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Effect of Woody Breast Condition on Instrumental Texture Characteristics of Poultry Deli Loaves

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Abstract: The use of broiler breast fillets affected by the woody breast (WB) condition in processed poultry products could be a feasible solution to this meat quality problem. This study assessed the impact of utilizing broiler breast fillets at different degrees of WB severity and percentages on instrumental texture characteristics of deli loaves. Breast fillets ($n = 270$) were collected from broiler carcasses and sorted based on palpation assessment in 3 WB categories (normal [NOR], mild [MIL], and severe [SEV]). Nine treatments of deli loaves were prepared from cubed portions in each of 3 replications: 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). Cooked deli loaves were subjected to texture profile analysis, cook loss, instrumental color, and dimensional modifications. Hardness of deli loaves increased ($P < 0.05$), whereas cohesiveness values decreased ($P < 0.05$), as WB severity increased in the meat added into the product formulation when compared with NOR samples and excluding treatments T_2 through T_4. The use of SEV fillets at 100% (T_9) or mixtures of MIL and SEV fillets (T_7 and T_8) yielded nonuniform deli loaves with different color parameters and higher levels of cook loss (>13%), coupled with reductions in diameter (>8%) and length (>5%), compared to NOR samples ($P < 0.05$). These results suggest that the negative effects of WB on quality and yield characteristics are not minimized by the preparation of this formed product when using high proportions of WB meat. Thus, broiler breast fillets affected by the WB condition may be used at relatively low percentages combined with NOR fillets as an option in commercial chicken deli loaf formulations.

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

The "wooden" or "woody" breast (WB) condition is currently one of the major meat quality problems in the poultry industry worldwide, characterized by an abnormal hardness with swollen and pale sections covered with viscous fluid or hemorrhages or both in chicken breast fillets severely affected by this myopathy (Sihvo et al., 2014; Mudalal et al., 2015). This WB meat exhibits histological and physicochemical defects that result in unwanted sensory, nutritional, and technological properties (Soglia et al., 2016b; Baldi et al., 2019; Petracci et al., 2019), causing significant economic losses due to its negative effects on consumer acceptability (Petracci et al., 2015). These negative implications make critical the development and selection of profitable options for the application of WB fillets once they are objectively identified and sorted (Petracci et al., 2019; Santos et al., 2019). The impaired functionality of WB meat has been well documented (Mudalal et al., 2015; Soglia et al., 2016a, 2016b; Xing et al., 2017; Dalgaard et al., 2018). The altered composition of WB fillets such as higher levels of fat, collagen, and moisture, as well as lower levels of protein and ash (Soglia et al., 2016a, 2016b; Baldi et al., 2019), negatively affects functional properties such as water-holding capacity and modifies texture attributes, resulting in downgrades and even condemnations (Petracci et al., 2019).

The use of WB meat in further processed products may be a feasible option to help the poultry industry deal with this meat quality problem, considering that the chemical composition can be changed during formulation (Petracci et al., 2015) and further processing operations can also modify meat properties (Aberle et al., 2001; Keeton and Osburn, 2010), which may mitigate unfavorable effects of the WB anomaly on final product quality (Petracci et al., 2019). Some efforts have been made to evaluate the utilization of WB fillets in commercial poultry meat products such as marinated whole muscle products (Mudalal et al., 2015; Soglia et al., 2016b; Tijare et al., 2016; Bowker et al., 2018), sausages (Qin, 2013), patties (Santos et al., 2019), and nuggets (Qin, 2013). In addition, meat batters made from WB meat have been evaluated (Xing et al., 2017). Considering the results from these studies, the effectiveness of the use of WB meat without causing a perceived quality defect in processed poultry meat products could be associated with important factors such as the proportion to be incorporated into the formulation, meat particle size (whole muscle, ground, coarsely or finely chopped), addition of nonmeat ingredients, and concentration of salt. Furthermore, it is hypothesized that the negative effect of WB on product quality and yields may be related to the degree of WB severity. Indeed, special attention should be given to the incorporation of WB meat into processed product formulations due to both functional and quality issues that could arise (Soglia et al., 2016a). In this context and considering the need to expand potential uses of WB fillets, the objective of the present study was to investigate the effect of the application of broiler breast fillets at varying degrees of WB severity and proportions on instrumental texture traits of chicken deli loaves along with other quality characteristics.

Materials and Methods

Sample collection

Boneless and skinless breast fillets belonging to commercial broilers (high breast-yielding strain) processed at 8 wk of age at the University of Arkansas Poultry Processing Pilot Plant following commercial-based practices (Mehaffey et al., 2006) were used. The process included the following operations: hanging, stunning, cutting, bleeding, scalding, defeathering, evisceration, and rinsing. Subsequent processing operations were prechilling (12°C, 15 min), chilling (1°C, 90 min), and storage at 4°C until the deboning time of 3 h postmortem.

