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Preparation of hamburgers with different inclusions of chicken breasts affected by deep pectoral myopathy

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Abstract

Deep pectoral myopathy (DPM) in broiler chickens is characterized by histological alterations in the birds' pectoral muscles, directly affecting the chicken breast meat utilization. The incidence of this condition has been increasing, resulting in significant economic losses for the food industry. In this context, the objective was to evaluate the physicochemical changes in hamburgers made with different inclusion levels of chicken breasts affected by deep pectoral myopathy. The experiment was conducted using a completely randomized design with five treatments (T): Control (0% DPM), T1 (25% DPM), T2 (50% DPM), T3 (75% DPM), and T4 (100% DPM). The protein content was affected, decreasing from 23% (Control) to 20.75% (T4). There was an increase in lipid concentration from 3.7% (Control) to 4.33% (T4). There were no differences ($p > .05$) between treatments for moisture, ash, caloric value, texture profile, color intensity, thawing weight loss, cooking weight loss, and shrinkage. The total carbohydrate content varied from 21.64 g per 100 g (Control) to 19.03 g per 100 g (T4). The amino acids histidine, isoleucine, and valine had the greatest reductions, of 41.5%, 10.8%, and 10.6%, respectively, between treatments T1 and T4. The non-essential amino acids cystine, glycine, and serine had the smallest reductions, of 2.4, 7.9, and 6.6%, respectively, between treatments T1 and T4. The essential amino acid profile in all treatments met the recommendations established by Food and Agriculture Organization and World Health Organization, except for methionine, cystine, and tyrosine. Investigating the chemical and physicochemical parameters in formulations with different levels of DPM-affected breast meat allowed for the characterization of the nutritional impact resulting from this product utilization in hamburger composition. Based on the study's information, it can be stated that, within the evaluated parameters, processing these meats for hamburger production is a viable utilization alternative.

Keywords: food utilization; food technology; meat product development; meat processing; nutritional composition; poultry industry.

Practical Application: Burgers with deep pectoral myopathy (DPM) meat reduce waste and add value, enabling use in the food industry.

1 INTRODUCTION

The global production of chicken meat reached 99.901 million tons in 2022. The USA, China, and Brazil, as the world's leading producers, accounted for 51% of this animal protein production (United States Department of Agricultural [USDA], 2023). Given this socioeconomic dimension, efforts to tackle issues related to waste due to condemnations and to contribute to meeting the growing global demand for food with quality become relevant.

In this context, chicken breast production is included, a product with great commercial acceptance. This has led to genetic selection among different poultry lines aimed at enhancing this characteristic, namely, rapid weight gain in less time until the birds are slaughtered, increasing the productivity of this noble part of the carcass. As a consequence of this selection, metabolic, bone, and muscular disorders have been described, but the one with the greatest impact is deep pectoral myopathy (DPM), which is largely responsible for product condemnations (Francelino, 2022).

DPM in broiler chickens is characterized by histological changes in the pectoral muscles, including degeneration and necrosis of muscle fibers. The incidence of this condition has increased, resulting in economic losses for the poultry industry (Assunção et al., 2020).

The challenge for genetics and the entire industrial chain lies in balancing gains and losses so that problems like myopathies

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can be controlled in a way that avoids losses, particularly regarding carcass condemnations, which occur during the industrial phase, where high-value-added products are lost.

The affected muscles are discarded during deboning, leading to economic losses for the processing industry. However, one of the main concerns is the consumption of whole carcasses that are silently affected, leading to consumer complaints. The condition is not associated with any infectious agents and is therefore of little relevance to public health, except for affecting the meat's appearance (Bilgilie & Hess, 2008).

DPM can alter the chemical composition and qualitative characteristics of the supracoracoideus muscles (tenderloins) and the pectoralis major muscles (breasts). To ensure the industry does not face losses related to consumer purchase intention, it is worth considering the production of processed meat products in such circumstances (Giampietro-Ganeco et al., 2021).

The popularity of meat consumption and its transformation into processed products also offers the advantages of convenience and comfort to consumers. A variety of products such as meatballs, burgers, breaded products, sausages, salamis, and nuggets are widely accepted in the market (Ferreira et al., 2014).

In this sense, an alternative destination for chicken breast cuts affected by DPM is processing the pectoral muscle for the production of restructured products. However, the determining factors of the physical, chemical, and especially sensory qualities, when using chicken breast meat affected by DPM in the preparation and consumption of these products, are not yet fully understood.

