Meat and Muscle Biology™

Quality Differences in Wooden and Normal Broiler Breast Meat Marinated with Traditional and Clean Label Marinades

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Abstract: Wooden breast (WB) is a *Pectoralis major* muscle myopathy in broilers that negatively impacts breast meat quality. The objective of this research was to evaluate quality differences between normal (NOR), moderately woody (MOD), and severely woody (SEV) broiler breast that were marinated with water (control); water, sodium phosphate, and salt (traditional); or water, potassium carbonate, and salt (clean label). Treatments were vacuum tumbled for 30 min and then frozen in a CO_2 cabinet. A 3×3 factorial structure within a randomized complete block design with 3 replications was used to evaluate the effects of marinade (control, traditional, clean label) and WB severity (NOR, MOD, SEV) on tumble and cook loss, shear force, and texture profile analysis. For sensory analysis, a 2×3 factorial structure was used because the control was not evaluated. When averaged over WB severity, clean label marinade had less tumble loss ($P < 0.05$) than traditional. When averaged over marinade, NOR had less tumble loss ($P < 0.05$) than MOD and SEV. Marinated SEV were crunchier and less tender ($P < 0.05$) than MOD and NOR, and MOD was less tender ($P < 0.05$) than NOR. Similarly, the clean SEV was chewier ($P < 0.05$) than MOD and NOR, but traditional SEV was only chewier ($P < 0.05$) than NOR. Clean and traditional SEV were less acceptable ($P < 0.05$) than MOD and traditional NOR, but no difference ($P > 0.05$) existed in acceptability between MOD and NOR for both marinades. In addition, when averaging over WB severity, the traditional marinade was preferred ($P < 0.05$) over the clean label marinade. Although the clean marinade samples were tender, the clean label formulation was not interchangeable with the traditional marinade when SEV was marinated. The use of salt and sodium phosphate or potassium carbonate improved the eating quality of MOD and SEV WB. However, differences remain between NOR and SEV in tenderness, gumminess, and crunchiness that negatively impact consumer acceptability.

Key words: chicken breast, woody, myopathy, water-holding capacity, marination
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Introduction

Broilers that weigh greater than 4.2 kg yield between 30% and 50% wooden breast (WB; also called "woody breast") meat, which downgrades the value of the breast meat and generates an excess of $200 million in annual losses to the poultry industry (Mudalal et al., 2015; Owens, 2016). WB is defined by visibly hardened, bulging, pale attributes within the *Pectoralis major* muscle (Sihvo et al., 2014). This hardness is not always consistent throughout the breast; therefore, breasts are graded by severity for research purposes. In the poultry industry, there is not a definitive differentiation for normal (NOR) breast versus WB but instead a continuous scale of degrees of woodiness. Currently, poultry plant employees are trained to grade meat and divert WB meat into products that will minimize quality problems and customer complaints. Therefore, it is necessary to explore potential profitable solutions to mitigate the undesirable characteristics of WB.

While WB has been thoroughly researched in recent years, there has not been a resolution to this issue. WB has the potential to be utilized in marinated or comminuted products rather than being condemned or rendered. Marination of WB meat partially masks breast meat woodiness and slightly increases consumer acceptability but does not eliminate the defect (Maxwell et al., 2018). The WB meat uptakes less marinade and has a lower water-holding capacity than NOR broiler breast meat (Mudalal et al., 2015). This is attributed to abnormal tissue (Sihvo et al., 2014) and not the distance of the meat pH from the isoelectric points of myofibrillar proteins, since WB meat usually has a greater pH than NOR breast meat (Dalle Zotte et al., 2017; Kuttappan et al., 2017; Xing et al., 2017; Cai et al., 2018; Dalgaard et al., 2018; Byron et al, 2020).