The deboned breast fillets were scored for degree of hardness using tactile assessment as described by Tijare et al. (2016). The WB classification considered in the palpation evaluation was as follows: 0.0 or 0.5 was considered a normal or unaffected fillet (NOR); 1.0 or 1.5 was considered mild WB or a fillet partially affected by WB (MIL); and 2.0, 2.5, or 3.0 was considered moderate or severe WB or a fillet considerably affected by WB (SEV). After scoring, fillets were aged in a 4°C cooler until compression force (CF) analysis which was carried out to confirm subjective tactile scores. Following WB scoring and CF assessments, a total of 270 sorted fillets (90 per WB category) were packed in zip-sealed plastic bags and stored overnight at 4°C.

Meat quality parameters

CF was measured 4 times at predetermined locations in the cranial area of each intact fillet at approximately 6 h postmortem using a texture analyzer (Model TA.XT Plus, Texture Technologies Corp., Scarsdale, NY). Breast fillets were compressed to 20% of their original height using a flat probe of 6 mm in diameter with a 5-kg loading cell and settings of trigger force of 5 g and a test speed of 5 mm/s (Sun et al., 2018). Broiler breast meat color and pH were determined at 24 h postmortem. The instrumental color (Commission Internationale de l´Eclairage ["International Commission on Illumination"; CIE] L^* = lightness, a^* = redness, and b^* = yellowness) was obtained by averaging 3 readings taken from the dorsal surface of each fillet using a calibrated CR-400 colorimeter (Konica Minolta Sensing Inc., Osaka, Japan) with settings of illuminant D_{65} and 2° observer as well as an 8-mm aperture. The pH was measured at the cranial end region of each breast fillet using a portable pH meter (Model Testo 205, Testo Inc., Sparta, NJ) equipped with a penetration pH tip embedded in break-proof plastic combined with temperature probe for automatic temperature compensation, which was placed directly into samples.

Preparation of chicken deli loaves

Nine chicken deli loaf treatments (T_1 through T_9) with 3 replicates were prepared using broiler breast meat at different degrees of WB severity (Table 1). Replicate was defined as 1 deli loaf per treatment that was made on each of 3 d using 30 fillets per WB category. The whole cranial section of breast fillets (caudal section discarded) was trimmed to remove all visible excess of fat and cartilage and then cubed into

Table 1. Broiler breast meat components at different degrees of WB severity and proportions in deli loaf formulation

	Coded proportions[1]					
Treatment	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]WB = woody breast; X1 = proportion of normal breast (NOR) fillets; X2 = proportion of mild WB (MIL) fillets; X3 = proportion of moderate or severe WB (SEV) fillets.

2.54 × 2.54 cm pieces separately by WB category, and subsequently formulated as described in Table 1. Separately by treatment, cubed chicken meat combinations were marinated in a vacuum tumbler (Model 40, Lyco, Columbus, WI) set at 20 rpm and 560 mm Hg for 1 h at 4°C. The brine solution was previously prepared by dissolving sodium tripolyphosphate (STP; Budenheim USA Inc., Plainview, NY) and sodium chloride or salt (North American Salt Co., Overland Park, KS) in water, respectively, and then this solution was chilled to 4°C. The marinade pickup target was 20% of meat weight (16.67% of product formulation) to obtain a final product concentration of 1.25% salt and 0.45% STP. After tumbling, vacuum-marinated samples were manually stuffed into 15-cm diameter by 40-cm length plastic casings and stored overnight at 4°C. Raw deli loaves were placed on a stainless steel wire rack and cooked in a smokehouse (Alkar, Lodi, WI) to an internal temperature of 75°C using a single stepped steam cycle program. Cooked samples were cooled to 4°C within 4 h, the casings were removed, and deli loaves were allowed to drain on a rack for 10 min and were subsequently weighed to determine the cook loss. Each cooked sample was sliced from its central section into 6 deli loaf disks (thickness: 15 mm) using a deli meat slicer (Model 1812, Hobart Corp., Troy, OH). Deli loaf disks were packed in zip-sealed plastic bags and stored overnight at 4°C prior to analysis.