In this context, the present study evaluates the possible alterations in the physicochemical composition of hamburgers made with different levels of inclusion of chicken breasts affected by DPM.

1.1 Relevance of the work

This study investigates the feasibility of using chicken breast meat with deep pectoral myopathy in the production of hamburgers. Controlled inclusion can reduce waste and add value to affected meats, offering an economically viable alternative for the food industry.

2 MATERIAL AND METHODS

2.1 Collection and selection of chicken breast samples

Chicken breast samples were collected at a processing plant located in the state of Goiás, following the slaughter and mechanical separation of the carcass. They were chilled and immediately transported to the Laboratory of Animal-Origin Products at the Federal Institute of Education, Science, and Technology of Goiás – Rio Verde Campus, for classification regarding the incidence of DPM. Subsequently, they were utilized for the preparation of hamburgers and physicochemical analyses.

According to the methodology proposed by Bilgilie and Hess (2008), chicken breast samples with well-defined lesions were classified as DPM-affected breasts. These lesions presented regions surrounded by a distinct hemorrhagic ring encompassing the breast muscle tissue, showing discoloration with a tendency toward a greenish appearance. For comparative evaluation, normal samples of the pectoralis major muscle, free of any abnormalities, were also reserved. This ingredient was referred to as chicken breasts without DPM.

The chicken breast samples were prepared by separating the pectoralis minor muscle (tenderloin) from the pectoralis major muscle. Figure 1 illustrates the visual alteration caused by DPM in the pectoralis major muscle when compared to a normal chicken breast, unaffected by DPM.

2.2 Processing of the hamburgers

The chicken breast samples used for hamburger processing were divided into two groups: breast without DPM and breast with DPM. The chicken breasts were weighed separately, as were all the ingredients described in Table 1.

The hamburger production followed the prescribed requirements for hygiene conditions and good practices (Brasil, 1998). Initially, the chicken breast samples were thawed under refrigeration at a temperature of 4°C for 8 h. According to the flowchart, thawed chicken breast samples, which were previously cleaned, cut, and ground in a Philco® food processor, Model PH900, were used.

Subsequently, the remaining ingredients were weighed and added to the minced chicken breast meat in the following order: salt (sodium chloride, Globo® brand), garlic powder (Fab D'gust Alimentos), black pepper (Ponzan® brand), textured soy protein

Source: Author (2023).

Figure 1. Morphological comparison between chicken breast samples: breast without deep pectoral myopathy **(A)** and breast with deep pectoral myopathy **(B)**, and breast with severe deep pectoral myopathy **(C)**.

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(Natural Life® brand), and antioxidant for meats and sausages (Kor Frescal F008® brand).

The ingredients were then dry-mixed, followed by the addition of water. Next, the resulting mixture (Figure 2) was homogenized for 10 min and manually shaped into patties with a diameter of 12 cm, yielding hamburgers with a net weight of approximately 120 g each.

The hamburgers were packaged in transparent plastic bags (low-density polyethylene [LDPE] for food use) with polyvinylidene chloride (PVC) plastic film placed between the pieces. They were stored under refrigeration at 4°C until the molding process was completed, and then kept in a vertical freezer at −18°C for subsequent analyses.

2.3 Physicochemical evaluation of hamburgers

Physicochemical analyses were carried out as recommended by the Association of Official Analytical Chemists (AOAC, 2000).

2.4 Moisture

The determination of the moisture content of the hamburgers was performed through direct drying in an oven (SOLAB SL-100) at 105°C. Porcelain capsules were used, which were dried in the oven for 1 h at a temperature of 105°C, cooled in a silica gel desiccator for 30 min, and weighed on an analytical balance (BEL MARK 210A).

In each previously tared capsule, 4 g of the sample was weighed. The samples were then heated in the oven at 105°C for 12 h until a constant weight was achieved. Subsequently, the capsules were placed in a desiccator until they reached room temperature and were weighed again until a constant weight was obtained (Instituto Adolfo Lutz [IAL], 2008).

The moisture determination was defined as the ratio between the water content of the sample and the weight of the wet sample, expressed as a percentage.

2.5 Crude protein

The analyses were conducted on post-cooking hamburger samples. Protein content was determined using the Kjeldahl method, which measures the nitrogen content of the samples and involves the steps of digestion, distillation, and titration.

In the digestion phase, 0.1 g of each sample was weighed into Kjeldahl tubes, and 0.5 g of catalyst (copper sulfate and potassium sulfate), along with 5 mL of concentrated sulfuric acid, was added. The sample was then digested in digestion blocks, starting at a temperature of 100°C, increasing by 50°C every 30 min until reaching 350°C, where it was maintained until complete digestion.

