna was prepared using the following formulation:39.96% chicken fillet (normal or WB), 23.0% mechanically separated meat, 15.1% ice, 11.67% chicken skin, 4.0% isolated soy protein, 3.0% cassava starch, 1.8% salt, 0.25% sodium tripolyphosphate, 0.6% sugar, 0.1% erythorbate, 0.1% curing sodium salt, 0.2% garlic powder, 0.06% onion powder, 0.08% white pepper, and 0.08% paprika. In total, 64 bologna were prepared, with 32 bologna of each meat type.

For the preparation of the bologna, the emulsion was performed in a cutter. The dough was then embedded in an artificial polyamide casing in units of approximately 300 g (± 50.0 g) each, subjected to

gradual cooking until it reached an internal temperature of 72 °C, and then subjected to thermal shock with water under pressure. The bologna were stored at 4 °C until further analysis.

Physical, chemical, and technological analyses of meat products

The chicken bologna and hamburgers were evaluated for quality parameters and physical, chemical, and technological stability during storage at 1, 30, 60, and 90 days from their production. At each time point, 8 hamburgers and 8 bolognas of each formulation were tested in triplicate.

Approximate chemical composition

Moisture, protein, ash, and lipid contents of chicken bologna and hamburgers were determined as described previously [15]. The moisture content was determined using the drying method in an oven at 105 °C until a constant weight was achieved. Ash content was quantified by incineration in a muffle furnace at 550 °C. Lipids were determined using the Soxhlet method with petroleum ether, and proteins were quantified using the Kjeldahl method.

Color and pH

The color of the meat products was determined using a Minolta CR400 Colorimeter with D65 illuminant. The results for L* (lightness), a* (green-red component), and b* (blue-yellow component) were expressed in the CIELab system [16]. The pH value was obtained by inserting an electrode in the contact potentiometer (Texto 205, Brazil), as described previously [17].

Water holding capacity (WHC) and water activity

WHC was quantified as described previously [18]. Samples of manufactured products (10.0 g) were cut into small cubes, transferred to plastic tubes, and heated in a water bath at 90 °C for 10 min. The samples were then cooled to room temperature, wrapped in gauze, and transferred to centrifuge tubes lined with cotton at the base. The samples were centrifuged at 8200 rpm at 4 °C for 10 min, and then weighed. The WHC of the samples was determined using Eq. (1):

$$\% \text{ WHC} = 1 - (Wi - Wf/M) \times 100, \quad (1)$$

where Wi and Wf are the initial and final sample weights, respectively, and M is sample moisture.

Water activity (aw) of bologna was measured in triplicate using a dew point in an Aqualab 4 water activity meter (AquaLab Series 4TEV, Decagon Devices Inc., Pullman, WA) with a precision of ±0.003.

Texture profile analysis

Texture profile analysis was performed in a texture analyzer (TAXT-2i) with a cylindrical probe (P035), under the conditions described previously [19]: height: 50 mm, pre-test speed: 5.0 cm min−1, test speed: 20.0 cm min−1, post-test speed: 10 cm min−1, distance: 0.70 cm, and force: 0.98 N. The analysis for hamburgers was performed with samples cut into cubes of 1 cm3 for each formulation of the grilled product, and the measurement for bologna was performed in cylindrical portions with a diameter of 3.0 cm and height of 2.2 cm. Each sample was subjected to six repetitions and five parameters were measured: hardness, elasticity, cohesiveness, chewiness, and resilience.

Yield after cooking and shrinking

The yield and shrinkage were evaluated only for hamburgers, as described previously [20]. Samples of each formulation were tested in triplicate. The hamburgers were weighed and grilled at 150 °C. After cooking, the hamburgers were cooled to room temperature and weighed.

Equations for % yield (1) and % shrinkage (2):

(1) % cooking yield = (Wf/Wi) × 100, where Wf and Wi correspond to the weight of the cooked and raw samples, respectively.

(2) % shrinkage = [(diameter of the raw sample - diameter of the cooked sample) / diameter of the raw sample] × 100.

Lipid oxidation

Lipid oxidation of meat products was measured by the method of reagent substances with thiobarbituric acid (TBARS) via the precipitation technique as described previously [21]. The values were expressed in mg of malondialdehyde (MDA) / kg of the sample. The analyses were performed on hamburgers and bologna stored at −18 °C and 4 °C, respectively, at 1, 30, 60, and 90 days after manufacture.

