PROCESSING AND PRODUCTS

Instrumental texture analysis of chicken patties prepared with broiler breast fillets exhibiting woody breast characteristics

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ABSTRACT Potential applications of chicken meat with the woody breast (**WB**) condition in further processed products could provide processors with alternatives to deal with this meat quality problem. The objective of this study was to evaluate the effect of the use of broiler breast fillets at varying degrees of WB severity and proportions on instrumental texture characteristics of chicken patties. A total of 54 breast fillets were collected from broilers processed as per commercial practices, previously classified based on tactile evaluation in 3 WB categories (normal [**NOR**]; mild [**MIL**], and severe [**SEV**]). Instrumental compression analysis was performed to validate subjective scores. Nine treatments with 6 replicates of chicken patties were prepared: 100% NOR (T_1), 67% NOR + 33% MIL (T_2), 67% NOR + 33% SEV (T_3), 33% NOR + 67% MIL (T_4), 33% NOR + 67% SEV (T_5), 100% MIL (T_6), 67% MIL + 33% SEV (T_7), 33% MIL + 67% SEV (T_8), and 100% SEV (T_9). Instrumental texture profile analysis along with cook loss, color, and dimensional changes was evaluated in cooked patties. Compared with normal samples and excluding treatments T_2 and T_4, hardness, springiness, and chewiness values of chicken patties decreased ($P < 0.05$) as WB severity increased in the meat incorporated into the formulation. Patties prepared using mixtures of MIL and SEV fillets (T_7 and T_8) including T_9 had higher levels of cook loss (>26%, $P < 0.05$) accompanied by significant reductions in diameter (>16%, $P < 0.05$) and distinguishable color changes ($\Delta E^*_{ab} > 2$) than normal patties. These data suggest that the potential use of WB meat in chicken patties is associated with the degree of WB severity and the incorporation rate. The inclusion of WB fillets at high levels into this product is not recommended owing to their poor functionality. However, feasible mixtures of normal breast fillets with those affected by WB myopathy at relatively low proportions could be considered by processors as an alternative in commercial chicken patty formulations.

Key words: woody breast, texture profile analysis, processing, poultry product, meat quality

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INTRODUCTION

Over the past few year, the global poultry industry has been facing the woody breast (**WB**) condition, an increasing and challenging meat quality problem that is characterized by a noticeable abnormal hardness in the chicken breast fillets (Sihvo et al., 2014; Mudalal et al., 2015). This myopathy can cause significant economic losses because broiler breast fillets affected by this anomaly show undesirable nutritional and sensorial characteristics that can negatively impact the consumer acceptability (Petracci et al., 2015), which makes urgent the development and selection of cost-effective alternatives for the use of WB meat once broiler carcasses or their corresponding breast fillets affected by this anomaly are effectively detected and classified (Petracci et al., 2019; Santos et al., 2019). This WB disorder has a detrimental effect on the broiler breast meat quality by changing its functional properties. Indeed, the WB meat exhibits an altered composition such as higher levels of fat, collagen, and moisture and lower levels of protein and ash (Soglia et al., 2016a,b; Baldi et al., 2019).

In the aforementioned context, the preparation of further processed products using chicken meat affected by WB abnormality could be a possible alternative because the chemical composition can be modified during formulation (Petracci et al., 2015) as well as further processing operations can modify meat properties (Acton, 1972; Aberle et al., 2001), which could mitigate or minimize undesirable effects on final product quality

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(Petracci et al., 2019) providing processors options to face this meat quality problem. In this regard, some attempts have been made to develop and evaluate poultry meat products using WB meat such as marinated whole muscle product (Tijare et al., 2016; Caldas-Cueva and Owens, 2020), sausages (Qin, 2013; Madruga et al., 2019), nuggets (Qin, 2013), and patties (Sanchez-Brambila et al., 2017; Santos et al., 2019). Moreover, functional properties of meat batters prepared from WB meat have been assessed (Xing et al., 2017; Chen et al., 2018). However, further research is still needed to understand the impact of using chicken meat with different degrees of WB severity at varying proportions in poultry meat products. For instance, none of these trials have used broiler breast fillets partially affected by WB myopathy at different proportions in their experimental designs. In addition, most of these studies have included food additives in their product formulations such as salt and phosphates, which could have masked the effect of WB myopathy on these products by the interaction between WB meat and those additives that can modify functional properties such as water holding capacity and texture attributes of cooked meat products (Sanchez-Brambila et al., 2017). With this in mind, investigating the effect of the application of only broiler breast fillets of different WB categories at varying proportions in processed products could be a suitable approach to evaluate the actual impact of this meat quality issue, which could serve as a base for the development of formulas including adequate ingredients for industrial applications. Thus, this study aimed to assess the effect of the use of broiler breast fillets at different degrees of WB severity and percentages on instrumental texture characteristics of chicken patties in addition to other quality traits.

MATERIALS AND METHODS

Sample Collection

Breast fillets (pectoralis major) were collected from commercial broilers (high breast yielding strain and 8 wk of age) processed at the University of Arkansas Poultry Processing Pilot Plant as per commercial-based practices (Mahaffey et al., 2006) including a prechill (15 min at 12°C), chill (90 min at 1°C), and debone time of 3 h postmortem.

Boneless and skinless breast fillets were scored for degree of hardness using tactile inspection (Tijare et al., 2016) after deboning. The scored fillets were classified into 3 WB categories, as follows: 0.0 or 0.5 as normal fillets of flexible consistency throughout; 1.0 or 1.5 as mild WB or fillets partially affected by WB condition of hard consistency primarily in the cranial region exhibiting some flexibility in the middle to caudal section, and 2.0, 2.5 or 3.0 for fillets moderately or severely affected by WB condition or fillets of very firm and hard texture throughout with nonexistent or limited flexibility in the middle to caudal area. In parallel, instrumental compression force analysis was performed to validate subjective scores. After WB scoring and compression force analyses, a total of 54 classified fillets (18 per WB category) were packed in zip-sealed plastic bags and stored overnight at 4°C.