After this, the tube was cooled, and 10 mL of distilled water was added to initiate distillation. During the distillation, the

Figure 2. Completion of the standardized molding process for a hamburger sample.

Table 1. Ingredients used in hamburger formulations with the inclusion of chicken breasts affected by deep pectoral myopathy.

Ingredients (%)	Treatments				
	Control	T1	T2	T3	T4
Breast fillet without DPM	90.6	68.0	45.3	22.7	0.0
Breast fillet with DPM	0.0	22.7	45.3	68.0	90.6
Textured soy protein*	3.9	3.9	3.9	3.9	3.9
Water (ice)	2.2	2.2	2.2	2.2	2.2
Salt	1.7	1.7	1.7	1.7	1.7
Antioxidants	1.1	1.1	1.1	1.1	1.1
Garlic powder	0.3	0.3	0.3	0.3	0.3
Ground pepper	0.1	0.1	0.1	0.1	0.1
TOTAL	100.0	100.0	100.0	100.0	100.0

*Brand Natural Life®; Sal marca Globo®; F008 – Brand Kor Frescal®; Fab D'Gust Alimentos; Brand Ponzan. DPM: deep pectoral myopathy; Treatment C: 0% chicken breast with DPM; T1: 25% chicken breast with DPM; T2: 50% chicken breast with DPM; T3: 75% chicken breast with DPM; T4: 100% chicken breast with DPM.

Kjeldahl tube containing the digested content was neutralized in a distiller (Model: NT 422, Brand: Novatecnica, Brazil) with approximately 30 mL of 50% sodium hydroxide (NaOH).

The distillate was collected in a 250 mL Erlenmeyer flask containing 10 mL of 4% (m/v) boric acid and a mixed indicator composed of methyl red and methylene blue. The titration was performed with 0.01 mol L^{-1} sulfuric acid (H_2SO_4).

The volume consumed was used to calculate the total nitrogen percentage in the hamburger samples, which was then converted into protein percentage using the factor 6.25 (the general nitrogen-to-protein conversion factor).

2.6 Fat

Fat content was determined using the Bligh and Dyer method (Bligh & Dyer, 1959), with chloroform, methanol, and water in a ratio of 1:2:0.8 (v/v) (Brum et al., 2009).

2.7 Carbohydrates and caloric value

Carbohydrates were calculated by difference, and the energy value was obtained using the conversion factors for carbohydrates (4 kcal.g^{-1}), proteins (4 kcal.g^{-1}), and lipids (9 kcal.g^{-1}) (Brasil, 2005).

2.8 Ash content

The ash content of the hamburgers was determined using 2 g of each sample, which was weighed directly into porcelain crucibles. The samples were then dehydrated in an oven at 105°C for 7 h and placed in a muffle furnace (Haut Model 7035, Brazil) at 550°C for 18 h. At the end of this period, the crucibles were transferred to desiccators for cooling and weighing.

2.9 pH

pH analyses were conducted on hamburger samples after thawing. Readings were taken using a portable pH meter (Hanna brand, model HI981036) with a measurement range of 0–14, equipped with a specific electrode for semi-solids, attached to the device for recording the readings.

For measurement, the electrode tip was inserted perpendicularly into the hamburger mass at three different points, waiting for the device to stabilize. A total of 16 readings were taken for each treatment, amounting to 80 results.

2.10 Texture profile determination

The texture profile analysis was conducted at a temperature of 25 ± 5°C using a texture analyzer TA-XT2i (CT3 Texture Analyzer, Brookfield, USA). A total of five cylindrical samples (approximately 2.5 cm in diameter × 1.0 cm in height) were obtained from each treatment.

The samples underwent a two-cycle compression test, compressed to 30% of their original height with a cylindrical probe measuring 3.5 cm in diameter at a speed of 5 mm s^{-1}. The parameters determined included hardness (N), chewiness (mJ), elasticity (dimensionless), and cohesiveness (dimensionless), following Bourne's methodology (Bourne, 1978).

2.11 Instrumental color parameters

The color analysis of chicken breast hamburgers was conducted on post-cooking samples using the Hunter Lab ColorFlex EZ equipment, obtaining the parameters a, b, and L*.