Statistical analyses

The results were analyzed using the Student's t-test to compare the types of hamburgers and bologna used. Tukey's test was used to evaluate the results obtained during the storage period (1, 30, 60, and 90 days after manufacture) using STATISTICA 7.0. Statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Hamburgers produced with WB fillets showed significant changes in their approximate chemical compositions (Table 1). Hamburgers with WB fillets showed an increase ($p < 0.05$) of 2.38% in moisture content and a 17% reduction in protein content compared to the control hamburger. Lipid and ash contents did not differ ($p > 0.05$) between the two types of hamburgers. Although WB chicken fillets had higher lipid content than normal fillets [10], no differences were observed in lipid content between the meat products (hamburger and bologna) manufactured with WB and those with normal fillets (Table 1). This finding is most likely due to the addition of other sources of fat, such as skin and CMS in the formulations, as a previous study also showed no significant difference in lipid content between sausages made with WB and normal fillets [22].

Table 1. Approximate chemical composition of hamburgers and bologna prepared with normal and WB fillets.

Meat product	Type of fillet	Moisture (%)	Proteins (%)	Lipids (%)	Ash (%)
Hamburger	**Normal**	$70.66^{b} \pm 0.39$	$21.02^{a} \pm 1.60$	$6.26^{a} \pm 0.25$	$2.70^{a} \pm 0.25$
	WB	$72.34^{a} \pm 0.17$	$17.46^{b} \pm 0.51$	$6.36^{a} \pm 0.23$	$2.69^{a} \pm 0.28$
Bologna	**Normal**	$65.59^{b} \pm 0.21$	$15.48^{a} \pm 0.26$	$6.17^{a} \pm 0.50$	$3.42^{a} \pm 0.02$
	WB	$66.37^{a} \pm 0.38$	$14.74^{a} \pm 0.56$	$6.61^{a} \pm 0.19$	$3.43^{a} \pm 0.03$

$^{a.b}$ Different letters on the same row denote statistical difference based on the Student's t-test ($p < 0.05$).

WB fillets showed a 1.15% increase in moisture content. These results are likely due to the inflammatory and degenerative muscle fiber processes that affect chickens with WB [23, 9]. According to the Technical Regulation of Identity and Quality (Brazil, 2000), the maximum moisture content allowed in chicken bologna is 65.0%; thus, adding ingredients to reduce the moisture content would be necessary for the use WB fillets in the manufacture of this emulsified product within the established standards.

Hamburgers with WB fillets did not differ from normal hamburgers in terms of cooking yield during storage (Table 2). Both hamburgers also showed stability in this parameter throughout the evaluation period. Regarding hamburger shrinkage, no difference was observed between the two classes of hamburgers; additionally, the percentage of shrinkage did not show a significant difference during the storage period. Other authors [13] also observed that the addition of fillets containing WB in the preparation of nuggets and sausages did not influence the yield of these products. WB chicken fillets have a low WHC due to a reduction in myofibrillar proteins, which are mainly responsible for the ability to retain water in their structure [23]. Despite the WB hamburgers having lower protein content and higher moisture content (Table 1), these results did not affect the yield and stability of hamburgers during storage, probably because of the presence of ingredients and additives used in the hamburger formulation. These results show that the use of WB fillets as a raw material in the preparation of hamburgers is a viable alternative for the use of these fillets, minimizing the financial losses generated by WB incidence.

Table 2. Cooking yield (%) and shrinkage (%) of hamburgers prepared with normal fillet and WB during the storage period.

Type of fillet	Storage period			
	1 day	**30 days**	**60 days**	**90 days**
	Cooking yield (%)			
Normal	88.26^{aA} ± 1.63	85.17^{aA} ± 2.01	87.55^{aA} ± 1.38	83.59^{aA} ± 2.68
WB	85.71^{aA} ± 1.78	85.94^{aA} ± 1.33	84.19^{aA} ± 2.59	86.89^{aA} ± 0.41
	Shrinkage (%)			
Normal	9.59^{aA} ± 0.73	9.47^{aA} ± 1.63	9.22^{aA} ± 1.84	9.10^{aA} ± 1.27
WB	9.06^{aA} ± 1.43	9.40^{aA} ± 0.53	10.04^{aA} ± 0.34	9.61^{aA} ± 0.53

^{a,b} Different letters in the same column denote statistical difference based on the Student's t-test ($p < 0.05$).
^{A,B} Different letters on the same row denote statistical difference based on Tukey's test ($p < 0.05$).

