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Quality of processed chicken breast with wooden chicken for sausage formulation

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Abstract

An increased incidence of muscular alterations in broiler meat has been observed, which is referred to as wooden breast. The present work aimed to produce two formulations of chicken sausages with 20 and 40% of moderated accentuated impairment of wooden breast, and compare them with normal breast as control formulation in terms of microbiological, nutritional, and physicochemical parameters including pH, shear force, textural profile, and sensorial characteristics. Results found that there was no significant difference ($p > 0.05$) in the carbohydrates, moisture, lipids, proteins, and shear force between the control formulation and the formulations with 20 and 40% wooden breast. However, in term of pH, there were significant differences ($p < 0.05$) between all three formulations. There was also a significant difference ($p < 0.05$) in term of hardness when comparing the control formulation with the formulations of 20 and 40% wooden breast, as well as adhesiveness and chewiness. There was a also significant difference ($p < 0.05$) in term of smoky aroma when comparing the control formulation with the formulations of 20 and 40% wooden breast, as well as texture defects and pink colour. The moderated accentuated impairment of wooden breast presents a technological potential for the production of chicken sausage. Finally, it was found that the formulation with 20% wooden breast was proven a better option. In this regard, it can be considered as an alternative to reduce economic losses incurred by the poultry industry since processing guarantees the characteristics of the final product including its sensorial quality are without unfavourable effects.

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Introduction

Brazil occupies a prominent position in the world market of chicken meat. It is the third largest producer of chicken meat, producing up to 13.845 million tons in 2020, only behind the United States and China. From the total volume of broilers produced in the country, 69% was destined for the domestic market, while 31% was destined for the foreign market. The *per capita* consumption reached 45.27 kg in 2020. The main destinations for Brazilian chicken exports are China, Saudi Arabia, and Japan (ABPA, 2021).

Meat is among the most important foods in the human diet, since it is as a source of proteins, minerals, and B complex vitamins. It has received great attention as a result of its nutritional value and conservation of its functional properties in order to ensure a high-quality product for consumers, and high profitability for the meat industry (Oliveira *et al.*, 2019).

Among the factors that boost poultry production in Brazil is genetic improvement which involves the production of animals with better food conversion and more developed breasts and thighs, proper nutrition for each stage of the bird's lives, and management with batch control, vaccination, lighting, and ventilation programs (Zanetti *et al.*, 2018). The intense genetic selection of chicken breeds for fast growth, greater weight gain, and better carcass yield have caused abnormal physiological behaviours that have consequently resulted in muscular tissue damage. In this context, breast meat stands out, which is the commercial cut with the highest yield in relation to the bird's carcass and its live weight. There is a concern from the poultry industry regarding the emergence of muscular changes which are the result of the changes that are

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generated in the aspects of the final product (Sihvo *et al*., 2017).

An example of the abnormal muscular state that has increased its incidence in broilers is known as wooden breast. This alteration affects the breast region to develop a more fibrous and harder aspect during preparation and consumption. The incidence of wooden breast in broilers has already been reported in different countries such as Brazil, China, Finland, the United States, and the United Kingdom (Sihvo *et al*., 2017; Ferreira *et al*., 2018; Zanetti *et al*., 2018; Xing *et al*., 2020).

The myopathy referred to as wooden breast is characterised by expansive pale areas of considerable hardness followed by white striations throughout the pectoralis major muscle of broilers. The superficial area of the pectoral muscle tends to be more affected than the deeper parts of the muscle. Lesions can be clinically detected by manual palpation of the breast muscle of live birds as early as three weeks of age. These macroscopic changes are restricted to the pectoralis major muscle, and do not affect other skeletal muscles. However, many of the affected breast fillets are rejected for human consumption, which causes significant economic losses to the food industry. This increased the interest in solving the aetiology of this condition, and finding ways to prevent it (Sihvo *et al*., 2017). Wooden breast not only affects the meat's appearance, but also the meat's quality and functional properties, especially the protein composition. Due to the inferior quality of the wooden breast as compared to the normal one, meat processing industries have already started removing these breasts from the processing line, thereby separating them to be used in isolated products (Velleman, 2015).