Note: a* and b* represent color intensity: +a: red, −a: green; +b: yellow, −b: blue; L* defines luminosity, where L* = 0 represents black and L* = 100 represents white. The Chroma (Cr) and Hue angle (°h) values were calculated using Equations 1 and 2, respectively.

$$Cr = [(a\hat{}2 + b\hat{}2)\hat{}1/2] \quad (1)$$

$$°h = [\arctan(b/a)] \quad (2)$$

2.12 Cooking weight loss

To determine cooking weight loss (CWL), the hamburger samples were weighed and subsequently cooked in an electric oven (Suggar brand, model Fe5012Pt) preheated to a temperature of 200°C for 20 min.

Afterward, the samples were left at room temperature to cool and then weighed again to calculate the CWL values (Vieira et al., 2007). The results were obtained by the difference between the initial and final weights, expressed as a percentage, as described by Equation 3.

$$PPC = \left(pi - \frac{pf}{pi}\right) \times 100 \quad (3)$$

Where PPC represents cooking weight loss, pi is the initial weight of the sample, and pf is the final weight of the sample.

2.13 Thawing weight loss

To determine thawing weight loss (TWL), the samples were removed from storage in a vertical freezer at −18°C, weighed, and then subjected to a slow thawing process in a refrigerator at 4°C for 12 h.

After thawing, the samples were weighed again to determine the final weight. The loss was calculated by the ratio of weight reduction to the initial weight, with the result expressed as a percentage.

2.14 Shrinkage after cooking

The hamburger samples were measured before the cooking process. For each sample, three diameter measurements were taken. After cooking, the samples were cooled and subjected to the same measurement process again. The shrinkage values were determined by the variation between the initial and final

measurements, with the results expressed as a percentage, as described in Equation 4.

$$Retração = (Mi - Mf/Mi) \times 100 \quad (4)$$

where Mi represents the initial diameter measurement, and Mf represents the final diameter measurement.

2.15 Amino acid profile

The amino acid composition was determined following the methodology described by White et al. (1986). Initially, the samples underwent acid hydrolysis with 6 N HCl containing 0.1% phenol at 110°C for 20 h, in accordance with the Pico-Tag method described by Hagen et al. (1986).

Subsequently, the samples were derivatized with 20 mL of an ethanol solution composed of water, triethylamine, and phenylisothiocyanate (7:1:1:1, v/v) for 20 min at room temperature. After derivatization in the pre-column, the amino acids were identified using high-performance liquid chromatography (HPLC) with a reverse-phase column (model PCX 3100, Pickering Laboratories, Mountain View, USA).

2.16 Experimental design and statistical analysis

The experiment was conducted using a completely randomized design with five treatments: Treatment C (0% chicken breast with DPM), T1 (25% chicken breast with DPM), T2 (50% chicken breast with DPM), T3 (75% chicken breast with DPM), and T4 (100% chicken breast with DPM). Each treatment included eight hamburger samples.

The results were subjected to analysis of variance (ANOVA) at 5%, and the means were compared using Tukey's test with significance defined as $p < .05$. The analysis was performed using Statistica software, version 7.0.

3 RESULTS AND DISCUSSION

Table 2 presents the results of the proximate composition of hamburgers processed with increasing levels of chicken breasts affected by DPM.

The moisture content increased from Treatment C to T4. Treatments 1 and 3 did not differ from each other and were similar to the others. Similar results were reported by Cavalcanti et al. (2021), demonstrating that meat with DPM has a greater capacity to retain water (making it softer) compared to normal meat, which explains the moisture results in Treatment 4 with the higher inclusion of chicken breasts affected by DPM.

Bilgilie and Hess (2008), assessing the impact of DPM on chicken breast muscles, affirmed that muscular edema is one of the main macroscopic characteristics caused by the anomaly. This edema condition, characteristic of chicken breasts with DPM, directly affects the moisture content of the hamburgers. This information is particularly relevant to the food industry as it draws attention to the importance of controlling this variable, which is entirely related to the preservation of the final product.

Regarding ash (mineral matter) content analysis, no significant differences ($p > .05$) were found among the formulations. These findings are consistent with those of Francelino (2022), who also observed no differences between treatments comparing regular hamburger samples and those with chicken meat affected by DPM.

The crude protein results of the hamburgers for Control and T1 treatments were similar to each other and different from the other treatments. This reduction is explained by the composition of chicken breast meat affected by DPM. The protein reduction in DPM-affected chicken breasts was elucidated by studies like those of Soglia et al. (2021), demonstrating that pectoral muscle hypertrophy in poultry, induced by genetic selection, is associated with reduced tissue vascularization, predisposing it to hypoxic conditions.