Meat Quality Characteristics

Compression force (**CF**) assessment was determined on intact fillets by averaging 4 readings at predetermined locations in the cranial section of each fillet using a texture analyzer (Model TA.XT Plus; Texture Technologies Corp., Scarsdale, NY). Broiler breast fillets were compressed to 20% of their initial height with a 6-mm-diameter flat probe using the following settings: pretest and post-test speeds of 10.0 mm/s, test speed of 5.0 mm/s, load cell capacity of 5 kg, and a trigger force of 5 g (Sun et al., 2018). At 24-h postmortem, instrumental color (CIE L* = lightness, a* = redness, and b* = yellowness) was measured in triplicate on the dorsal surface (bone side) of each fillet using a calibrated colorimeter (Model CR-400; Konica Minolta Sensing Inc., Osaka, Japan), whereas the pH was determined at the cranial end section of each fillet using a portable spear-tip probe and pH meter (Model Testo 205; Testo Inc., Sparta, NJ).

Preparation of Chicken Patties

Nine formulations or treatments (T_1 through T_9) with 6 replicates of chicken patties were prepared from broiler breast fillets at varying degrees of WB severity as described in Table 1. The preparation of one patty sample per treatment on a different trial batch using 3 fillets per WB category was considered a replicate. The entire cranial region of breast fillets (the thickest portion; approximately 2/5 of each fillet) was cut, trimmed, and ground separately by WB category using an electric meat grinder (Chefmate, CC12; GFE, Dayton, OH) through a 3-mm plate. Subsequently, the ground breast meat groups were added into the recipe as per the proportions shown in the experimental design (Table 1). Each combination or treatment was manually mixed until a homogeneous consistency was obtained and then placed in a plastic Petri dish to obtain a consistent circular-shaped chicken patty (diameter: 87 mm, height or thickness: 15 mm; weight: 85 g). Samples were individually vacuum-packed and stored at −22°C for no more than 7 d until cooking for further analysis.

Sample Cooking

Frozen chicken patties were thawed at 2°C for 24 h and cooked on a preheated (150°C) 20-inch electric griddle (Model 0705305; National Presto Industries Inc., Eau Claire, WI) turning them at 3 min until the targeted core temperature reached 75°C. Internal patty temperatures were recorded using a 12-channel Digisense scanning thermometer (Model 69200-00; Barnant Co., Barrington, IL). Cooked patties were cooled to room temperature (23°C ± 2°C) and analyzed.

Table 1. Experimental design of 3 broiler breast meat constituents at varying percentages and degrees of woody breast (WB) severity in chicken patty formulation.

	Ingredient proportions[1]					
Treatment (mixture)	X1	X2	X3	Nor (%)	MIL (%)	SEV (%)
T_1	1	0	0	100	0	0
T_2	0.67	0.33	0	67	33	0
T_3	0.67	0	0.33	67	0	33
T_4	0.33	0.67	0	33	67	0
T_5	0.33	0	0.67	33	0	67
T_6	0	1	0	0	100	0
T_7	0	0.67	0.33	0	67	33
T_8	0	0.33	0.67	0	33	67
T_9	0	0	1	0	0	100

[1] X1, proportion of normal breast (NOR) meat; X2, proportion of mild WB (MIL) meat; X3, proportion of moderate or severe WB (SEV) meat.

Determination of Cook Loss and Dimensional Changes

The patties were weighed before and after cooking to determine the percentage of cook loss as per the formula: cook loss (%) = ([raw patty weight–cooked patty weight]/raw patty weight) × 100. The diameter and height of raw and cooked chicken patties were measured at 3 different points per sample using a digital vernier caliper (Model W80152; Wilmar Corp., Tukwila, WA). The values from the 3 points for each dimension were averaged before further use. Reduction levels (%) in diameter and height were determined using the formula: reduction in diameter or height (%) = ([raw patty measurement–cooked patty measurement]/raw patty measurement) × 100.

Instrumental Color Evaluation

Instrumental color (CIE L* = lightness, a* = redness, and b* = yellowness) was measured in triplicate on the cross-sectional surface of each cooked chicken patty using a calibrated colorimeter (Model CR-400; Konica Minolta Sensing Inc., Osaka, Japan). The settings of illuminant D_{65} and 2° observer (Caldas-Cueva et al., 2016) were used. The total color difference (ΔE^*_{ab}) was calculated to evaluate the overall color change between a given cooked chicken patty and the reference sample that was the cooked chicken patty prepared with 100% of normal or unaffected broiler breast meat. The ΔE^*_{ab} value was determined as per the formula: $\Delta E^*_{ab} = [(L^*_i – L^*_o)^2 + (a^*_i – a^*_o)^2 + (b^*_i – b^*_o)^2]^{1/2}$, where L^*_o, a^*_o and b^*_o were the values of the color reference (normal chicken patty), and L^*_i, a^*_i, and b^*_i were the values of each chicken patty evaluated.

Texture Profile Analysis

Texture profile analysis (**TPA**) was carried out at room temperature (23.0°C ± 2°C) with a texture analyzer (Model TA.XT Plus; Texture Technologies Corp., Scarsdale, NY). Cylindrical test samples (diameter: 23.0 mm and thickness: 14.4 mm) were taken from the central portion of cooked chicken patties using a corer and subjected to a two-cycle compression test. Test samples were compressed to 25% of their original height using a cylindrical probe of 5.08 cm in diameter with the following settings: pretest speed of 1.0 mm/s, test speed of 2.0 mm/s, post-test speed of 2.0 mm/s, load cell capacity of 5 kg, and a trigger force of 5 g. The test samples were analyzed for four TPA parameters: hardness (N), cohesiveness, springiness, and chewiness (N).