According to the Ministry of Agriculture, Livestock and Food Supply of Brazil (MAPA, 2020), the wooden breast is classified in different degrees of intensity. The first classification is light and moderately light. The muscle presents less than 40% of its affected tissue in the caudal and cranial regions of the chest, with hardening in some parts of the breast fillet and without the presence of petechiae. They must follow the normal flow of the process, and can be sold as fresh meat. The second classification is the moderated accentuated, which presents 40 to 80% of lesions on the tissue, and the possible presence of petechiae located in the caudal and cranial regions, with complete hardening of this portion. The breast must follow the normal flow of the process, with the removal of the apparent lesions. The part without any lesions can be sold as fresh meat. The product of the trimming (removal of lesions) can be destined for raw material for industrialisation. The third classification is severe. This muscle presents more than 80% of its affected tissue, with the presence of haemorrhages and yellowish fluid, which characterise an extensive lesion. The whole affected part must be destined for the production of inedible products (condemnation).

It is known that although having an undesirable appearance and expansive hardness, the wooden breast does not involve any risks for consumers' health. This way, it is possible to use it in the meat industry, where modern processing technologies increase the possibility of using less acceptable meats in newly processed meat products since a huge part of the buying markets does not accept this standard of chicken breast. Besides, it makes its natural trade unfeasible. Given its visual appearance and texture's resistance to palpation, the incidence of the wooden breast myopathy reduces the general consumer acceptability for chicken breasts, thus having an impact on consumers' choices (Soglia *et al*., 2016).

In Brazil, it was reported that slaughterhouse condemnation cases due to white striping and the wooden breast amounted to 0.8% in the assessed flocks. Economic losses were calculated based on the price of the poultry breast on a per-kilogram basis in the retail sector in the assessed firm (U$ 1.86) and a weight of 1,800 grams, with an average daily slaughter of 260,000 birds/day. The losses would be approximately U$ 68,040.00, provided that the firm slaughters 250,000 broilers/day. It is also projected that during 22 business days and over the period of 12 months, the losses would reach U$ 17,962.56 only at this firm (Zanetti *et al*., 2018).

In addition, it was roughly estimated that the cost of such conditions is $200 million per year only in the United States. Given the remarkable economic loss incurred by these emerging myopathies, developing products and checking their stability, considering that they are not regular raw materials, is essential for the meat sector to adequately ascribe breast muscles to suitable processing technology, and minimise the negative impact of the myopathy on chicken quality and consumer acceptability (Kuttappan *et al*., 2016). Due to the lack of standardisation of these samples, and the great opportunity of generating income with these residues, with the purpose of promoting a more sustainable production chain, developing and studying new products from these raw materials is a crucial step for food scientists and technologists to contribute to the animal products industry.

Therefore, the search for new alternatives of adjuvants for the process is of great importance for companies in the meat industry. The production of smoked and sliced chicken breast sausage using this cut is an alternative to reduce economic losses caused by this muscular change. In the present work, chicken breast sausages formulated with 20 and 40% wooden breasts of moderated accentuated degree were produced and compared with the control formulation (normal breast chicken) in terms of microbiological and physicochemical parameters, shear force, textural profile, and sensorial characteristics.

Materials and methods

Materials

Normal chicken breasts, wooden breasts, and all other ingredients used in the formulations were supplied by a slaughterhouse located at Marau (RS, Brazil, latitude 28°26'57 south and longitude 52°12'00 west), where the experiments were performed.

Wooden breast materials

Experiments were performed in a slaughterhouse located in the Northern region of the state of Rio Grande do Sul, Brazil. Wooden breasts of moderated accentuated degree were classified by palpation and visual appearance following the criteria defined by Ministry of Agriculture, Livestock and Food Supply of Brazil (MAPA, 2020). Wooden breasts were selected from the normal breasts by palpation and visual appearance where the muscle presented 40 to 80% of lesions, petechiae located in the caudal and cranial regions, and complete hardening of this portion, which is classified as second class of wooden breast.