Determination of cook loss and dimensional modifications

The deli loaf treatments were weighed before and after cooking to calculate their cook-loss levels using the following equation: cook loss (%) = [(raw product weight − cooked product weight) ÷ raw product weight] × 100. The length and diameter of raw and cooked deli loaves were determined at 3 different points per sample using a ruler and digital Vernier caliper (Model W80152, Wilmar Corp., Tukwila, WA), respectively. The measurements from the 3 points for each dimension were averaged before further use. Reduction levels (percent) in length and diameter were calculated according to the following formula: reduction in length or diameter (%) = [(raw product measurement − cooked product measurement) ÷ raw product measurement] × 100.

Instrumental color assessment

The instrumental color parameters lightness (L^*), redness (a^*), and yellowness (b^*) were measured in triplicate on the surface of each sliced deli loaf disk using a calibrated CR-400 colorimeter (Konica Minolta Sensing Inc., Osaka, Japan) with settings of illuminant D_{65}, 2° observer, and an 8-mm aperture (Caldas-Cueva et al., 2016). Additionally, the total color difference (ΔE^*_{ab}) was determined to assess the overall color variation between a given cooked deli loaf and the reference sample, which was the NOR deli loaf sample (T_1) produced using 100% of NOR breast fillets. The ΔE^*_{ab} value was calculated using the following equation: $\Delta E^*_{ab} = [(L^*_i - L^*_o)^2 + (a^*_i - a^*_o)^2 + (b^*_i - b^*_o)^2]^{1/2}$, in which L^*_o, a^*_o, and b^*_o were the readings of the color of the reference sample or T_1 and L^*_i, a^*_i, and b^*_i were the individual readings of each treatment assessed.

Texture profile analysis

Texture profile analysis (TPA) was performed at room temperature (23.0°C ± 2°C) using a texture analyzer (Model TA.XT Plus, Texture Technologies Corp., Scarsdale, NY). Test samples with a cylindrical shape (diameter: 23 mm and thickness: 15 mm) were taken from 3 different locations of each sliced deli loaf disk using a corer, and then they were subjected to a two-cycle compression test. These test samples were compressed to 25% of their initial height using a 5.08-cm-diameter cylindrical probe with the following settings: a pre-test speed of 1.0 mm/s, test and post-test speeds of 2.0 mm/s, a load cell capacity of 5 kg, and a trigger force of 5 g. Four TPA parameters, hardness (Newton), cohesiveness, springiness, and chewiness (Newton) were considered from the analysis of test samples.

Statistical analysis

Data were analyzed by one-way ANOVA with WB category (for meat quality traits) or treatment factor (for TPA, instrumental color, cook loss, and dimensional changes of chicken deli loaves) fit as fixed effect. When the main effect was significant, means were separated by Tukey's honest significant difference test at $P < 0.05$. Furthermore, feasible mixtures of NOR fillets (X1), MIL fillets (X2), and SEV fillets (X3) to produce acceptable deli loaves were estimated using the simplex lattice mixture design. These possible combinations were determined based on TPA parameters, cook loss, and reduction levels in dimensions of NOR deli loaves. The statistical analysis was achieved using JMP software version 14.3.0 (SAS Institute Inc., Cary, NC).

Results and Discussion

Meat quality parameters

Meat quality parameters of intact broiler breast fillets exhibiting different degrees of WB severity are shown in Table 2. The SEV fillets were the heaviest ($P < 0.05$), which was comparable to other reports (Chatterjee et al., 2016; Xing et al., 2017), whereas intermediate fillet weight values were achieved for MIL fillets ($P < 0.05$). CF, pH, and lightness (L^*) values increased ($P < 0.05$) as WB severity increased in the raw broiler breast meat. Although it was not possible to differentiate MIL fillets in terms of redness (a^*) and yellowness (b^*) values, SEV fillets showed higher a^* and b^* values than NOR fillets ($P < 0.05$).

Consistent with previous reports, higher CF values were found in SEV fillets compared to NOR fillets (Mudalal et al., 2015; Soglia et al., 2017; Dalgaard et al., 2018). The abnormal hardness of WB fillets may be related to the fibrosis as a result of the accretion of highly cross-linked collagen fibrils (Velleman et al., 2017); indeed, the increase of connective tissue components typically observed in WB meat provides a high degree of inherent strength that results in altered textural properties (Soglia et al., 2017). Various authors have also reported higher pH values in WB fillets in comparison with NOR fillets (Chatterjee et al., 2016; Kuttappan et al., 2017; Xing et al., 2017; Dalgaard et al., 2018), which could be associated with a depletion of the glycogen content or alteration of the onset of acidification during the postmortem time due to this anomaly (Mudalal et al., 2015). In addition, no consensus has been reached about the instrumental color characterization of WB fillets, which could be attributed to the heterogeneous distribution of this defect throughout the fillet (Bowker et al., 2018; Wold et al., 2019) as well as the existence of hemorrhages on the anomalous chicken meat surface (Sihvo et al., 2014; Dalle Zotte et al., 2017; Santos et al., 2019). Nevertheless, some studies have also reported higher values of L^*, a^*, and b^* parameters for SEV cases compared to NOR fillets (Wold et al., 2017; Aguirre et al., 2018; Cai et al., 2018).