Statistical Analysis

Data were analyzed using a 1-way ANOVA with WB category (for meat quality characteristics) or treatment factor (for TPA parameters, instrumental color parameters, cook loss levels, and reduction levels in dimensions of chicken patties) fit as fixed effect. When the main effect was significant, means were separated by Tukey's honestly significant difference test at P-value < 0.05. The simplex lattice mixture design was used to estimate suitable combinations of normal or unaffected broiler breast meat (X1), mild WB meat (X2), and moderate or severe WB meat (X3) to produce acceptable products. The estimation of feasible mixtures was based on TPA parameters, cook loss levels, and reduction levels in dimensions of chicken patties prepared with 100% of normal broiler breast fillets. The statistical analysis was achieved using JMP software, version 14.3.0 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Meat Quality Characteristics

The results from this study showed that quality characteristics of raw broiler breast fillets were significantly different among WB categories ($P < 0.01$) (Table 2). Broiler breast fillets severely affected by WB anomaly were heavier than normal breast fillets ($P < 0.05$), which was consistent with other studies (Mudalal et al., 2015; Dalle Zotte et al., 2017) confirming the association of WB incidence with heavy weight of broiler breast

Table 2. Effect of woody breast (WB) condition on quality characteristics of raw broiler breast fillets.

	WB category[1]		
Parameter	Nor	MIL	SEV
Fillet weight (g)	394.28 ± 7.52^{c}	431.00 ± 10.12^{b}	473.22 ± 9.76^{a}
Compression force (N)	4.29 ± 0.21^{c}	9.85 ± 0.38^{b}	17.64 ± 0.62^{a}
pH	5.73 ± 0.02^{c}	5.82 ± 0.03^{b}	6.01 ± 0.02^{a}
Lightness (L*)	54.67 ± 0.40^{b}	56.91 ± 0.51^{a}	58.67 ± 0.66^{a}
Redness (a*)	1.81 ± 0.24^{b}	1.94 ± 0.23^{b}	2.95 ± 0.29^{a}
Yellowness (b*)	12.98 ± 0.30^{b}	$13.71 \pm 0.39^{a,b}$	14.92 ± 0.45^{a}

$^{a\text{-}c}$Means ± SEM with no common superscripts within a row differ significantly ($P < 0.05$).

[1] MIL, mild WB meat; NOR, normal breast meat; SEV, moderate or severe WB meat.

muscles that could be related to the intensive selection of broilers for rapid muscle growth and high yields (Sihvo et al., 2014; Petracci et al., 2015, 2019). Broiler breast fillets partially affected by WB defect were also heavier than normal breast fillets but lighter than severely affected samples ($P < 0.05$).

With respect to the CF, breast fillets from broilers more severely affected by WB condition presented the highest CF value ($P < 0.05$), whereas normal samples had the lowest CF ($P < 0.05$). Intermediate CF values were observed in mild WB fillets that were lower than those for severely affected by WB condition ones but higher than CF values for normal samples ($P < 0.05$). The CF results of this study are similar to those of previous reports that highlight higher CF values for breast fillets severely affected by WB condition in comparison with unaffected or normal samples (Mudalal et al., 2015; Soglia et al., 2017; Sun et al., 2018; Baldi et al., 2019). In this regard, some authors state that abnormal hardness of WB meat could be associated with the fibrosis as a result of the accumulation of highly cross-linked collagen fibrils (Velleman et al., 2017), which is in agreement with another study (Soglia et al., 2017) that suggests that the increased amount of connective tissue components observed in WB fillets leads to a high degree of inherent strength that results in modified textural properties.

Muscle pH values increased ($P < 0.05$) as WB severity increased in broiler breast fillets. Fillets severely affected by WB condition showed higher ($P < 0.05$) pH values in comparison with normal fillets, which was consistent with recent publications (Dalle Zotte et al., 2017; Sanchez-Brambila et al., 2017; Baldi et al., 2019; Madruga et al., 2019). The higher pH values within abnormal broiler breast fillets could be related to a reduction of the glycogen content or modification of the onset of acidification during the postmortem time caused by this myopathy (Mudalal et al., 2015). With respect to the instrumental color, the dorsal side of the fillets severely affected by WB anomaly showed significantly higher ($P < 0.05$) values of lightness (L*), redness (a*), and yellowness (b*) in comparison with normal samples. Overall, there is no consensus about the instrumental color characterization of WB meat which may be associated with the irregular distribution of this myopathy throughout the breast fillet in addition to the presence of small hemorrhages on its abnormal ventral surface (Sihvo et al., 2014; Dalle Zotte et al., 2017; Santos et al., 2019). However, the results from this study were consistent with the data published by Geronimo et al. (2019), who also measured the color on the dorsal surface of breast fillets and reported higher values of L*, a*, and b* parameters for fillets exhibiting severe levels of WB condition compared to normal fillets. Typical pale colors of WB meat (Sihvo et al., 2014) that were also observed on its dorsal surface in this experiment could be related to an increased scattering or dispersion of light in the abnormal meat owing to the muscle fiber degeneration (Santos et al., 2019) along with the accretion of extracellular water as a result of edema and inflammatory processes (Sihvo et al., 2014; Petracci et al., 2019).