The results for color (L*, a*, and b*) during the storage period for the hamburgers and bologna are shown in Table 3. Hamburgers produced with WB fillets showed greater lightness (L* value) ($p < 0.05$) after 1 day. Meanwhile, bologna had the highest L* values ($p < 0.05$) on days 1, 30, and 60. Other authors [13] also noted an increase in the L* value when adding WB fillets into nuggets and sausages. According to previous findings [5,10], WB fillets have a higher L* value with the presence of pale areas, a macroscopically observed characteristic, which is one of the main visual changes considered in the detection of fillets with the anomaly. Chicken fillets affected by WB show denaturation of sarcoplasmic proteins, degeneration of muscle fibers, and an increase in intramuscular fat deposition (lipidosis), processes responsible for paler meat [23,7], and consequently, greater lightness. Such histological changes were also reported in the PSE (pale, soft, and exudative) anomaly, which also increases the lightness of chicken fillets [25,26]. The chicken breast fillet was the ingredient present at the highest percentage in both manufactured meat products, corresponding to approximately 68.0% of the hamburger formulation and 39.0% of the bologna. Therefore, the highest L* value after one day of the manufacture of hamburgers and up to 60 days for bologna produced with WB fillets can be attributed mainly to the type of fillet. The formulation used for the hamburger and bologna was not sufficient to correct the L* value; however, the difference was small; moreover, it cannot be observed by consumers, as the threshold for human detection is 2 units of CIELab [27]. No significant differences ($p>0.05$) were observed at other storage time points between the formulations of bologna and hamburgers. Furthermore, both products showed stable L* values during storage.

No differences were observed in the a* value (red-green component) between the two formulations for hamburgers and bologna, and both remained stable during the storage period. In contrast, the b* value (yellow-blue component) showed that the hamburgers with WB fillets had a greater intensity of yellow color at 1 and 30 days after manufacturing. However, no differences were observed between the two formulations after 60 days. Moreover, no significant differences were observed ($p>0.05$) between bologna manufactured with WB and normal fillets. The greater intensity of the yellow color observed during earlier storage of hamburgers may be associated with the presence of yellowish areas in the chicken fillets affected by the anomaly; considering that hamburgers had a higher proportion of chicken fillets, they consequently had a higher b* value [10].

Table 3 Color (L*, a* e b*) of meat products prepared with normal fillet and *WB* during the storage period.

Meat product	Type of fillet	Storage period			
		1 day	30 days	60 days	90 days
		L* (lightness)			
Hamburgers	**Normal**	$60.66^{bB} \pm 0.38$	$63.11^{aA} \pm 0.47$	$60.81^{aB} \pm 0.50$	$62.82^{aA} \pm 0.49$
	WB	$61.93^{aAB} \pm 0.93$	$63.57^{aA} \pm 0.79$	$61.57^{aB} \pm 0.84$	$63.36^{aA} \pm 0.84$
Bologna	**Normal**	$64.80^{bA} \pm 0.37$	$65.08^{bA} \pm 0.75$	$64.93^{bA} \pm 0.43$	$65.34^{aA} \pm 0.59$
	WB	$65.93^{aA} \pm 0.29$	$66.12^{aA} \pm 0.49$	$66.31^{aA} \pm 0.29$	$65.85^{aA} \pm 0.19$
		a* (red-green component)			
Hamburgers	**Normal**	$4.62^{aA} \pm 0.15$	$4.64^{aA} \pm 0.12$	$4.68^{aA} \pm 0.24$	$4.67^{aA} \pm 0.08$
	WB	$4.34^{aA} \pm 0.44$	$4.60^{aA} \pm 0.33$	$4.48^{aA} \pm 0.20$	$4.35^{aA} \pm 0.42$
Bologna	**Normal**	$11.45^{aA} \pm 0.15$	$11.42^{aA} \pm 0.17$	$11.79^{aA} \pm 0.23$	$11.78^{aA} \pm 0.15$
	WB	$11.17^{aC} \pm 0.24$	$11.35^{aBC} \pm 0.01$	$11.55^{aAB} \pm 0.11$	$11.85^{aA} \pm 0.11$
		b* (yellow-blue component)			
Hamburgers	**Normal**	$13.04^{bB} \pm 0.22$	$13.97^{bA} \pm 0.37$	$12.67^{aB} \pm 0.41$	$13.25^{aAB} \pm 0.68$
	WB	$13.97^{aB} \pm 0.26$	$14.85^{aA} \pm 0.23$	$12.96^{aC} \pm 0.42$	$13.54^{aBC} \pm 0.50$
Bologna	**Normal**	$11.67^{aB} \pm 0.18$	$12.37^{aA} \pm 0.13$	$11.68^{aB} \pm 0.19$	$11.48^{aB} \pm 0.28$
	WB	$11.82^{aA} \pm 0.45$	$11.94^{aA} \pm 0.38$	$11.43^{aAB} \pm 0.31$	$10.94^{bB} \pm 0.22$