Chicken sausage formulations

Three chicken sausage formulations were prepared to compare the analytical parameters as shown in Table 1. Test formulations were prepared in batches of approximately 500 kg, and raw materials were separated and weighed one after the other on a conveyor belt with an attached scale calibrated to the formulations shown in Table 1. Chicken sausage production followed the rules established by a commercial company.

Table 1. Percentage of raw material used in chicken sausage formulations.

Raw material	Control formulation (%)	Formulation 1 (20% wooden breast) (%)	Formulation 2 (40% wooden breast) (%)
Normal breast	70	56	42
Wooden breast	-	14	28
Water	22	22	22
Soy protein	2	2	2
Starch	1.9	1.9	1.9
Other ingredients	4.1	4.1	4.1

Chicken breast cuts were ground in a specific grinder (Incomaf, TR 200); afterward, they were sent to the tumbler (Inject Star, Magnum 2600) along with the brine and other components of the composition which were already ground when added. The blending/mixing was performed for 2 h. Afterwards, the meat dough was mechanically portioned by the meatpacking machine (Handtmann, VF 300) in a previously hydrated artificial casing of collagen (Doremus, São Paulo, SP, Brazil), and sealed with an aluminium clip.

During the whole processing, products had a maximum temperature of 16°C. Portioned pieces were placed in cages, and subjected to cooking and natural smoking made with the burning of non-resinous, dry, and hardwoods in an oven for 6 h, where the temperature was gradually raised from at least 50°C to a maximum of 92°C so that in the total cooking time, the product reached 71°C in its thermal centre, thus, constituting a critical control point.

After this process, the pieces were cooled in chambers with cold air circulation (0 to 5°C) to ensure that the temperature of the products was at a maximum of 12°C. Cooled parts were removed from the docks, and placed in the nitrogen cabinet (70% of nitrogen and 30% of CO_2) for surface freezing. Afterward, the pieces were sent to the slicing room through an oculus. The product without casing was sliced using appropriate equipment (Schiwa, AFK 5833.52) in portions of up to 3 mm. Sliced parts were weighed, wrapped in a thermoformed plastic film without printing, sealed with a printed lid, and sealed *via* a vacuum process. Eighty samples (200 g) of the formulation were each separated and stored in a cold chamber at 4°C.

Microbiological analysis

Samples were collected for analysis of *Escherichia coli*, coagulase-positive *Staphylococcus*, *Clostridium perfringens*, and *Salmonella* (Anvisa, 2019). The following methodologies were used for the tests: *Escherichia coli* (AOAC, 2016a); coagulase-positive *Staphylococcus* (AOAC, 2016b); *Clostridium perfringens* (ISO, 2004); and *Salmonella* (AOAC, 2016c). The analyses were performed at the company's laboratory following the standard method on the first day after the production date, when the product was considered ready and packaged. At least 400 g of samples were collected per formulation for each analysis.

Nutritional analysis

Carbohydrates, moisture, lipids, and proteins were the nutritional parameters evaluated for the chicken sausages. The methodologies used were carbohydrates (MAPA, 2019), moisture (ISO, 1997), lipids (ISO, 1973), and proteins (ISO, 2009). These analyses were performed at the company's laboratory on the first day after the production date. At least 400 g of samples were collected per formulation for each analysis.

pH and shear force analyses

Determination of pH was carried out according to ISO (1999). Shear force was analysed in the CEPA (Food Research Centre) laboratory at University of Passo Fundo, Brazil according to López-Pedrouso *et al*. (2018). The texturometer equipment (model TA-TX plus, Stable Micro Systems) with a Warner-Bratzler blade was used for this analysis. All three formulations were sheared at a speed of 1.5 mm/s, and a distance of 20 mm, which represented how far the probe went down when it touched the sample before ending the test to shear it completely.