Cook Loss and Dimensional Changes of Chicken Patties

The water holding capacity was evaluated through the determination of the cook loss level in chicken patties. The effect of WB severity on the cook loss levels of chicken patties is shown in Figure 1. The results showed that chicken patty treatments T_5 and T_7 through T_9 had higher cook loss levels than patties

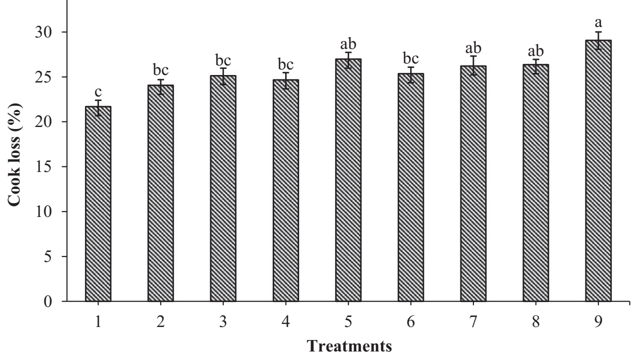

Figure 1. Effect of woody breast (WB) condition on cook loss of chicken patties. $^{a\text{-}c}$Means ± SEM with no common superscripts differ significantly ($P < 0.05$).

made from normal breast meat or treatment T_1 ($P < 0.05$), which suggested that the cook loss of chicken patties increased ($P < 0.05$) as WB severity increased in the broiler breast meat added into the product formulation. These significant increasing trends in cook loss levels were accompanied by a significant ($P < 0.05$) reduction in diameter of chicken patties prepared using combinations of breast meat partially and severely affected by WB abnormality (T_7 and T_8) including the treatment T_9 in comparison with normal patties (Figure 2). Nevertheless, no differences were observed in the thickness or height reduction levels among chicken patty treatments.

The poor ability to bind water observed in WB samples could be explained by the degeneration of muscle fibers accompanied by fibrosis, lipidosis and alterations in fiber membrane integrity caused by WB anomaly (Soglia et al., 2016b; Petracci et al., 2019). Indeed, changes in the chemical composition (Soglia et al., 2016a,b; Baldi et al., 2019) and reduction in muscle fiber number (Sihvo et al., 2014; Mazzoni et al., 2015) play an important role in the reduction of water holding capacity in breast fillets affected by WB defect, which could have been reflected in the chicken patty samples. It has also been hypothesized that the higher proportion of extra-myofibrillar water and the greater mobility of intramyofibrillar water could be responsible for the increased losses of fluids during cooking in WB meat (Soglia et al., 2016a), which may have also been reflected in the chicken patty treatments.

It has been suggested that unwanted differences in sensory texture features between intact cooked normal and WB fillets can be minimized in a ground product (Sanchez-Brambila et al., 2017). However, the benefits of grinding breast fillets with WB condition might be related to important factors such as the meat particle size. In fact, the importance of the meat particle size reduction is related to the increase in the surface area and the extraction of myofibrillar proteins that influence the functionality of them (Barbut, 2015). In this study, breast fillets were ground separately by WB category using an electric meat grinder through a 3-mm plate. Qin (2013) reported that ground chicken nuggets containing WB meat (replacing the 30% of the total lean meat in the recipe) processed in a pilot plant using a grinder with a 3-mm plate presented higher cook loss percentages than normal samples, whereas Sanchez-Brambila et al. (2017) did not find differences in cook loss levels between normal and WB patties produced using a grinder with a chopper plate of approximately 6-mm square hole. Madruga et al. (2019) also observed that even though the cook loss results displayed increasing trends for WB sausages prepared using a grinder with a 10-mm plate, there was no difference in comparison with normal samples. In contrast, Chen et al. (2018) found differences in cook loss levels between normal and WB meatballs processed using a grinder with a 6-mm plate. Because of these contrasting results in terms of cook loss levels in addition to the large standard deviation of this parameter for WB patties reported by Sanchez-Brambila et al. (2017), further research is needed to better understand the effect of WB myopathy on cook loss levels of ground products prepared at different meat particle sizes along with an evaluation of the effect of incorporation of ingredients into the formulation that can have contributed to these differences.

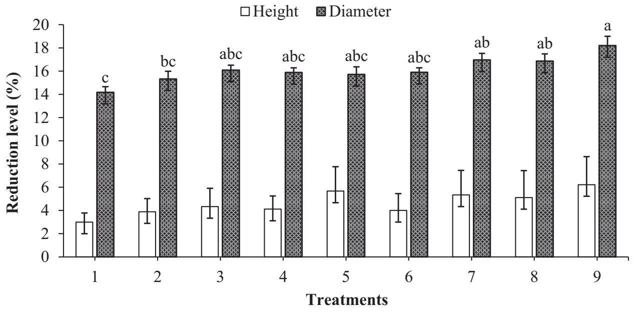

Figure 2. Effect of woody breast (WB) condition on reduction levels in height and diameter of chicken patties. $^{a-c}$Means ± SEM with no common superscripts differ significantly ($P < 0.05$).

Texture Profile Analysis of Chicken Patties

The instrumental TPA results of cooked chicken patties prepared with broiler breast fillets at varying degrees of WB severity are shown in Table 3. The use of breast fillets with WB condition modified ($P < 0.05$) instrumental texture characteristics of cooked chicken patties significantly. Chicken patties prepared with breast meat severely affected by WB condition or treatment T_9 presented lower average values of hardness, cohesiveness, springiness, and chewiness than normal chicken patties or treatment T_1 ($P < 0.05$). Chicken patties prepared using exclusively breast fillets partially affected by WB or treatment T_6 also had lower hardness, springiness, and chewiness values than normal samples ($P < 0.05$), but they showed higher hardness and chewiness values than treatment T_9 ($P < 0.05$). In this sense, Chen et al. (2018) also reported that the TPA hardness, cohesiveness, springiness, and chewiness values of meatballs made from WB meat were lower than those for normal samples, highlighting defects caused by WB such as decreased ability to bind water and increased water overflowed during the gelation. Moreover, Xing et al. (2017) found that the TPA hardness and cohesiveness of thermal-induced gels prepared from WB meat were lower than those for normal samples at different salt concentrations (0–4%), describing that the gel formed by WB meat batter was more irregular. Recently, Santos et al. (2019) also observed that normal emulsified chicken patties were tougher than WB samples. However, there are some authors (Madruga et al., 2019) who did not find differences in TPA parameters between normal and WB chicken sausages. In another study conducted by Sanchez-Brambila et al. (2017), it was observed that the average scores for sensory attributes of hardness, cohesiveness, juiciness, fibrous, and rate of breakdown were not different between normal and WB patties; however, WB patties showed lower springiness and chewiness scores than normal samples ($P < 0.05$).