The use of sodium phosphate in meat products improves water-holding capacity, thereby improving tenderness and juiciness (Lopez et al., 2012). Therefore, phosphates may increase the usability of WB. Sodium phosphate is regulated by the United States Department of Agriculture to levels at or below 0.5% of the final product and must be labeled on an ingredient label (9 Code of Federal Regulations [CFR] 318.7)

Because there is a consumer market for marinated chicken without sodium phosphate, the impact of using clean label marinades with WB meat needs to be evaluated. Potassium carbonate is used as a partial replacement for phosphate and is not required to be included on a food label (21 CFR 184.1619 and 21 CFR 184.16.13). Potassium carbonate is Generally Recognized As Safe and without any limitation on usage, but it is recommended for use in accordance to good manufacturing practices (21 CFR 184.1619). The CFR also recognizes potassium carbonate as a "pH control agent and processing aid" (21 CFR 184.170.3). Potassium carbonate is added to water prior to mixing in a brine, as a processing aid to buffer water pH.

In order to determine whether utilization of sodium phosphate or potassium carbonate in conjunction with salt alleviates WB characteristics in marinated chicken breasts, the objective of this research was to evaluate differences in quality between chicken breasts classified as NOR, moderately woody (MOD), and severely woody (SEV) that were marinated with water (control); water, sodium phosphate, and salt (traditional); or water, potassium carbonate, and salt (clean label).

Materials and Methods

Sample collection

Chicken breasts were collected from 9-wk-old Ross 708 broilers (Aviagen Group, Huntsville, AL) with an average live weight of 4.2–4.3 kg from a commercial poultry plant. These chicken breasts were graded by hand palpation based on degree of woodiness: NOR, which was flexible throughout the breast; MOD, which was hard but flexible throughout the breast or hard mainly in the cranial portion of the breast and flexible throughout the rest of the breast; and SEV, which was extremely hard and rigid throughout the breast (Tijare et al., 2016). All breasts were slit to 30 ± 2 mm using a Grasseli meat slicer and portioner (KSL Model; Albinea, Italy), and ventral portions were marinated 24 h post mortem.

Marination

Total batch weights of 18.2 kg were used to marinate NOR, MOD, and SEV WB with control, traditional, and clean label marinades. This was replicated with 3 different collection dates and their respective processing dates. Each batch consisted of 37 ± 3 breasts; because the batch size was constant, breast numbers varied due to differences in breast weights. Each marinade was applied to chicken breast meat to reach a final concentration of 15.25% of the total batch. Ingredient levels were chosen with assistance from industry professionals based on common usage rates for salt, phosphate, and sodium carbonate. The control marinade was formulated with reverse osmosis (RO) water only (15.25%). The traditional marinade was formulated with RO water (13.98%), salt (0.85%), and sodium tripolyphosphate (0.42%; Nutrifos 088, ICL Food Specialties, St. Louis, MO). The clean label marinade was formulated with RO water (14.15%), salt (0.85%), and potassium carbonate (0.25%; Aquahawk GFS, Hawkins Inc., Roseville, MN). Each meat batch was vacuum tumbled for 30 min at 12 rpm (3.33 KPa) in a 22.7 kg tumbler (Model LT-5; Lance Industries, Allentown, WI). To calculate the tumble loss, each tumbler was weighed alone, then before and after removing each meat batch.

Drip loss

All sample breasts ($n = 37 \pm 3$) from each batch were set on racks on trays for 30 min at approximately 13°C to collect drip loss. The drip loss was calculated as described below.

$$\text{Drip Loss (\%)} = \left(1 - \frac{\text{wt of marinated breast meat} - \text{wt of purge}}{\text{wt of marinated breast meat}}\right)*100$$

Instrumental color

After collection of drip loss, Commission Internationale de l'Éclairage (CIE; "International Commission on Illumination") L* (lightness), a* (redness), and b* (yellowness) values were measured at 3 different locations (cranial, medial, and caudal) (Figure 1) on 10 raw marinated breasts from each treatment using a HunterLab MiniScan EZ spectrophotometer (Model 4500L; Hunter Associates Laboratory Inc., Reston, VA), with a 31.8-mm port size, a 10° standard observer, and a D65 illuminant. The instrument was calibrated with standard white and black Hunter MiniScan calibration plates.