Texture profile analysis

A texturometer (model TA-TX plus, Stable Micro Systems) was used to determine the texture of chicken sausages according to López-Pedrouso *et al*. (2018). Samples were subjected to 40% compression at a speed of 0.50 mm/s, and an interval of 1 s between one compression and another. Hardness, adhesiveness, and chewiness were evaluated and analysed for the chicken sausages. These analyses were performed in the CEPA laboratory of Passo Fundo University, Brazil.

Sensory evaluation

Sensory analysis was performed by the control difference test on the first day after the production date (Meilgaard *et al*., 2007). The chicken sausage with 100% normal breast was considered the control sample. The other samples were compared against the control sample in terms of grades from -3 to 3 on a structured bilateral seven-point scale, where -3 indicated much less intense or present characteristics, -2 indicated moderately less intense or present characteristics, -1 indicated slightly less intense or present characteristics, 0 indicated characteristics based on the standard sample, 1 indicated slightly more intense or present characteristics, 2 indicated moderately more intense or present characteristics, 3 indicated much more intense or present characteristics. Sensory analysis was performed at the company's laboratory with five panellists trained by the company to identify the characteristics of the standard sausage along with the evaluation form.

Samples were coded with three-digit random numbers, and presented in identical containers to prevent bias. The order of the presentation of the samples was the standard (P) first, followed by the two coded random samples. The panellists evaluated the standard sample first, followed by the coded samples from left to right, indicating the degree of difference between the standard and coded samples, with emphasis on appearance, texture, and taste. Panellists did the sensory test in individual sensorial booths, and were given a glass of water to rinse their mouths before tasting each sample. The trained panellists were selected within the employees from the food industry where the present work was performed. They have been employed in the industry's quality control analysis due to their greater ability to identify the characteristics of the control formulation.

In the sensory test, panellists were asked to evaluate the sausages in terms of the attributes of slice integrity, internal colour homogeneity, pink colour, appearance defects, smoky, salty taste, seasoning, flavour defects, tenderness, juiciness, meat texture, and texture defects; assigning scores based on the seven-point bilateral structured scale.

Statistical analysis

Test rates were compared by analysis of variance (ANOVA), followed by Tukey's *post-hoc* test. Differences between samples were considered statistically significant when $p < 0.05$. All analyses were performed in triplicates. The correlation between the physicochemical properties, textural profile, and sensorial parameters was determined using Pearson correlation using Excel 10.0 software. When the correlation coefficient (r) was greater than 0.70, the correlation between parameters was considered strong (Myers and Montgomery, 2002). The significance of the correlation was evaluated by ANOVA of regression analysis when $p < 0.05$.

Results and discussions

Microbial loads of chicken sausages

For the three formulations, microbiological parameters for *Escherichia coli*, coagulase-positive *Staphylococcus*, *Clostridium perfringens*, and *Salmonella* showed results of < 10 UFC/g, thus complying with the law (Anvisa, 2019). The microbiological profile of chicken sausages produced from the normal and wooden chicken breasts were not significantly ($p > 0.05$) different after 6 to 8 d of storage in packages with modified atmosphere (70% of nitrogen and 30% of CO_2) (Dalgaard *et al*., 2018). Other study also found that all formulations of mortadella with wooden breasts were also in compliance with the microbiological standards recommended in the legislation (Oliveira *et al*., 2019).

Nutritional contents of chicken sausages

Table 2 presents the results of nutritional contents and physicochemical properties of chicken sausages. Results showed that there was no significant difference ($p > 0.05$) in terms of carbohydrates, moisture, lipids, proteins, and shear force between the control chicken sausage and the formulations with 20 and 40% wooden breast. Other researcher identified that wooden breasts could have increased moisture and lipids, and decreased proteins (Baldi *et al*., 2018). This discrepancy might have been due to the fact that the breast used in the present work was ground, and used on a processed product along with other ingredients.