^{a,b} Different letters in the same column denote statistical difference based on the Student's t-test ($p < 0.05$).
^{A,B} Different letters on the same row denote statistical difference based on Tukey's test ($p < 0.05$).

Hamburgers with WB had a higher pH ($p < 0.05$) throughout the storage period (1, 30, 60, and 90 days), whereas a higher pH value was observed for bologna at 30 and 60 days (Table 4) compared to pH of products with normal fillets. The degeneration of muscle fibers in WB fillets modifies their glycolytic potential, with a reduction in the available glycogen, and consequently, less acidification in the post-mortem period and a higher final pH value [8,23]. Thus, considering that the hamburger formulation had a higher percentage of chicken fillets, this result indicates that the pH of this meat product was directly influenced by the high pH value in WB fillets.

Regarding water activity, both meat products prepared with WB did not show a significant difference ($p>0.05$) compared hamburgers and bologna prepared with normal fillets during the entire storage period ($p > 0.05$). Hamburgers with normal fillets showed a reduction in water activity at 60 days and later after manufacture, and those produced with WB showed a reduction observed only after 90 days. This result is in agreement with previous findings [28], showing a reduction in water activity in hamburgers with both WB and normal fillets during the storage period. A reduction in water activity was observed only in hamburgers of both formulations, which were the only meat products frozen throughout the storage period. This result is due to the effectiveness of freezing in preserving the quality of perishable foods, which presents a reduction in water activity when subjected to negative temperatures, minimizing the chances of microbial growth [28].

WHC is considered one of the main functional properties of meat products [29]. The chicken fillets affected by WB have a reduced capacity to retain water in their structure, resulting in cuts with lower yields [10]. However, no difference was observed in this parameter between the formulations of hamburgers and bologna during the entire storage period. Similarly, previous authors [28] demonstrated that the addition of WB chicken fillets did not influence the WHC of hamburgers. Nanbing [13] studied the use of WB fillets in the preparation of nuggets and sausages, and found no significant differences in WHC in these products when compared to normal fillets. These results suggest that the use of WB fillets in meat product manufacture, particularly that of hamburgers and bologna, can minimize or reduce the negative effects of the low WHC of fillets, thereby minimizing possible economic losses. It is likely that the addition of cassava starch and isolated soy protein contributed to the compensation for the lower WHC of WB fillets.

Table 4. Values of pH, water activity and water holding capacity (WHC) for hamburgers and bologna prepared with normal fillet and *WB* during the storage period.