Cook loss and dimensional modifications

Cook-loss levels of chicken deli loaves prepared using breast fillets at varying degrees of WB severity are shown in Figure 1. The results indicate that cook-loss levels of loaves prepared using mixtures of NOR meat with MIL meat at 33% and 67% (T_2 and T_4, respectively) or SEV meat at 33% (T_3) were comparable to those for NOR loaves (or T_1). However, compared to NOR samples and excluding treatments T_2 through T_4, the cook loss of deli loaves increased ($P < 0.05$) as WB severity increased in the broiler breast meat incorporated into the product formulation. These significant increasing trends in cook-loss levels were accompanied by significant ($P < 0.05$) reductions

Table 2. Quality parameters of raw broiler breast fillets at different degrees of WB severity

Parameter	WB category[1] NOR	MIL	SEV	SEM	P value
Fillet weight (g)	401.52[c]	445.69[b]	493.34[a]	4.21	< 0.001
Compression force (N)	4.33[c]	8.15[b]	13.57[a]	0.33	< 0.001
pH	5.74[c]	5.80[b]	5.94[a]	0.02	< 0.001
Lightness (L^*)	52.97[c]	54.52[b]	55.65[a]	0.32	< 0.001
Redness (a^*)	2.75[b]	3.04[ab]	3.31[a]	0.13	0.012
Yellowness (b^*)	8.96[b]	9.68[ab]	10.60[a]	0.35	0.004

[1]MIL = mild WB; NOR = normal breast; SEV = moderate or severe WB; WB = woody breast.

[a–c]Means within a row followed by different superscripts differ significantly ($P < 0.05$).

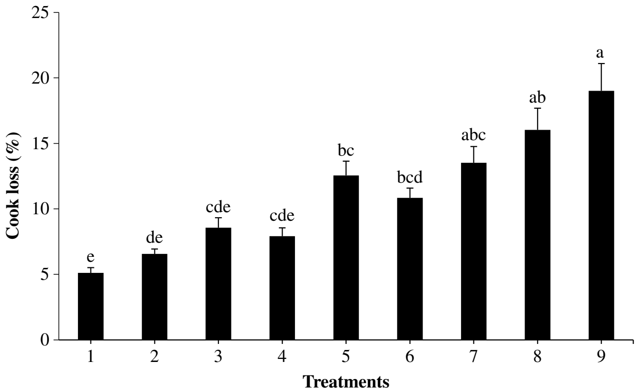

Figure 1. Cook loss of deli loaves prepared with broiler breast fillets at different degrees of woody breast (WB) severity and proportions. [a–e]Means with different superscripts differ significantly ($P < 0.05$).

in length (>5%) and diameter (>8%) that were observed especially in deli loaf treatments formulated with mixtures of breast fillets partially and severely affected by WB condition (T_7 and T_8) as well as loaves prepared using entirely SEV fillets (T_9) compared with NOR samples (Figure 2). These results suggest that the negative impact of WB on the product quality and yields of formed deli loaves containing high percentages of WB meat is not minimized by vacuum-tumbling marination, which is consistent with several studies that reported a significant impairment of water-holding capacity in marinated breast fillets with WB defect (Mudalal et al., 2015; Soglia et al., 2016b; Aguirre et al., 2018; Bowker et al., 2018).

The reduced product yields observed in deli loaf samples containing high proportions of WB meat could be associated with the impaired functionality of SEV raw breast fillets, particularly their poor ability to hold water, that has been widely investigated. This altered functionality of WB meat can be attributed to the severe degeneration of muscle fibers (accompanied by fibrosis, lipidosis, and impairments in fiber membrane integrity) (Soglia et al., 2016b; Petracci et al., 2019) that results in alterations in the chemical composition (Soglia et al., 2016a, 2016b; Baldi et al., 2019) and muscle fiber number (Sihvo et al., 2014; Mazzoni et al., 2015), which would explain the poor ability to bind water observed in WB fillets. Additionally, the higher proportion of extra-myofibrillar water and the greater mobility of intra-myofibrillar water observed in WB meat (Soglia et al., 2016a; Xing et al., 2017) may help to explain the increased volume of drained fluids from cooked deli loaves prepared using high percentages of WB fillets.