Table 3. Effect of woody breast (WB) condition on the texture profile analysis of cooked chicken patties.

Treatment (mixture)[1]		Hardness (N)	Cohesiveness	Springiness	Chewiness (N)
T$_1$)	100% NOR	30.11 ± 1.57^{a}	0.78 ± 0.01^{a}	0.91 ± 0.01^{a}	21.45 ± 0.98^{a}
T$_2$)	67% NOR + 33% MIL	28.64 ± 0.70^{a}	0.77 ± 0.01^{a}	0.83 ± 0.01^{a,b}	18.40 ± 0.56^{a,b}
T$_3$)	67% NOR + 33% SEV	27.97 ± 1.10^{a,b}	0.75 ± 0.01^{a,b}	0.81 ± 0.02^{b}	16.88 ± 0.89^{b,c}
T$_4$)	33% NOR + 67% MIL	28.13 ± 1.46^{a,b}	0.76 ± 0.01^{a,b}	0.85 ± 0.01^{a,b}	18.00 ± 0.90^{a,b}
T$_5$)	33% NOR + 67% SEV	23.43 ± 0.87^{b,c}	0.75 ± 0.01^{a,b}	0.81 ± 0.02^{b}	14.28 ± 0.83^{c,d}
T$_6$)	100% MIL	20.55 ± 1.24^{c}	0.74 ± 0.01^{a,b}	0.79 ± 0.02^{b}	12.10 ± 0.94^{d}
T$_7$)	67% MIL + 33% SEV	19.14 ± 1.21^{c,d}	0.74 ± 0.01^{a,b}	0.80 ± 0.02^{b}	11.33 ± 0.69^{d,e}
T$_8$)	33% MIL + 67% SEV	18.62 ± 0.56^{c,d}	0.75 ± 0.02^{a,b}	0.81 ± 0.03^{b}	11.29 ± 0.51^{d,e}
T$_9$)	100% SEV	14.56 ± 0.50^{d}	0.71 ± 0.01^{b}	0.78 ± 0.02^{b}	8.09 ± 0.45^{e}

$^{a\text{-}e}$Means ± SEM with no common superscripts within a column differ significantly ($P < 0.05$).
[1] MIL, mild WB meat; NOR, normal breast meat; SEV, moderate or severe WB meat.

With exception to treatments T$_1$ through T$_4$, the hardness of chicken patties decreased ($P < 0.05$) as WB severity increased in the broiler breast meat incorporated into the formulation. Furthermore, excluding treatments T$_1$, T$_2$, and T$_4$, the chewiness of patties decreased ($P < 0.05$) as WB severity increased in the broiler breast meat added to the product recipe. Internal cracked and mushy layers were visually observed in test samples of cooked patties starting from treatment T$_5$ that were more evident as treatment number increased. The impaired texture properties observed in chicken patties made from WB meat could be associated with the severe degeneration of muscle fibers and reduction of myofibrillar proteins caused by this myopathy (Mudalal et al., 2015; Soglia et al., 2016b) which in turn generates more irregular and disorderly arranged gel structures (Xing et al., 2017) that can be reflected in the final product quality. Although higher levels of cook loss and reduction in diameter were observed in WB patties, the TPA hardness and chewiness values of these samples were still lower than those for normal samples, which may be related to the fact that WB meat typically shows lower levels of myofibrillar proteins (i.e., less functional abilities).

Instrumental Color Measurements of Chicken Patties

The results of the internal color evaluation of cooked chicken patties are shown in Table 4. No differences were observed in the L* parameter, whereas a* and b* values differed among treatments ($P < 0.01$). Chicken patties made from broiler breast meat partially (T$_6$) and severely (T$_9$) affected by WB defect displayed a significant increase ($P < 0.05$) in a* parameter by 0.32 and 0.35 units, respectively, in comparison with normal samples. In contrast, chicken patties produced using combinations of mild WB fillets and severe WB fillets (T$_7$ and T$_8$) including the treatment T$_9$ showed a significant reduction ($P < 0.05$) in b* parameter compared with normal samples. Although the L* values were not different among treatments, paler colors were visually observed on the cross-sectional surface of cooked patties containing high proportions of WB meat that might be associated with the typical pale color of WB fillets (Sihvo et al., 2014) that was also reported in this study (Table 2).

Overall color changes were evaluated through the calculation of the total color difference (ΔE^*_{ab}) between a given chicken patty and the reference sample or normal chicken patty (T$_1$). Table 4 shows that T$_9$ treatment had a higher ($P < 0.05$) ΔE^*_{ab} value than treatments T$_2$ through T$_6$. However, the interpretation of ΔE^*_{ab} results were carried out using the criteria suggested by Francis and Clydesdale (1975), who considered that changes in instrumental color measurements are visually noticeable when ΔE^*_{ab} values are higher than 2, whereas these color modifications are obvious or evident for the human eye when ΔE^*_{ab} values are higher than 3. In this sense, patties prepared using mixtures of mild WB fillets and severe WB fillets (T$_7$ and T$_8$) including T$_9$ showed noticeable internal color modifications ($\Delta E^*_{ab} > 2$) when compared with normal patties. In other words,

Table 4. Effect of woody breast (WB) condition on instrumental color measurements of cooked chicken patties.