Meat product	Type of fillet	Storage period			
		1 day	30 days	60 days	90 days
		pH			
Hamburger	**Normal**	$5.82^{bB} \pm 0.05$	$5.93^{bA} \pm 0.01$	$6.00^{bA} \pm 0.06$	$6.00^{bA} \pm 0.04$
	WB	$5.98^{aC} \pm 0.06$	$6.04^{aBC} \pm 0.06$	$6.14^{aA} \pm 0.01$	$6.11^{aAB} \pm 0.04$
Bologna	**Normal**	$6.31^{aAB} \pm 0.01$	$6.30^{bB} \pm 0.01$	$6.31^{bAB} \pm 0.01$	$6.33^{aA} \pm 0.02$
	WB	$6.31^{aB} \pm 0.02$	$6.33^{aAB} \pm 0.02$	$6.33^{aAB} \pm 0.01$	$6.36^{aA} \pm 0.01$
		Water activity			
Hamburger	**Normal**	$0.986^{aA} \pm 0.002$	$0.982^{aAB} \pm 0.002$	$0.981^{aB} \pm 0.004$	$0.974^{aC} \pm 0.002$
	WB	$0.985^{aA} \pm 0.002$	$0.986^{aA} \pm 0.003$	$0.982^{aA} \pm 0.005$	$0.974^{aB} \pm 0.001$
Bologna	**Normal**	$0.983^{aA} \pm 0.001$	$0.981^{aA} \pm 0.008$	$0.967^{aB} \pm 0.002$	$0.983^{aA} \pm 0.006$
	WB	$0.983^{aA} \pm 0.002$	$0.987^{aA} \pm 0.003$	$0.971^{aB} \pm 0.003$	$0.982^{aA} \pm 0.003$
		WHC (%)			
Hamburger	**Normal**	$96.02^{aA} \pm 0.41$	$95.85^{aA} \pm 0.34$	$95.97^{bA} \pm 0.17$	$96.26^{aA} \pm 0.12$
	WB	$96.02^{aA} \pm 0.30$	$95.98^{aA} \pm 0.28$	$96.37^{aA} \pm 0.14$	$96.34^{aA} \pm 0.18$
Bologna	**Normal**	$97.82^{aA} \pm 0.17$	$97.65^{aAB} \pm 0.17$	$97.77^{aA} \pm 0.07$	$97.47^{aB} \pm 0.20$
	WB	$97.54^{aA} \pm 0.16$	$97.54^{aA} \pm 0.22$	$97.51^{aA} \pm 0.24$	$97.14^{aA} \pm 0.22$

^{a,b} Different letters in the same column denote statistical difference based on the Student's t-test ($p < 0.05$).
^{A,B} Different letters on the same row denote statistical difference based on Tukey's test ($p < 0.05$).

Table 5 shows the results of lipid oxidation of the prepared meat products, expressed in mg of malondialdehyde kg^{-1} of the sample. Chicken meat is highly susceptible to lipid oxidation due to the presence of polyunsaturated fatty acids in its composition, and meat products are also highly susceptible to this process mainly because of the production steps, which include crushing and emulsification processes, and these are responsible for the rupture of fat globules with a resulting exposure to light and heat, factors that promote their oxidation [30].

The hamburgers were kept at −18 °C throughout the storage period. The use of WB fillets in the preparation of hamburgers resulted in products with higher MDA concentrations at all testing time points; that is, products that were more oxidized than those prepared with normal fillets. This result agrees with previous findings [9,31] that showed an increase in thiobarbituric acid reactive substances (TBARS) in WB fillets. Furthermore, a reduction in the total number of heme pigments has been previously observed [9]. This reduction is associated with catalase activity, which may directly reflect the lower oxidative stability observed in fillets affected by the anomaly [9,32]. Moreover,, heme iron can act as a pro-oxidant [9]; WB fillets exhibit degeneration of muscle fibers, with consequent disruption of their structure, which can damage the porphyrin ring, and consequently, break the heme molecule and release iron [5,30]. Histological lesions in WB fillets [5,7] can contribute to phospholipid exposure, which accelerates the development of lipid oxidation [9,33].

Hasegawa and coauthors [34] also observed an accumulation of lipofuscin (an indicator of oxidative stress) with a consequent increase in lipid oxidation in WB fillets. Hamburgers with WB and normal fillets had TBARS values of 0.195 and 0.158 mg malondialdehyde kg^{-1} of the sample at the end of the storage period, respectively. Furthermore, both formulations showed an increase in MDA concentration during the evaluation period compared to that in products using normal fillets. However, no significant influence ($p>0.05$) was observed on lipid oxidation when using WB fillets in the preparation of bologna. In addition, both formulations showed higher MDA concentrations at the last testing time point, with TBARS values ranging from 0.171 to 0.174 mg of malondialdehyde kg^{-1} of the sample.

Considering that the hamburger contained the highest percentage of WB chicken fillets, the highest MDA concentration per kg of sample on the first testing day may be due to the type of fillet used in its formulation.