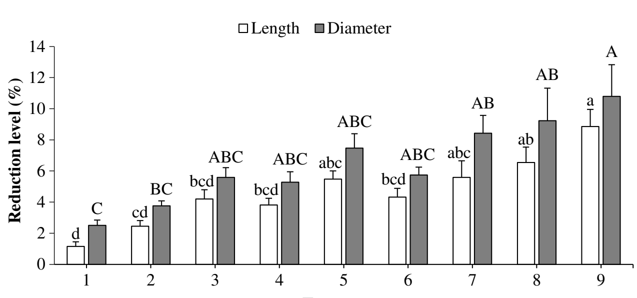

Figure 2. Dimensional changes of deli loaves prepared with broiler breast fillets at different degrees of woody breast (WB) severity and proportions. [a–d]Means with different lower-case superscripts differ significantly ($P < 0.05$) for length reduction. [A–C]Means with different upper-case superscripts differ significantly ($P < 0.05$) for diameter reduction.

TPA

The effect of WB myopathy on TPA parameters of cooked deli loaves is shown in Table 3. The outcomes suggest that textural traits of loaves prepared with combinations of NOR fillets with MIL fillets at 33% (T_2) and 67% (T_4) as well as SEV fillets at 33% (T_3) were comparable to those for NOR samples (or T_1). Nevertheless, compared to NOR samples and excluding treatments T_2 through T_4, the hardness of chicken deli loaves increased ($P < 0.05$), whereas their cohesiveness values decreased ($P < 0.05$) as WB severity increased in the breast meat incorporated into the product formulation. These results are in agreement with those obtained from the instrumental texture analysis of intact raw breast fillets, from which it was determined that MIL and SEV fillets presented greater hardness (higher CF values) compared to NOR fillets. This suggests that the abnormal hardness caused by WB defect can be reflected in formed deli loaves prepared using high proportions of WB meat. Indeed, the higher cook losses of samples containing higher proportions of SEV fillets were also likely contributors to the greater hardness observed because some studies have also reported higher values of hardness in WB fillets with higher cook-loss percentages compared to NOR fillets (Soglia et al., 2016 b; Aguirre et al., 2018). Regardless of the cooking method, various authors have also reported higher TPA hardness values in non-marinated or marinated cooked SEV chicken breast fillets compared with NOR fillets (Chatterjee et al., 2016; Soglia et al., 2016 b; Aguirre et al., 2018). Additionally, Chatterjee et al. (2016) found lower TPA cohesiveness values in raw WB fillets compared to NOR samples, which might have also been reflected in cooked deli loaves containing high percentages of WB meat. On the other hand, no differences were observed in the springiness and chewiness values among deli loaf treatments. Conversely in whole

Table 3. TPA and cooked color measurements of deli loaves prepared with broiler breast fillets at different degrees of WB severity and proportions

		Textural properties				Color measurements			
	Treatment[1]	Hardness (N)	Cohesiveness	Springiness	Chewiness (N)	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	ΔE^*ab
T_1	**100% NOR**	21.82[d]	0.83[a]	0.89	16.20	82.00[a]	1.48[a]	15.15[a]	0.00
T_2	**67% NOR + 33% MIL**	22.49[cd]	0.81[ab]	0.88	16.02	81.82[a]	1.25[ab]	14.59[a]	1.56[c]
T_3	**67% NOR + 33% SEV**	23.01[bcd]	0.82[a]	0.89	16.73	81.74[a]	1.26[ab]	14.60[a]	2.08[bc]
T_4	**33% NOR + 67% MIL**	23.06[bcd]	0.80[abc]	0.88	16.25	81.49[ab]	1.18[ab]	14.46[ab]	2.16[bc]
T_5	**33% NOR + 67% SEV**	25.21[ab]	0.77[bcd]	0.89	17.36	80.32[bcd]	1.14[ab]	14.36[ab]	2.54[bc]
T_6	**100% MIL**	24.84[abc]	0.77[cd]	0.86	16.40	80.79[abc]	1.17[ab]	13.94[ab]	2.30[bc]
T_7	**67% MIL + 33% SEV**	25.45[ab]	0.76[de]	0.88	17.03	80.16[bcd]	0.96[b]	14.43[ab]	2.77[bc]
T_8	**33% MIL + 67% SEV**	25.77[a]	0.74[de]	0.87	16.54	79.61[cd]	0.89[b]	14.26[ab]	3.18[ab]
T_9	**100% SEV**	27.12[a]	0.72[e]	0.87	17.01	79.18[d]	1.01[b]	12.87[b]	4.16[a]
SEM		0.56	0.01	0.01	0.46	0.30	0.09	0.36	0.29
***P* value**		< 0.001	< 0.001	0.424	0.474	< 0.001	< 0.001	0.003	< 0.001

[1]MIL = mild WB; NOR = normal breast; SEV = moderate or severe WB; WB = woody breast.