Treatment (mixture)[1]		Lightness (L*)	Redness (a*)	Yellowness (b*)	ΔE^*_{ab}
T$_1$)	100% NOR	79.58 ± 0.46	1.44 ± 0.03^{c}	14.43 ± 0.25^{a}	0.00
T$_2$)	67% NOR + 33% MIL	80.87 ± 0.37	1.47 ± 0.07^{b,c}	14.39 ± 0.18^{a}	1.40 ± 0.29^{b}
T$_3$)	67% NOR + 33% SEV	80.57 ± 0.32	1.42 ± 0.05^{c}	13.61 ± 0.13^{a,b}	1.45 ± 0.34^{b}
T$_4$)	33% NOR + 67% MIL	79.88 ± 0.56	1.41 ± 0.07^{c}	14.05 ± 0.31^{a,b}	1.56 ± 0.36^{b}
T$_5$)	33% NOR + 67% SEV	80.72 ± 0.17	1.57 ± 0.03^{a,b,c}	13.92 ± 0.21^{a,b}	1.60 ± 0.48^{b}
T$_6$)	100% MIL	79.98 ± 0.53	1.76 ± 0.04^{a,b}	14.19 ± 0.20^{a,b}	1.54 ± 0.33^{b}
T$_7$)	67% MIL + 33% SEV	80.83 ± 0.36	1.68 ± 0.10^{a,b,c}	13.08 ± 0.33^{b,c}	2.12 ± 0.39^{a,b}
T$_8$)	33% MIL + 67% SEV	81.14 ± 0.50	1.71 ± 0.07^{a,b,c}	12.22 ± 0.32^{c,d}	3.09 ± 0.53^{a,b}
T$_9$)	100% SEV	81.39 ± 0.46	1.79 ± 0.09^{a}	11.74 ± 0.43^{d}	3.74 ± 0.62^{a}

$^{a\text{-}d}$Means ± SEM with no common superscripts within a column differ significantly ($P < 0.05$).
[1] MIL, mild WB meat; NOR, normal breast meat; SEV, moderate or severe WB meat.

differences in internal color between these cooked patties and the control may be noticed by consumers. On the other hand, T_8 and T_9 treatments exhibited evident internal color changes ($\Delta E^*_{ab} > 3$) compared to normal samples.

Significant increasing trends were observed in ΔE^*_{ab} values as WB severity increased in the chicken meat incorporated into the patty formulation, which were explained by changes in a* and b* parameters as well as the increasing trends observed in L* parameter. The redness of chicken patties increased ($P < 0.05$), whereas the yellowness decreased ($P < 0.05$) as WB severity increased in the meat added to the product recipe. In this regard, Santos et al. (2019) reported that emulsified chicken patties made from WB meat exhibited paler colors with a reduction in redness. Qin (2013) also found that the lightness of sausage and chicken nuggets increased, whereas the redness and yellowness of these products decreased as the proportion of WB meat increased in the product formulation. Nevertheless, Madruga et al. (2019) did not find differences in color parameters L*, a* and b* between normal and WB chicken sausages. Chen et al. (2018) also reported that L* values were not different between normal and WB meatballs.

Estimation of WB Meat Proportions for Chicken Patty Production

Some studies have suggested the incorporation of WB meat into poultry meat product formulations at different proportions (Qin, 2013; Madruga et al., 2019; Santos et al., 2019). However, these researchers included food additives in their formulations such as soy protein isolate, salt, and phosphates, which could have masked the effect of WB myopathy on these processed products by the interaction between WB meat and those additives that can modify functional properties such as water holding capacity which in turn can change texture attributes of cooked meat products (Sanchez-Brambila et al., 2017). For example, soy proteins are commonly used as binders in products such as meat patties, meat loaves, and sausages (Barbut, 2015). Thus, the study of the effect of WB on further processed products using only chicken meat at varying degrees of WB severity may be a suitable approach to assess the actual impact of this meat quality problem and subsequently optimize formulas for industrial applications including adequate ingredients. In this sense, it was estimated WB meat proportions at different degrees of severity for chicken patty preparation without causing significant quality changes in this product compared with normal patties. This estimation was performed using the mixture profiler plot based on TPA parameters, cook loss, and reduction in diameter of chicken patties and including all these quality parameters together in the analysis (Figure 3).

The combinations of broiler breast meat of regular quality with mild WB meat up to 60% or severe WB meat up to 37% could be considered to produce acceptable patties in terms of TPA hardness and cohesiveness. These results are relatively consistent with those from the comparison of TPA parameters among treatments from which no differences were observed in hardness and cohesiveness values of patties prepared using mixtures of normal breast fillets with mild WB fillets at 33 and 67% or severe WB fillets at 33% compared with normal patties. In contrast to these samples, irregular reductions in TPA hardness and cohesiveness values have been reported as a result of an impaired gel structure observed in gel-type meat products prepared using exclusively WB meat compared with normal samples (Xing et al., 2017; Chen et al., 2018) that could be associated with the degeneration of muscle fibers and the