Moreover, oxidative processes are multiple chemical reactions that are more likely with increasing time and temperature [35]; therefore, the highest MDA concentration per kg of sample for bologna produced with normal and WB fillets at the last testing time point (90 days) can be a result of storage temperature. According to previous findings [36], meat and meat products with MDA values between 2 and 2.5 mg of MDA kg^{-1} do not have a noticeable rancid taste and odor to the consumer. Thus, both meat products were within the established limits of oxidative rancidity.

Table 5. Lipid oxidation (mg malondialdehyde kg^{-1} of sample) for hamburgers and bologna prepared with normal fillet and WB fillets stored at 4 ºC for 1, 30, 60 and 90 days.

		Storage period			
Meat product	**Type of fillet**	**1 day**	**30 days**	**60 days**	**90 days**
Hamburger	**Normal**	$0.141^{bC} \pm 0.007$	$0.143^{bBC} \pm 0.011$	$0.157^{bAB} \pm 0.007$	$0.158^{bA} \pm 0.006$
	WB	$0.161^{aB} \pm 0.008$	$0.171^{aB} \pm 0.011$	$0.166^{aB} \pm 0.004$	$0.195^{aA} \pm 0.010$
Bologna	**Normal**	$0.066^{aB} \pm 0.007$	$0.071^{aB} \pm 0.004$	$0.070^{aB} \pm 0.007$	$0.171^{aA} \pm 0.019$
	WB	$0.068^{aB} \pm 0.003$	$0.078^{aB} \pm 0.009$	$0.070^{aB} \pm 0.006$	$0.174^{aA} \pm 0.003$

^{a,b} Different letters in the same column denote statistical difference based on the Student's t-test ($p < 0.05$).
^{A,B} Different letters on the same row denote statistical difference based on Tukey's test ($p < 0.05$).

Table 6 show the results for texture profile analysis (TPA) for hamburgers and bologna. The hamburger formulated with WB fillets presented lower hardness at 30 and 90 days after manufacture. Fillets affected by the anomaly have a palpable increase in hardness, which may be related to an increase in collagen deposition due to fibrosis [5,10]. However, a reduction in the hardness of this product was observed when used in the manufacture of hamburgers, indicating that the presence of ingredients and the technology involved in the production can contribute to variations in the texture of meat products. De Oliveira [28] also verified a reduction in the hardness of hamburgers with WB as the degree of severity of the anomaly increased. This increase in tenderness in meat products produced with severe WB fillets may be caused by muscle fiber degeneration and increased intramuscular fat deposition [24].

Furthermore, both formulations showed stability of this parameter over the storage period. The use of WB fillets showed no significant differences ($p>0.05$) in bologna. Thus, only hamburgers showed an influence on the hardness parameter when replacing normal with WB fillets, which is probably related to the higher percentage of fillets in a hamburger compared with that of bologna, suggesting that in products with higher percentages of fillets, WB may have greater influence on their texture profile.

The use of WB fillets did not influence the elasticity and cohesiveness of the meat products ($p > 0.05$). The chewiness of hamburgers with WB fillets did not differ from that of hamburgers with normal fillets 1, 30, and 60 days after manufacture. Substitution of normal with WB fillets in the preparation of hamburgers resulted in a significant decrease in chewiness 90 days after manufacture ($p < 0.05$). However, no significant influence was observed in the chewiness parameter for bologna. The lower chewiness in hamburgers is related to an increase in tenderness, a result also observed during the storage period, which may be explained by the degeneration of muscle fibers in fillets affected by the anomaly and lipid accumulation due to lipidosis [24,5]. Both formulations were stable for this parameter throughout the storage period. Moreover, no difference was observed in resilience between the formulations for both meat products ($p > 0.05$), which showed stability until the last testing time point.

Table 6. Texture profile analysis (TPA) for meat products prepared with normal and WB fillets during the storage period.