Once hypoxia sets in, it triggers a sequence of events, resulting in the activation of response mechanisms (such as energy metabolism modifications, inflammation, degeneration, and regeneration), all of which are closely linked to the progression of myopathies and the consequent alteration in the pectoral muscle's protein profile. Based on this, it can be inferred that the compromised protein content of DPM-affected pectoral muscles impacted the protein composition of the hamburgers, leading to reductions in the treatments with higher inclusion levels.

The lipid results for Treatments 2 and 4 were higher than for the other treatments, highlighting the influence of a higher

Table 2. Mean values and standard deviations for moisture (g per 100 g of sample), proteins (g per 100 g of sample), lipids (g per 100 g of sample), carbohydrates (g per 100 g of sample), ash (g per 100 g of sample), and caloric value (kcal) of hamburgers processed with increasing levels of chicken breasts affected by deep pectoral myopathy.

Variables	Treatments				
	Control	T1	T2	T3	T4
Moisture	69.99 ± 0.92^{b}	70.47 ± 0.63^{ab}	70.06 ± 0.83^{b}	70.75 ± 1.01^{ab}	71.36 ± 0.39^{a}
Proteins	23.00 ± 0.95^{a}	22.01 ± 0.73^{a}	20.67 ± 0.63^{b}	20.85 ± 0.82^{b}	20.75 ± 0.96^{b}
Lipids	3.70 ± 0.87^{b}	3.58 ± 0.45^{a}	4.82 ± 0.91^{a}	3.75 ± 0.54^{b}	4.33 ± 0.97^{ab}
Carbohydrates	0.56 ± 0.53^{b}	1.26 ± 0.63^{ab}	1.73 ± 1.02^{ab}	2.02 ± 1.47^{a}	0.78 ± 0.47^{b}
Ash	2.75 ± 0.26a	2.68 ± 0.09^{a}	2.73 ± 0.05^{a}	2.62 ± 0.22^{a}	2.77 ± 0.16^{a}
Caloric value	127.53 ± 6.21^{ab}	125.31 ± 4.00^{b}	132.93 ± 5.56^{a}	125.28 ± 5.51^{b}	125.12 ± 5.97^{a}

Distinct letters within the row indicate significant differences according to Tukey's test at a 5% probability level. DPM: deep pectoral myopathy; Treatment C: 0% chicken breast with DPM; T1: 25% chicken breast with DPM; T2: 50% chicken breast with DPM; T3: 75% chicken breast with DPM; T4: 100% chicken breast with DPM.

inclusion level of DPM-affected chicken breasts. This result aligns with the findings of Praud et al. (2020), who reported that histological lesions associated with DPM can affect the chemical properties of the meat, such as fibrosis and subsequent replacement with adipose tissue. This explains the lipid increase in treatments with higher inclusion of DPM-affected chicken breasts.

Velleman and Clark (2015) also observed this replacement of degenerative fibrous tissue with adipose tissue caused by myopathies, which directly affects the lipid composition of hamburgers made with DPM-affected chicken breast muscles.

The carbohydrate content of the hamburgers varied ($p < .05$), with the highest content observed in T3, which was similar to T1 and T2, but different from Control and T4. The higher carbohydrate content in T3 is related to the impact of DPM, a condition that affects chicken breast muscles, resulting in an increased proportion of connective tissue relative to muscular tissue. This can result in a drier, less succulent chicken texture.

This information holds importance for the food industry since adding carbohydrates can help improve product stability and shelf life while reducing the fat needed to achieve the desired texture.

The protein, lipid, and carbohydrate levels in all treatments met the identity and quality requirements for hamburger-type meat products, as regulated by Normative Instruction No. 20 (Brasil, 2000), which stipulates maximum fat values of 23.0 g per 100 g, total carbohydrates of 3.0 g per 100 g, and a minimum protein content of 15.0 g per 100 g.

The caloric value was higher in T2 and T4 samples, which did not differ from each other ($p > .05$) and were similar to Control but differed ($p > .05$) from T1 and T3. These differences can be explained by the variations in the protein content observed in the study, with each gram of protein corresponding to four calories. According to Chen et al. (2019), who showed protein composition alterations caused by various myopathies, these changes were responsible for the caloric value variations among the samples.

Since chicken breast meat is the main ingredient of the hamburgers, the absence of DPM impact on samples with 0% DPM explains the higher protein content in the control group. Although this protein reduction slightly increased with higher inclusion levels of DPM meat, the caloric impact did not follow the same linear trend, reaching higher values in T2 and T4.