[a–e]Means within a column followed by different superscripts differ significantly ($P < 0.05$).

TPA = texture profile analysis.

chicken fillets, some studies have highlighted that the texture of cooked WB samples was springier and chewier compared with unaffected fillets (Chatterjee et al., 2016; Aguirre et al., 2018).

Quality defects were visually observed especially in deli loaf treatments produced using high proportions of SEV meat or mixtures of MIL and SEV meats (Figure 3). The sample made using exclusively SEV fillets (T_9) displayed the poorest quality. Indeed, the utilization of WB meat at high percentages had a negative effect on the uniformity of formed deli loaves. The impaired instrumental texture properties observed in deli loaves prepared from WB meat may be related to chemical and structural changes, particularly in the muscle fibers and connective tissues, caused by this abnormality (Soglia et al., 2016 b). The texture of restructured or formed products is also associated with processing conditions, the inclusion of nonmeat ingredients, and the degree of extension with the addition of water and other ingredients (Luckett et al., 2014). In this study, a basic brine composed of STP and salt (final concentration in the product: 0.45% STP and 1.25% NaCl) was used. The critical factor in the process was binding the meat pieces together with optimum strength, which was essentially achieved with the help of brine that allowed the extraction of proteins, the mechanical action from tumbling that brought the dissolved functional proteins to the meat particle surfaces, and the cooking process that allowed the dynamic process of unfolding and coagulation of proteins (Aberle et al., 2001; Keeton and Osburn, 2010). Thus, the irregular texture observed in WB deli loaves could also be attributed to their lower salt-soluble protein content and the profile of these extracted proteins, as suggested by Xing et al. (2017) comparing WB meat batters to NOR ones with 1% or 2% of salt content.

Instrumental color parameters

Instrumental color parameters (L^*, a^*, and b^*) of cooked chicken deli loaves are also presented in

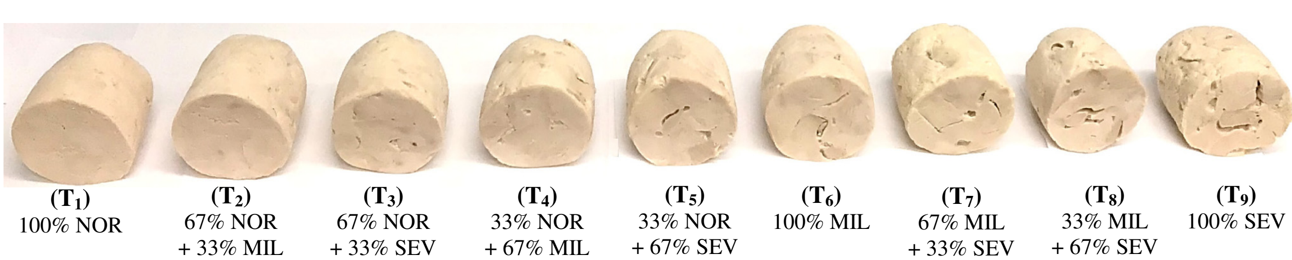

Figure 3. Deli loaves prepared with broiler breast fillets at different degrees of woody breast (WB) severity and proportions. MIL = mild WB; NOR = normal breast; SEV = moderate or severe WB.

Table 3. The internal surface of deli loaf samples prepared with high percentages of SEV fillets or mixtures of MIL and SEV fillets was darker (lower L^* values) than that of NOR samples ($P < 0.05$). These results are consistent with those recently reported by Zhuang and Bowker (2018), who found that the ventral surface of cooked WB fillets was considerably darker than that of NOR fillets regardless of marination treatment. These authors observed that surface areas on the raw chicken breast fillets with hemorrhaging were linked to visible dark discoloration after cooking. In this experiment, the presence of hemorrhages on the meat surface was observed on some SEV fillets used to prepare deli loaves. Moreover, deli loaf treatments T_7 through T_9 presented lower ($P < 0.05$) a^* values compared with NOR samples, whereas only the treatment T_9 exhibited a lower ($P < 0.05$) b^* value compared with the NOR sample. In this regard, contrasting objective color measurements have been reported for cooked WB fillets. Zhuang and Bowker (2018) reported that the WB defect caused increases in a^* and b^* parameters on the cooked ventral surfaces of affected fillets regardless of marination treatment or frozen storage. However, Mudalal et al. (2015) reported that there were no differences in cooked color measurements between marinated NOR and WB meats.