pH

After color was measured, 4 pH readings (Figure 1) from the same 10 raw marinated breasts were measured using an Accumet pH meter (Model Accumet 61; Fisher Scientific, Hampton, NH) with a meat penetrating probe (Model FlexipHet SS Penetration tip; Cole Palmer, Vernon Hills, IL). These 10 raw marinated breasts were then discarded. Prior to measuring the pH of marinated chicken breasts, the pH probe was standardized using calibration buffers at pH 4 and pH 7. Then, the pH meter was recalibrated after 10 breasts were analyzed to ensure measurement accuracy.

Sample freezing and storage

All remaining samples, not used for pH and color measurements ($n = 27 \pm 3$ per treatment), were individually frozen for 20 min in a CO_2 cabinet (CES Group, Cincinnati, OH) to an internal temperature of −80°C. Samples were stored in sealed bags and shipped to Mississippi State University and stored at −23°C. All samples were utilized within 3 mo of processing.

Thaw loss

Frozen chicken breast samples ($n = 10$ per treatment) were individually placed in preweighed plastic

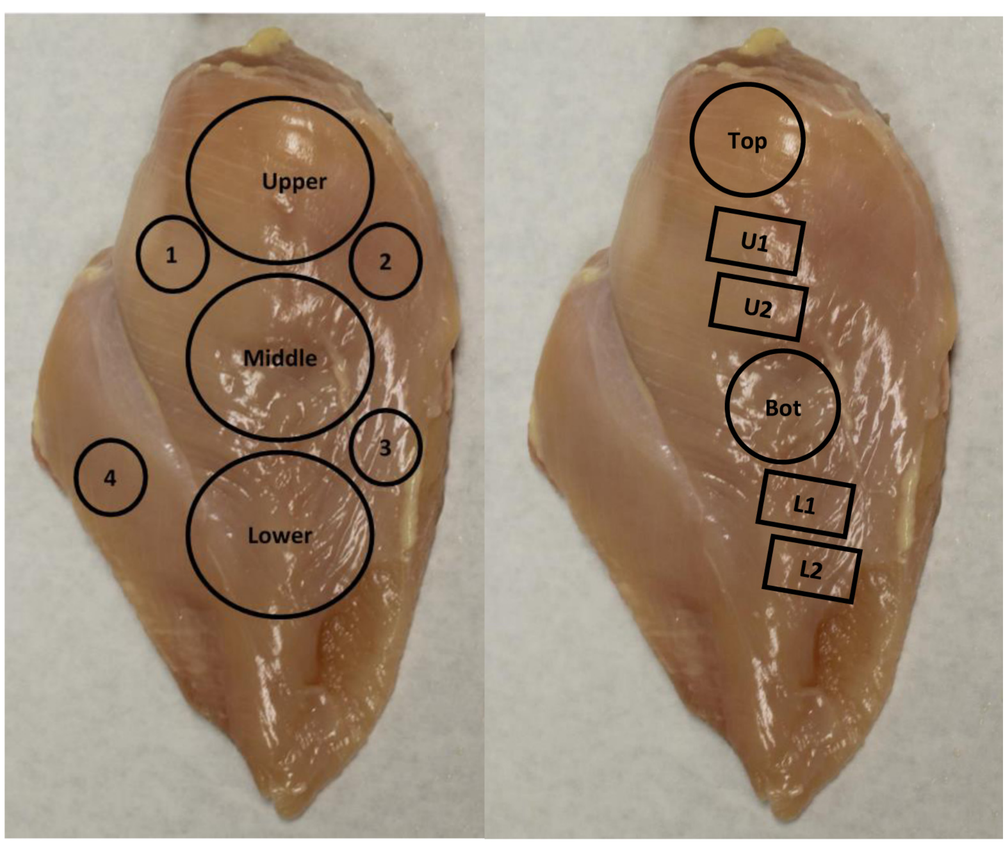


Figure 1. Positions of HunterLab MiniScan EZ (Hunter Associates Laboratory Inc., Reston, VA) spectrophotometer (upper, middle, lower) and pH measurements (1, 2, 3, 4) (left) taken from a raw chicken breast and positions of texture profile analysis (top and bottom) and Warner-Bratzler shear force (U1, U2, L1, L2) measurements taken from a cooked chicken breast.