Table 3 shows the results of the pH analysis, texture parameters (hardness, elasticity, cohesiveness, and chewiness), instrumental color parameters (L*, a*, and b*), CWL, TWL, and shrinkage of the hamburgers.

The pH values were higher for T1 and T2, which differed significantly ($p < .05$) from the other treatments. This finding aligns with the study by Lesiów and Kijowski (2003), which observed increased lactic acid production and muscle stiffness in conditions associated with DPM, resulting in pH changes for hamburgers with greater inclusion of DPM-affected meat. Similarly, Francelino (2022), when studying chicken meat affected by DPM in hamburger formulations, found that the pH values of hamburgers decreased with the inclusion of DPM-affected meat.

This finding is highly significant for the food industry, as it underscores the importance of controlling this variable, which is crucial for preserving the quality characteristics of the final product.

No variation ($p > .05$) was observed in texture parameters, including hardness (N), elasticity (mm), cohesiveness, and chewiness (mJ), confirming that the hamburgers were not technologically affected, particularly in terms of tenderness. This aspect is critical for the food industry, as tenderness is a key technological attribute for consumer satisfaction.

This observation is consistent with prior studies emphasizing the importance of tenderness as a determining factor

Table 3. Results of the pH analysis, texture parameters (hardness, elasticity, cohesiveness, and chewiness), instrumental color parameters (L*, a*, and b*), cooking weight loss (CWL), thawing weight loss (TWL), and shrinkage of the hamburgers.

Variables	Treatments				
	Control	T1	T2	T3	T4
pH	5.60 ± 0.05^{b}	5.68 ± 0.04^{a}	5.67 ± 0.04^{a}	5.58 ± 0.03^{b}	5.42 ± 0.01^{c}
Hardness (N)	14.58 ± 3.16^{a}	27.12 ± 6.72^{a}	25.38 ± 4.35^{a}	16.32 ± 5.21^{a}	20.65 ± 9.29^{a}
Elasticity (mm)	3.31 ± 0.43^{a}	4.08 ± 3.13^{a}	6.92 ± 4.79^{a}	4.17 ± 7.99^{a}	4.15 ± 7.60^{a}
Cohesiveness	0.76 ± 0.13^{a}	0.78 ± 0.03^{a}	0.83 ± 0.12^{a}	0.79 ± 0.26^{a}	0.78 ± 0.11^{a}
Chewiness (mJ)	10.09 ± 1.64^{a}	21.78 ± 5.57^{a}	22.32 ± 3.91^{a}	11.79 ± 5.23^{a}	15.75 ± 9.01^{a}
L*	73.39 ± 0.80^{a}	71.55 ± 2.10^{a}	67.86 ± 10.81^{a}	72.32 ± 0.68^{a}	72.03 ± 1.42^{a}
a*	2.28 ± 0.31^{a}	2.27 ± 0.42^{a}	2.02 ± 0.28^{a}	2.50 ± 0.15^{a}	2.19 ± 0.64^{a}
b*	20.14 ± 0.82^{ab}	19.18 ± 1.25^{b}	19.13 ± 1.24^{b}	20.69 ± 0.49^{a}	20.35 ± 0.85^{ab}
Chroma	20.27 ± 0.83^{ab}	19.32 ± 0.83^{b}	19.24 ± 1.26^{b}	20.84 ± 0.50^{a}	20.48 ± 0.90^{ab}
h°	1.46 ± 0.02^{a}	1.45 ± 0.01^{a}	1.46 ± 0.01^{a}	1.45 ± 0.01^{a}	1.46 ± 0.03^{a}
PPC (%)	13.54 ± 2.94^{a}	15.10 ± 3.10^{a}	17.19 ± 5.19^{a}	15.10 ± 3.82^{a}	17.71 ± 3.69^{a}
PPD (%)	3.12 ± 2.95^{a}	4.17 ± 2.23^{a}	5.21 ± 6.95^{a}	2.60 ± 2.15^{a}	3.64 ± 1.47^{a}
Retraction (%)	9.25 ± 1.79^{a}	8.45 ± 2.60^{a}	10.17 ± 3.21^{a}	11.41 ± 3.15^{a}	9.84 ± 4.02^{a}

Distinct letters within the row indicate significant differences according to Tukey's test at a 5% probability level. DPM: deep pectoral myopathy; PPC: weight loss by cooking; PPD: weight loss by thawing; Treatment C: 0% chicken breast with DPM; T1: 25% chicken breast with DPM; T2: 50% chicken breast with DPM; T3: 75% chicken breast with DPM; T4: 100% chicken breast with DPM.

in consumer acceptance of processed meat products (Calkins & Hodgen, 2007). Furthermore, it reinforces the idea that the stability of sensory properties in processed foods is essential for the industry, as it directly influences consumer perception (Resurreccion, 2004).