Table 2. Nutritional properties of chicken sausages.

Sample	Carbohydrate (%)	Moisture (%)	Lipid (%)	Protein (%)
Control formulation	2.25 ± 0.27[a]	72.56 ± 0.83[a]	1.73 ± 0.11[a]	19.17 ± 0.90[a]
Formulation 1	2.82 ± 0.05[a]	72.66 ± 0.41[a]	1.60 ± 0.1[a]	17.98 ± 0.42[a]
Formulation 2	2.74 ± 0.28[a]	72.93 ± 0.47[a]	1.56 ± 0.05[a]	17.84 ± 0.17[a]

Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$).

pH and shear force of chicken sausages

Table 3 shows that the pH values of chicken sausage increased significantly ($p < 0.05$) with increasing percentage of the wooden breast in chicken sausage. Previously, Brambila *et al*. (2017) reported the pH value in cooked hamburgers with wooden breasts as compared to control formulation. The highest pH value reported for the wooden breast was attributed to reduced levels of glycogen and/or modified onset of acidification during the post-mortem time (Chatterjee *et al*., 2016). The glycolytic activity in the chicken breast muscle increases with age, which explains why the availability of glycogen in the muscle decreases with age (Petracci *et al*., 2017). Similarly, Soglia *et al*. (2016) reported that chicken breasts affected by the wooden breast condition had higher pH values (less acidic).

In the context of shear force, it was found that chicken sausages formulated with wooden breast had similar ($p > 0.05$) shear force to control chicken sausage (Table 3). Previously, Qin (2013) also reported that nuggets using wooden breast did not present a significant difference ($p > 0.05$) in terms of shear force as compared to the nuggets processed with meat from the normal breast. After grinding, wooden breast meat showed different properties than the whole wooden breast meat. In addition, Brambila *et al*. (2017) found that there was no difference ($p > 0.05$) in terms of shear force between cooked hamburgers made with normal chicken and wooden breast, and was consistent with the findings in the present work. On the other hand, Zhuang *et al*. (2016) observed that wooden broiler breasts of moderate degree required a greater shear force than normal broiler breasts. The increased shear force in the cooked wooden breast condition fillets has been attributed to increased moisture losses during cooking and/or to the accumulation of interstitial connective tissue (Zhuang *et al*., 2016).

Table 3. pH and shear force of chicken sausages.

Sample	pH	Shear force (N/mm.sec)
Control formulation	6.32 ± 0.005[c]	3.62 ± 0.47[a]
Formulation 1	6.43 ± 0.02[b]	3.52 ± 0.16[a]
Formulation 2	6.49 ± 0.02[a]	3.48 ± 0.07[a]

Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$).

Textural profile of chicken sausages

Table 4 shows the results of the textural profile of chicken sausages. It was found that there was a significant difference ($p < 0.05$) in terms of hardness between the control formulation and the formulations with 20 and 40% wooden breast. These differences were associated with severe histological changes, chemical changes in the muscle fibres, and the accumulation of the interstitial connective tissue (Xing *et al*., 2020).

In the context of adhesiveness, there was no difference ($p > 0.05$) between the control formulation and the formulation with 20% wooden breast chicken sausage. However, there was a significant difference ($p < 0.05$) between the control formulation and the formulation with 40% wooden breast, as well as between the two test formulations (20 and 40%).