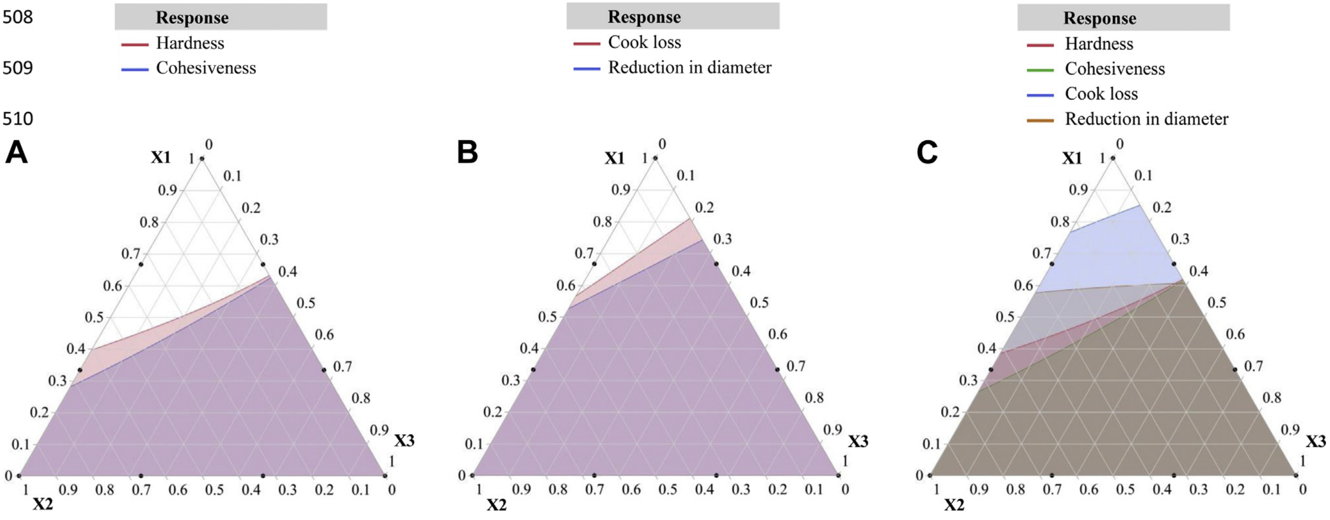

Figure 3. Mixture profiler plots of broiler breast meat constituents at varying degrees of woody breast (WB) severity based on TPA parameters (A), cook loss and reduction in diameter (B) of chicken patties as well as all these parameters together in the analysis (C). X1, proportion of normal breast meat; X2, proportion of mild WB meat; X3, proportion of moderate or severe WB meat. Mixture profiler plots show unshaded regions as feasible mixtures of normal, mild WB, and moderate or severe WB meats to produce acceptable patties based on quality characteristics of chicken patties prepared with 100% of normal broiler breast fillets.

reduction of myofibrillar proteins caused by this defect (Mudalal et al., 2015; Soglia et al., 2016b).

On the other hand, considering levels of cook loss and reduction in diameter of patties, the mixtures of normal breast meat with mild WB meat up to 43% or severe WB meat up to 19% may be feasible to produce acceptable patties. These proportions of broiler breast meat partially and severely affected by WB were lower than those obtained from the mixture profiler plot based on TPA parameters; however, WB meat proportions decreased when the analysis included all these quality parameters together. Thus, the combinations of breast fillets of normal quality with mild WB fillets up to 23% or severe WB fillets up to 15% could be possible to produce acceptable patties comparable with normal samples in terms of hardness, cohesiveness, cook loss, and reduction in diameter.

This study confirmed that the grinding process can significantly change the relationship initially found between normal and WB fillets for some texture attributes (Sanchez-Brambila et al., 2017). For example, unlike intact broiler breast fillets, chicken patties prepared with 100% of ground WB meat were less hard than normal patties ($P < 0.05$). It has been suggested that the grinding process contributes to ease of extracting surface soluble proteins, reduce cooking loss, and improve binding strength (Acton, 1972). However, the benefits of grinding WB meat may be limited, even with the incorporation of food additives into the ground meat product formulation. In this sense, Qin (2013) verified at a pilot plant scale that formulations of sausage and 2 types of chicken nuggets (coarsely chopped and ground) enabled the addition of WB meat to replace only 15 and 30% of the normal lean meat without causing significant quality changes in these products, respectively. This author also observed that coarser comminuting methods allowed higher proportions of broiler breast fillets with WB in meat products in comparison with comminuting methods producing finer particles. Nevertheless, some authors have concluded that WB meat could not be suitable to produce gel-type meat products owing to this abnormal meat shows inferior functional properties through processing (Xing et al., 2017; Chen et al., 2018). Recently, Santos et al. (2019) concluded that the most adequate meat combination to develop emulsified chicken patties consisted of 50% of normal breast meat mixed with 50% of WB meat.

In conclusion, the results from this study showed that the effect of using broiler breast fillets affected by WB condition on quality characteristics of chicken patties is related to the degree of WB severity and the proportion to be incorporated into the formulation. There is evidence of the poor functionality associated with the inclusion of WB meat at high levels in chicken patties in terms of water holding capacity and texture properties. Compared with normal samples, chicken patties prepared using severe WB fillets, either alone or combined with mild WB fillets, presented lower values of hardness, springiness, and chewiness parameters as well as higher levels of cook loss along with a significant reduction in diameter and noticeable internal cooked color changes. Thus, these data suggest that the combinations of breast fillets of normal quality with those affected by WB myopathy at relatively low proportions could be considered by processors as an alternative in commercial chicken patty recipes. For example, in this study, combinations of breast fillets of normal quality with up to 15% moderate/severe WB fillets could be possible to produce acceptable patties. However, further research is needed to optimize the incorporation of WB meat into chicken patty formulations for industrial applications considering the meat particle size and including suitable food additives accompanied by technological, sensorial, and nutritional profile assessments.

DISCLOSURES

There is no conflict of interest.

REFERENCES

Aberle, E. D., J. C. Forrest, D. E. Gerrard, and E. W. Mills. 2001. Principles of Meat Science. 4th ed. Kendall/Hunt Publishing Company, Dubuque, IA.

Acton, J. C. 1972. The effect of meat particle size on extractable protein, cooking loss and binding strength in chicken loaves. J. Food Sci. 37:240–243.

Baldi, G., F. Soglia, L. Laghi, S. Tappi, P. Rocculi, S. Tavaniello, D. Prioriello, R. Mucci, G. Maiorano, and M. Petracci. 2019. Comparison of quality traits among breast meat affected by current muscle abnormalities. Food Res. Int. 115:369–376.

Barbut, S. 2015. The Science of Poultry and Meat Processing. University of Guelph, Guelph, Ontario, Canada.