Overall color variations were assessed by computing the total color difference (ΔE^*_{ab}) values (Table 3), which were subsequently interpreted considering the criteria that are often used by researchers performing instrumental color evaluations in meat and meat products. These criteria suggest that changes in instrumental color measurements are visually noticeable and obvious for the human eye when ΔE^*_{ab} values are higher than 2 and 3, respectively (Francis and Clydesdale, 1975). The results from this evaluation indicated that the color differences between the NOR deli loaf and treatments T_3 through T_9 would be noticed by consumers ($\Delta E^*_{ab} > 2$); however, only T_8 and T_9 treatments showed obvious or evident color modifications ($\Delta E^*_{ab} > 3$) compared to NOR samples. Table 3 also shows that treatment T_9 had a higher ($P < 0.05$) ΔE^*_{ab} value in comparison with the other treatments excluding T_8. These color differences may be noticed in Figure 3, particularly in samples containing high proportions of SEV fillets or mixtures of MIL and SEV fillets. The irregular color distribution observed in deli loaves containing high percentages of WB meat could be related to the heterogeneous distribution of this myopathy throughout the broiler breast fillet (Bowker et al., 2018; Wold et al., 2019). Although there are limited published data available with respect to the instrumental color characteristics of cooked fillets affected by WB, it has been hypothesized that the surface discoloration observed in some areas of cooked WB fillets could be attributed to the increased hemorrhaging on the surface of intact WB fillets (Zhuang and Bowker, 2018). Nevertheless, the association of WB myopathy with hemorrhage severity (Dalle Zotte et al., 2017; Kuttappan et al., 2017) may not be the only factor explaining the discoloration observed in deli loaf samples containing high proportions of WB meat because of the absence of visible petechial hemorrhaging in some raw SEV fillets. In fact, it has been suggested that the impaired surface traits that are commonly observed in WB fillets—such as increased white striations, connective tissue, and gelatinous-viscous fluid (Sihvo et al., 2014; Dalle Zotte et al., 2017)—could also contribute to the discoloration of cooked WB meat (Zhuang and Bowker, 2018), which might have also been reflected in WB deli loaf samples. The higher levels of cook loss that were found especially in samples prepared with high percentages of SEV fillets may also explain the discoloration observed in these treatments as suggested by Zhuang and Bowker (2018) in cooked WB fillets.

Estimation of WB meat proportions for deli loaf production

WB meat proportions that would not cause significant quality changes were estimated based on quality traits of NOR deli loaves. This assessment was carried out using the mixture profiler plot based on TPA parameters (Figure 4A), cook loss, and dimensional changes (Figure 4B) of chicken deli loaves, and including all these quality parameters together in the analysis (Figure 4C). The mixture of NOR fillets with MIL fillets up to 21% or SEV fillets up to 18% may be considered to produce acceptable formed deli loaves in terms of TPA hardness and cohesiveness. These relatively low proportions of WB meat estimated for the preparation of suitable deli loaves could be associated with the meat particle size because of the resemblance of this formed product to a whole muscle product. Therefore, deli loaves made with cubed meat portions (or larger) may be more affected by the WB condition compared to ground products in terms of textural characteristics. Such low percentages of WB meat may also be attributed to the higher variability in TPA parameters observed especially in deli loaf treatments prepared using SEV fillets at 100% or mixtures of MIL and SEV fillets compared with NOR samples.