Regarding chewiness, there was a significant difference ($p < 0.05$) only between the control formulation and the formulation with 40% wooden breast. The connective tissue may be an important contributor to the altered texture and tactile traits of the wooden breast meat. The meat texture can be also related to muscle shortening during rigor and sarcomere length (Tasoniero *et al*., 2019). Texture evolution during cooking is linked to myofibrillar and sarcoplasmic protein denaturation, shrinkage of myofibres, and intramuscular collagen occurring at different temperatures. These findings suggested that wooden breast meat might possess a greater amount of insoluble collagen stabilised by heat-resistant intermolecular bonds. Indeed, the hardness of sausages formulated with wooden breast in combination with normal chicken breast was harder than sausages formulated with normal breast chicken alone (Rocha *et al*., 2020). Similarly, a study by Madruga *et al*. (2019) observed that wooden breasts chicken sausages were harder, more adhesiveness, and chewiness as compared to control formulation, but the differences were not statistically significant ($p > 0.05$) between formulations. For hamburgers, the effect of the wooden breast condition and storage time on hardness values was identified, but a significant increase was not ($p > 0.05$) observed on all treatments over the storage time, where samples with the addition of the normal breast to the wooden breast were more tender at the end of the storage period as compared to the hamburgers formulated with only normal breast or wooden breast (Santos *et al*., 2019).

It is important to mention that the occurrence of fibrosis on the wooden breast myopathy may not necessarily affect the texture properties of the breast (Sihvo *et al*., 2017). Also, processing can modify meat properties including the texture not being expressed in the same way in the processed product (Chatterjee *et al*., 2016). Several factors can influence the textural profile of a meat product such as the animal's age at the time of slaughter, cooking methods applied, oxidation reactions, or even the lowering of moisture content during storage (Ferreira *et al*., 2018). Regarding the investigated products, the wooden breast influenced them by intensifying the hardness of the sausages; it also influenced the chewiness of the formulation with 40% wooden breast because the harder the product, the more the energy is required to chew it.

Table 4. Texture profile analysis.

Sample	Hardness	Adhesiveness	Chewiness
Control formulation	12,356.87 ± 904.85[b]	-116.29 ± 40.27[b]	8,360.54 ± 684.41[b]
Formulation 1	15,075.18 ± 574.50[a]	-418.10 ± 94.39[b]	10,035.04 ± 817.48[ab]
Formulation 2	15,210.81 ± 593.23[a]	-798.26 ± 154.53[a]	10,870.61 ± 802.21[a]

Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$).

Sensorial properties of chicken breast sausages with wooden breasts

Table 5 shows the scores for sensory attributes of smoked and sliced chicken breast sausages with the addition of the wooden breast and the control formulation.

There was no significant difference ($p > 0.05$) between the three formulations in the sensory analysis in terms of the control difference test for slice integrity, internal colour homogeneity, seasoning, salty taste, flavour defects, appearance defects, tenderness, juiciness, and meat texture. However, there was a significant difference ($p < 0.05$) between the control formulation and the formulation with 20% wooden breast, and between the control formulation and the formulation with 40% wooden breast, in terms of the pink colour. Sihvo *et al*. (2017) reported that wooden breast fillets were visually pale. According to Mazzoni *et al*. (2015), these fibres have severe multifocal regeneration myodegeneration with different quantities of collagen-rich connective tissue or fibrosis. These fibre changes affect quality traits such as pH, colour, water holding capacity, and texture of fillets (Mazzoni *et al*., 2015). In terms of smoky aroma, there was a significant difference ($p < 0.05$) only between the control formulation and the formulation with 20% wooden breast. Furthermore, there was a significant difference ($p < 0.05$) between the control formulation and the formulation with 40% wooden breast, and between the two test formulations, in terms of texture defects. Despite the statistically significant alterations mentioned in the present work, the results did not influence ($p > 0.05$) the practical sensory acceptability which showed scores ranging from -1 to 1 in the bilateral structured scale, which was acceptable by the standards of the test applied. Some authors established a time limit for the sensory study. Tasters are giving an average value for smell and taste, smaller than 3 on a scale of 1 to 5, since this indicates that the product has already lost its sensory acceptability (Kotzekidou and Bloukas, 1996).