Caldas-Cueva, J. P., P. Morales, F. Ludeña, I. Betalleluz-Pallardel, R. Chirinos, G. Noratto, and D. Campos. 2016. Stability of betacyanin pigments and antioxidants in Ayrampo (*Opuntia soehrensii* Britton and Rose) seed extracts and as a yogurt natural colorant. J. Food Process. Preserv. 40:541–549.

Caldas-Cueva, J. P., and C. M. Owens. 2020. A review on the woody breast condition, detection methods, and product utilization in the contemporary poultry industry. J. Anim. Sci. 98:1–10.

Chen, H., H. Wang, J. Qi, M. Wang, X. Xu, and G. Zhou. 2018. Chicken breast quality – normal, pale, soft and exudative (PSE) and woody – influences the functional properties of meat batters. Int. J. Food Sci. Technol. 53:654–664.

Dalle Zotte, A., G. Tasoniero, E. Puolanne, H. Remignon, M. Cecchinato, E. Catelli, and M. Cullere. 2017. Effect of "wooden breast" appearance on poultry meat quality, histological traits, and lesions characterization. Czech J. Anim. Sci. 62:51–57.

Francis, F. J., and F. M. Clydesdale. 1975. Food Colorimetry: Theory and Applications. AVI Publishing Company Inc., Westport, CT.

Geronimo, B. C., S. M. Mastelini, R. H. Carvalho, S. B. Júnior, D. F. Barbin, M. Shimokomaki, and E. I. Ida. 2019. Computer vision system and near-infrared spectroscopy for identification and classification of chicken with wooden breast, and physicochemical and technological characterization. Infrared Phys. Technol. 96:303–310.

Madruga, M. S., T. C. Rocha, L. M. Carvalho, A. M. B. L. Sousa, A. C. S. Neto, D. G. Coutinho, A. S. C. Ferreira, A. J. Soares, M. S. Galvão, E. I. Ida, and M. Estévez. 2019. The impaired quality of chicken affected by the wooden breast myopathy is counteracted in emulsion-type sausages. J. Food Sci. Technol. 56:1380–1388.

Mazzoni, M., M. Petracci, A. Meluzzi, C. Cavani, P. Clavenzani, and F. Sirri. 2015. Relationship between pectoralis major muscle histology and quality traits of chicken meat. Poult. Sci. 94:123–130.

Mehaffey, J. M., S. P. Pradhan, J. F. Meullenet, J. L. Emmert, S. R. McKee, and C. M. Owens. 2006. Meat quality evaluation of minimally aged broiler breast fillets from five commercial genetic strains. Poult. Sci. 85:902–908.

Mudalal, S., M. Lorenzi, F. Soglia, C. Cavani, and M. Petracci. 2015. Implications of white striping and wooden breast abnormalities on quality traits of raw and marinated chicken meat. Animal 9:728–734.

Petracci, M., S. Mudalal, F. Soglia, and C. Cavani. 2015. Meat quality in fast-growing broiler chickens. Worlds Poult. Sci. J. 71:363–374.

Petracci, M., F. Soglia, M. Madruga, L. Carvalho, E. Ida, and M. Estévez. 2019. Wooden-Breast, White Striping, and Spaghetti Meat: Causes, consequences and consumer perception of emerging broiler meat abnormalities. Compr. Rev. Food Sci. Food Saf. 18:565–583.

Qin, N. 2013. The Utilization of Poultry Breast Muscle of Different Quality Classes. Thesis. Department of Food and Environmental Sciences, University of Helsinki; Helsinki, Finland.

Sanchez-Brambila, G., D. Chatterjee, B. Bowker, and H. Zhuang. 2017. Descriptive texture analyses of cooked patties made of chicken breast with the woody breast condition. Poult. Sci. 96:3489–3494.

Santos, M. M. F., D. A. S. Lima, T. K. A. Bezerra, M. S. Galvão, M. S. Madruga, and F. A. P. Silva. 2019. Effect of wooden breast condition on quality traits of emulsified chicken patties during frozen storage. J. Food Sci. Technol. 56:4158–4165.

Sihvo, H. K., K. Immonen, and E. Puolanne. 2014. Myodegeneration with fibrosis and regeneration in the pectoralis major muscle of broilers. Vet. Pathol. 51:619–623.

Soglia, F., J. Gao, M. Mazzoni, E. Puolanne, C. Cavani, M. Petracci, and P. Ertbjerg. 2017. Superficial and deep changes of histology, texture and particle size distribution in broiler wooden breast muscle during refrigerated storage. Poult. Sci. 96:3465–3472.

Soglia, F., L. Laghi, L. Canonico, C. Cavani, and M. Petracci. 2016a. Functional property issues in broiler breast meat related to emerging muscle abnormalities. Food Res. Int. 89:1071–1076.

Soglia, F., S. Mudalal, E. Babini, M. Di Nunzio, M. Mazzoni, F. Sirri, C. Cavani, and M. Petracci. 2016b. Histology, composition, and quality traits of chicken pectoralis major muscle affected by wooden breast abnormality. Poult. Sci. 95:651–659.

Sun, X., D. A. Koltes, C. N. Coon, K. Chen, and C. M. Owens. 2018. Instrumental compression force and meat attribute changes in woody broiler breast fillets during short-term storage. Poult. Sci. 97:2600–2606.

Tijare, V. V., F. L. Yang, V. A. Kuttappan, C. Z. Alvarado, C. N. Coon, and C. M. Owens. 2016. Meat quality of broiler breast fillets with white striping and woody breast muscle myopathies. Poult. Sci. 95:2167–2173.

Velleman, S. G., D. L. Clark, and J. R. Tonniges. 2017. Fibrillar collagen organization associated with broiler wooden breast fibrotic myopathy. Avian Dis. 61:481–490.

Xing, T., X. Zhao, L. Cai, Z. Guanghong, and X. Xu. 2017. Effect of salt content on gelation of normal and wooden breast myopathy chicken pectoralis major meat batters. Int. J. Food Sci. Technol. 52:2068–2077.