Therefore, maintaining the tenderness of hamburgers despite the absence of variation in textural analyses represents a positive outcome for the processing industry, offering a quality that can be perceived by consumers in formulations with varying levels of DPM-affected chicken breasts.

The results of the instrumental color parameters of the hamburgers after cooking showed no variation ($p > .05$) between treatments for luminosity (L) and red/green intensity (a). The highest yellow/blue intensity (b*) value was observed in T3, which differed significantly ($p < .05$) from T1 and T2 but was similar to Control and T4.

The consistency in L, a, and b* values (across treatments C–T4) suggests no perceptible color alteration on the hamburger surface due to the gradual inclusion of DPM-affected chicken breasts.

In studies on raw chicken breasts affected by DPM, Giampietro-Ganeco et al. (2021) observed differences in color parameters (L, a, and b*), indicating significant qualitative alterations in the product. This comparative analysis highlights a key feature of hamburger processing, which mitigates the depreciative aspect of color alterations in DPM-affected raw material, preserving the standardization of the final product. This characteristic is attributed to the role of other ingredients added to the formulation.

The descriptive analysis of total amino acids demonstrated variation in the composition with the increasing inclusion of DPM-affected chicken breasts (Table 4). The lowest value observed in treatment T2 (18.71%) corresponded to a 13.5% reduction compared to the Control treatment.

The amino acids histidine, isoleucine, and valine showed the greatest reductions, at 41.5, 10.8, and 10.6%, respectively, when comparing the results of T1–T4 with the Control. This finding holds nutritional importance since amino acids contribute to muscle and tissue formation, enzyme and hormone synthesis, antibody production, substance transportation, chemical reaction catalysis, and the composition of bodily fluids (Ramos & Gomide, 2007).

The reductions were less pronounced for non-essential amino acids cystine, glycine, and serine, with values of 2.4, 7.9, and 6.6%, respectively. This alteration in the total amino acid content may be explained by the finding that DPM affected the chemical composition of chicken breasts, resulting in a higher proportion of connective tissue relative to muscular tissue.

Although this change did not compromise the texture of the hamburgers, protein levels were reduced (Table 2). Therefore, it is inferred that the reduced protein availability in chicken meat was reflected in the amino acid composition of the treatments with added DPM-affected chicken breasts.

Table 4. Descriptive values of amino acids in hamburger samples obtained from the treatments using formulations with chicken breasts affected by deep pectoral myopathy.

Amino acids	Treatments[1]				
	Control	T1	T2	T3	T4
Aspartic acid	2.16	2.07	1.90	1.92	1.94
Glutamic acid	3.37	3.22	2.97	3.00	3.03
Serine	0.91	0.89	0.83	0.83	0.85
Glycine	0.95	0.92	0.84	0.86	0.88
Histidine	0.97	0.61	0.54	0.56	0.56
Taurine	0.01	0.02	0.02	0.02	< 0.01
Arginine	1.45	1.38	1.27	1.28	1.28
Threonine	0.99	0.95	0.87	0.88	0.88
Alanine	1.42	1.36	1.26	1.28	1.27
Proline	0.81	0.78	0.72	0.73	0.74
Tyrosine	0.76	0.73	0.67	0.68	0.68
Valine	1.12	1.06	0.97	1.00	0.98
Methionine	0.64	0.62	0.55	0.58	0.57
Cystine	0.21	0.21	0.21	0.20	0.20
Isoleucine	1.04	0.99	0.90	0.92	0.90
Leucine	1.85	1.77	1.62	1.65	1.64
Phenylalanine	0.91	0.88	0.80	0.81	0.81
Lysine	2.06	1.96	1.78	1.83	1.80
Hydroxyproline	< 0.01 (LQ)	< 0.01	< 0.01	< 0.01	< 0.01
Total	**21.64**	**20.42**	**18.71**	**19.02**	**19.03**

DPM: deep pectoral myopathy; LQ: limit of quantification.

[1]Treatment C: 0% chicken breast with DPM; T1: 25% chicken breast with DPM; T2: 50% chicken breast with DPM; T3: 75% chicken breast with DPM; T4: 100% chicken breast with DPM. Significant differences determined by ANOVA ($p < .05$).