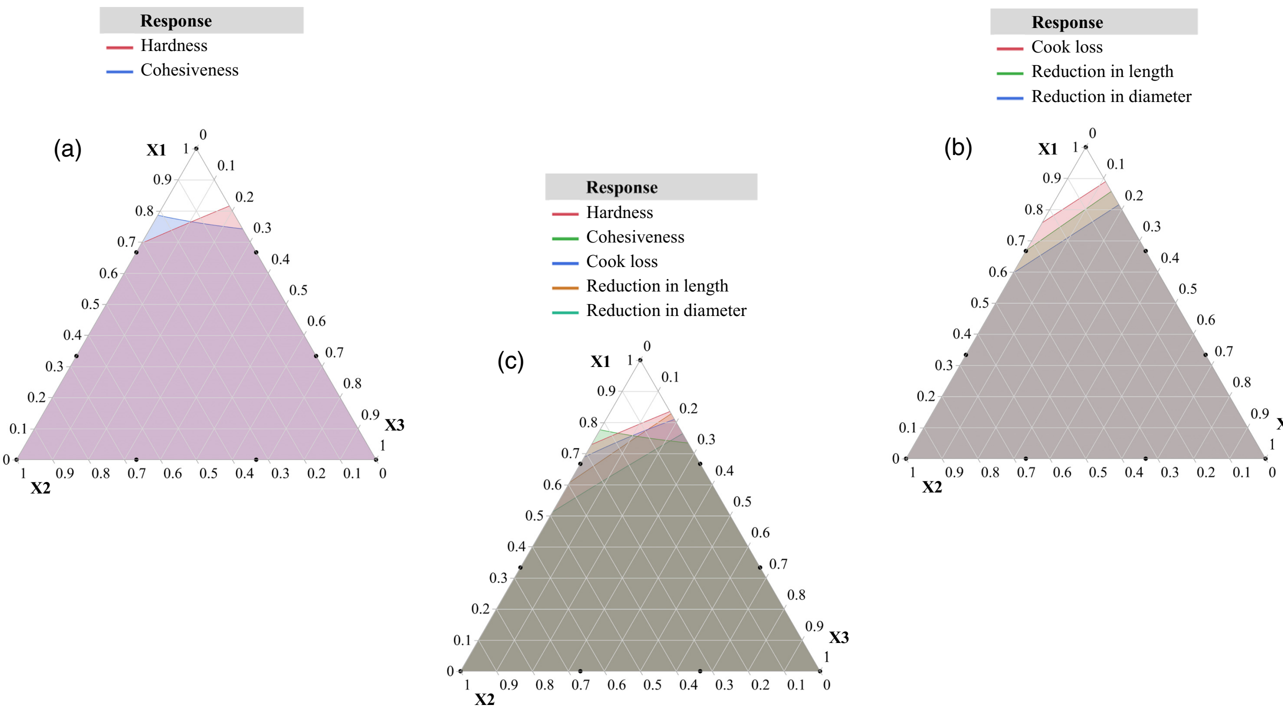

Figure 4. Mixture profiler plots of broiler breast meat components at different degrees of woody breast (WB) severity based on textural traits (A) and cook loss and dimensional changes (B) of deli loaves, as well as the inclusion of all these measurements together in the analysis (C). X1 = proportion of normal breast (NOR) fillets; X2 = proportion of mild WB (MIL) fillets; X3 = proportion of moderate or severe WB (SEV) fillets. Mixture profiler plots show unshaded regions as feasible or acceptable meat combinations.

On the other hand, considering cook loss and reduction levels in length and diameter of deli loaves, the combination of NOR meat with MIL meat up to 24% or SEV meat up to 11% could be possible to prepare deli loaves comparable to NOR samples. Finally, when the analysis includes all parameters together, the mixture of NOR fillets with MIL fillets up to 22% or SEV fillets up to 17% may be feasible to produce acceptable formed deli loaves. These results suggest that special attention should be given to the incorporation of WB meat into processed product formulations such as chicken deli loaves because of quality defects that could arise, particularly in samples containing high percentages of WB meat. Mixtures of NOR fillets with relatively low ratios of fillets affected by WB abnormality that were estimated for the preparation of acceptable deli loaves are partially in agreement with results reported by Qin (2013). This author found that formulations of sausage and 2 types of chicken nuggets enabled the incorporation of WB meat to replace 15% and 30% of the NOR lean meat without causing significant quality changes in these products, respectively. The use of high salt levels (≥3%) may improve the quality of WB products; however, it is not a commercial alternative due to possible health concerns associated with high-salt foods (Xing et al., 2017).

In summary, combining the results from the present study with previous research findings, the feasibility of the use of WB meat without causing a perceived quality defect in poultry meat products such as chicken deli loaves is attributed to the degree of WB severity and the percentage to be added into the formulation. Deli loaves prepared using SEV broiler breast fillets—either alone or combined with MIL breast fillets—were harder and less cohesive as well as less uniform, with higher levels of cook loss accompanied by significant reductions in diameter and length compared with NOR samples. In addition, noticeable cooked color changes, particularly associated with dark discolored areas, were observed in deli loaves containing high percentages of WB meat compared with NOR samples. Therefore, special attention should be given to the inclusion of WB fillets in processed poultry product recipes such as whole muscle chicken deli loaves, which are generally perceived as high-quality products. Nevertheless, WB fillets could be combined at relatively low proportions with NOR fillets in commercial chicken deli loaf formulations as a feasible solution to help the poultry industry deal with this meat quality problem. The optimization of the incorporation of WB meat into deli loaf formulations needs to be investigated for industrial applications that consider the inclusion of adequate nonmeat ingredients along with technological, sensorial, and nutritional profile evaluations, in addition to sliceability and other quality assessments of thin slices of the final product.

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