In fact, Santos *et al*. (2019) reported that the emulsified chicken hamburgers with wooden breasts did not influence ($p > 0.05$) consumers' acceptability. In addition, sensory attributes of mortadella including texture, flavour, colour, consistency, and odour were not different ($p > 0.05$) from the products formulated with 25, 50, 75, and 100% chicken breasts, and with wooden breast alterations as compared to the chicken breast formulations without alterations after 30 and 60 days (Oliveira *et al*., 2019). Similarly, in three sausage formulations with wooden breast, except for the attribute of pink colour, there were no significant differences ($p > 0.05$) observed among panellists in the present work.

Table 5. Sensory properties of chicken breast sausages with the addition of wooden breast.

Attribute	Control formulation	Formulation 1	Formulation 2
Slice integrity	0^a	0^a	0^a
Internal colour homogeneity	0^a	0^a	0^a
Pink colour	-0.6 ± 0.54^a	0^b	0^b
Appearance defect	0.6 ± 0.54^a	0.6 ± 0.54^a	0.8 ± 0.44^a
Smokey	0^a	-0.8 ± 0.44^b	-0.6 ± 0.54^a
Salty taste	0^a	0^a	0.2 ± 0.44^a
Seasoning	0.6 ± 0.54^a	0^a	0.6 ± 0.54^a
Flavour defect	0^a	0^a	0^a
Tenderness	0^a	0^a	0^a
Juiciness	0^a	0^a	0^a
Meat texture	0^a	0^a	0^a
Texture defect	0^a	0^a	0.8 ± 0.44^b

Means followed by different lowercase superscripts in the same row are significantly different ($p < 0.05$).

Pearson correlation between analyses

To check the interactions between sensorial attributes and some physicochemical parameters of chicken breast sausages formulated with wooden breast, a correlation analysis was performed, and the results of the strong correlations are presented in Table 6.

Table 6. Correlation between sensory attributes and some physicochemical parameters by the Pearson correlation.

Attribute	Hardness	Chewiness	Pink colour
Carbohydrate	0.92	0.77	0.89
pH	0.82	0.86	-
Protein	-0.79	-0.77	-
Hardness	-	0.90	0.86
Adhesiveness	-	-	-0.77
Chewiness	-	-	0.76

A strong positive correlation was established between hardness with carbohydrates and pH, and between chewiness with carbohydrates and pH, thus, demonstrating that there was an increase in the deposition of the connective tissue when introducing the wooden breasts in the formulations, thereby making it harder. The increase in pH in wooden breasts has been reported by Jarvis *et al*. (2020). There was a negative correlation between hardness and protein, and between chewiness and protein, since wooden breasts presented a lower level of protein than normal breasts (Tasoniero *et al*., 2016). A strong positive correlation was found between chewiness and hardness, which confirmed that the harder the chicken breast, the more energy is required to chew it (Wee *et al*., 2018). Pink colour had a positive correlation with carbohydrates, hardness, and chewiness which indicated that an increase in one factor led to a corresponding increase in the other. There was a negative correlation of pink colour with chewiness. However, the relationship between these parameters has not yet been elucidated using wooden breast. Previously, Barbieri *et al*. (2016) observed that appearance attributes (characteristic ham aspect, intense pink, colour, and uniform aspect) were positively correlated with the preference and willingness to pay, whereas a pale colour had a negative influence on liking. Rocha *et al*. (2020) also observed that the protein level was strongly and negatively correlated with the instrumental hardness in the evaluation of wooden breast sausages.

Conclusion

The present work concluded that the chicken sausage formulation with 20% wooden breast was a better option due to lower pH, shear force, and better texture profile results. In that regard, it can be considered an alternative for use, and for the reduction of economic losses incurred by the poultry industry since processing guarantees the characteristics of the final product including its sensory quality are without any adverse effects. Further research is, however, needed to ascertain the possibility that the improvements in the tactile properties of chicken breast sausages could be further enhanced by refrigerated or frozen storage in different periods as reported in some research with wooden breasts. In addition, tests with higher cooking temperature for denaturation and solubilisation of the thermally-labile collagen cross-links, and grinding of the wooden breast with smaller granulometry, should be carried out to try to reduce the higher hardness as compared to control.

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