Meat product	Type of fillet	Parameters	Storage period.			
			1 day	30 days	60 days	90 days
Hamburgers	Normal	Hardness (g)	$2935^{aA} \pm 366$	$3048^{aA} \pm 289$	$3377^{aA} \pm 376$	$3816^{aA} \pm 524$
	WB		$3342^{aA} \pm 759$	$2309^{bA} \pm 185$	$2897^{aA} \pm 501$	$2259^{bA} \pm 112$
Bologna	Normal		$3550^{aA} \pm 309$	$3830^{aA} \pm 146$	$3496^{aA} \pm 499$	$3822^{aA} \pm 265$
	WB		$3164^{aA} \pm 297$	$3461^{aA} \pm 319$	$3106^{aA} \pm 358$	$3421^{aA} \pm 430$
Hamburgers	Normal	Elasticity	$1.03^{aA} \pm 0.10$	$0.95^{aA} \pm 0.02$	$0.96^{bA} \pm 0.01$	$1.04^{aA} \pm 0.04$
	WB		$1.08^{aA} \pm 0.06$	$1.27^{aA} \pm 0.27$	$1.04^{aA} \pm 0.04$	$1.08^{aA} \pm 0.12$
Bologna	Normal		$2.25^{aA} \pm 0.30$	$2.14^{aA} \pm 0.26$	$2.32^{aA} \pm 0.54$	$2.21^{aA} \pm 0.43$
	WB		$2.46^{aA} \pm 0.41$	$2.74^{aA} \pm 0.33$	$2.59^{aA} \pm 0.26$	$2.80^{aA} \pm 0.36$
Hamburgers	Normal	Cohesiveness	$0.40^{aB} \pm 0.01$	$0.41^{aB} \pm 0.01$	$0.46^{aA} \pm 0.01$	$0.43^{aAB} \pm 0.01$
	WB		$0.39^{aAB} \pm 0.01$	$0.37^{aB} \pm 0.02$	$0.43^{aB} \pm 0.01$	$0.41^{aB} \pm 0.01$
Bologna	Normal		$0.83^{aA} \pm 0.01$	$0.83^{aA} \pm 0.01$	$0.84^{aA} \pm 0.01$	$0.84^{aA} \pm 0.01$
	WB		$0.83^{aB} \pm 0.01$	$0.83^{aB} \pm 0.01$	$0.84^{aB} \pm 0.01$	$0.87^{aA} \pm 0.02$
Hamburgers	Normal	Chewiness (g/cm)	$1200^{aA} \pm 107$	$1182^{aA} \pm 97$	$1515^{aA} \pm 228$	$1876^{aA} \pm 505$
	WB		$1444^{aA} \pm 383$	$1010^{aA} \pm 201$	$1339^{aA} \pm 324$	$1044^{bA} \pm 32$
Bologna	Normal		$7018^{aA} \pm 1206$	$5993^{aA} \pm 2319$	$6841^{aA} \pm 1690$	$7267^{aA} \pm 259$
	WB		$6593^{aA} \pm 347$	$7841^{aA} \pm 860$	$6755^{aA} \pm 1385$	$8637^{aA} \pm 2060$
Hamburgers	Normal	Resilience	$0.14^{aA} \pm 0.01$	$0.13^{aA} \pm 0.01$	$0.15^{aA} \pm 0.01$	$0.14^{aA} \pm 0.01$
	WB		$0.13^{aA} \pm 0.01$	$0.12^{aA} \pm 0.01$	$0.15^{aA} \pm 0.01$	$0.14^{aA} \pm 0.01$
Bologna	Normal		$0.46^{aB} \pm 0.01$	$0.46^{aB} \pm 0.01$	$0.48^{aA} \pm 0.01$	$0.47^{aA} \pm 0.01$
	WB		$0.46^{aB} \pm 0.01$	$0.46^{aB} \pm 0.01$	$0.48^{aAB} \pm 0.01$	$0.51^{aA} \pm 0.03$

[a,b] Different letters in the same column denote statistical difference based on Student's t-test ($p < 0.05$).
[A,B] Different letters on the same row denote statistical difference based on Tukey's test ($p < 0.05$).

CONCLUSION

The production of bologna and hamburgers with WB chicken fillets resulted in stable meat products without compromising yield and quality parameters during the storage period, thus demonstrating meat product manufacture to be a viable alternative to minimize costs. However, the results suggest that meat products with a higher percentage of WB meat in their formulation may have increased lipid oxidation.

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Data Availability The datasets that support the findings of this study are available from the corresponding author, Bruna Caroline Geronimo, upon reasonable request.
Conflict of Interest The authors declare no conflict of interest.

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