As such, the increasing inclusion of DPM-affected chicken breasts may have impacted the proportion of proteins in the formulations, leading to both qualitative and quantitative reductions in total amino acid content.

This alteration represents a quantitative reduction by decreasing total amino acid volume and a qualitative reduction by primarily affecting the group of essential amino acids. The observed protein and amino acid changes highlight critical considerations for the food industry to establish stringent controls to ensure compliance with minimal nutritional content standards.

Despite variations among groups, the essential amino acid profiles across all treatments met the recommendations established by the Food and Agriculture Organization (FAO, 2007) and World Health Organization (WHO, 2007), except for methionine, cystine, and tyrosine.

Table 5 shows the level of essential amino acids provided by each hamburger unit, compared to the recommendation set by the FAO (2007) and WHO (2007). There were reductions in the levels of methionine, cystine, and tyrosine provided by each hamburger unit, although the levels remained below the daily recommendation across all treatments. This nutritional analysis is fundamentally important in composing consumers' diets.

A decrease in histidine relative to the daily recommendation was observed in T2, T3, and T4. This change is based on the qualitative reduction in the concentrations of this amino acid, which was most affected by the inclusion of DPM-affected chicken meat. This finding holds nutritional relevance, as it signals the need for supplementation to restore nutritional quality when using such ingredients.

Based on the total amino acid profile, it can be stated that chicken breast hamburgers, in all treatments, are a good source of amino acids. The analysis across treatments (Table 5) also showed variations that did not compromise the daily intake of essential amino acids recommended for a 70 kg adult, as provided by one hamburger unit (120 g).

In all treatments, the good availability of isoleucine, leucine, lysine, phenylalanine, threonine, and valine stood out. This result is consistent with the study by Sanchez Brambila et al. (2017), which stated that chicken meat is highly valued by various consumers due to its affordable price and nutritional quality, featuring low fat content and excellent levels of essential amino acids. For this reason, chicken meat is used in various ways, primarily in the form of processed meat products.

4 CONCLUSIONS

The present study demonstrated that the use of chicken breasts affected by DPM in the production of hamburgers is a viable alternative within the evaluated physicochemical parameters. Although the inclusion of DPM-affected meat negatively impacted protein content and increased lipid concentration, other characteristics such as moisture, ash, caloric value, texture profile, color intensity, TWL, CWL, and shrinkage showed no significant differences between treatments.

The amino acid analysis revealed variations, with greater reductions observed for histidine, isoleucine, and valine, and smaller reductions for cystine, glycine, and serine. Nevertheless, most essential amino acids met the FAO and WHO recommendations, except for methionine, cystine, and tyrosine.

Therefore, the use of DPM-affected chicken breasts at varying inclusion levels in hamburger formulations can be considered an effective strategy for the poultry industry, enabling the utilization of meat that would otherwise result in significant economic losses. This approach does not substantially compromise the nutritional quality of the final product, which is of

Table 5. Comparative analysis between the recommended daily intake of essential amino acids and the nutritional supply per hamburger unit[3] made with different levels of inclusion of chicken breasts affected by deep pectoral myopathy.

Essential amino acids	RDI (mg)1	Treatments2				
		Control	T1	T2	T3	T4
Histidine	700	166%	105%	93%	96%	96%
Isoleucine	700	178%	170%	154%	158%	154%
Leucine	980	227%	217%	198%	202%	201%
Lysine	840	294%	280%	254%	261%	257%
Methionine	910	84%	82%	73%	76%	75%
Cystine	910	28%	28%	28%	26%	26%
Phenylalanine	980	111%	108%	98%	99%	99%
Tyrosine	980	93%	89%	82%	83%	83%
Threonine	490	242%	233%	213%	216%	216%
Valine	700	192%	182%	166%	171%	168%

[1]RDI: Recommended daily intake for a 70 kg adult (FAO, WHO, & United Nations University [UNU], 1985).

[2]Treatment C (0% chicken breast with deep pectoral myopathy); T1 (25% chicken breast with deep pectoral myopathy); T2 (50% chicken breast with deep pectoral myopathy); T3 (75% chicken breast with deep pectoral myopathy); T4 (100% chicken breast with deep pectoral myopathy).

[3]Nutritional offer per 120 g hamburger sample.

Significantly different from Product B ($p < .05$). Not significantly different from other samples.

great relevance for the sustainable and economic development of the food industry.

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