Ziploc (S.C. Johnson & Son Inc., Racine, WI) bags, and then thawed for 24 ± 2 h at 2.8°C. After thawing, each breast was weighed with and without purge. After adjusting measurements according to bag weights, thaw loss was calculated from these measurements:

$$\text{Thaw Loss (\%)} = \left(1 - \frac{\text{wt of thawed breast w/purge} - \text{wt of purge}}{\text{wt of thawed breast w/purge}}\right) * 100$$

Cook loss

Thawed chicken breast samples ($n = 10$ per treatment) were randomly assigned to one of 9 positions on an aluminum foil covered tray that was 45 cm × 65 cm × 2.5 cm below a rack with dimensions of 45 cm × 65 cm × 0.5 cm to allow for heat to circulate above and below the samples. Chicken breast samples were then cooked uncovered in a convection oven (Model SCVX20E; Hobart, Chattanooga, TN) at 177°C for 27 min to an internal temperature of 76°C, measured with a waterproof instant read thermometer (Model 9842, Taylor Precision Products, Oak Brook, IL).

$$\text{Cook Loss (\%)} = \left(1 - \frac{\text{wt of thawed breast w/o purge} - \text{wt of cooked breast}}{\text{wt of thawed breast w/o purge}}\right) * 100$$

Instrumental shear force

After cooking, samples were cooled for 30 min at room temperature, reweighed, and cut for Warner-Bratzler shear force (SF) analysis. Four SF samples of 1 cm (width) × 1 cm (thickness) × 2 cm (length) were cut from each chicken breast in the direction of the muscle fibers (Figure 1). SF was measured against the grain of the muscle fibers of the samples using a Warner-Bratzler SF attachment that was secured to an Instron Universal Testing Center (Model 3345; Instron, Norwood, MA) and programmed at a speed of 200 mm/min. SF was reported as the maximum amount of force (in newton) required to shear through each sample (Schilling et al., 2012).

Texture profile analysis

For texture profile analysis (TPA), two 2.5-cm diameter cores, one from the top of the breast and one from the bottom (Figure 1), were cut from the same cooked breast samples that were used for SF. The top of each core was sliced off thinly, then each sample was cut to 20 mm in height. TPA (Bourne, 1978) samples were compressed twice to 50% of the original sample height at 100 mm/min using a metal weighted 5.2-cm–diameter cylinder mounted onto an Instron (Model 3345; Instron, Norwood, MA).

Descriptive sensory analysis

Prior to descriptive sensory analysis, chicken breast samples that were marinated with traditional and clean label marinades (6 treatments) were thawed individually in 0.908 L Ziploc bags (S.C. Johnson & Son Inc., Racine, WI) for 24 h at 2.8°C, and then cooked, ventral side up, uncovered in a convection oven (Model SCVX20E; Hobart, Chattanooga, TN) at 177°C for 27 min to an internal temperature of 76°C. The small portion of meat to the side of the band that consists of fat and connective tissue and the very cranial and very caudal portions of the breast were removed, and the remaining portion of the breast was cut into 10–12 bite-sized samples. Eight descriptive panelists were trained for 12 h (twelve 1-h sessions) to evaluate the texture and flavor attributes of chicken breasts on a 0- to 15-cm line scale, where 0 and 15 are relevant to chicken standards only. The texture and flavor attributes that were evaluated included tenderness, cohesiveness, chewiness, mushiness, fibrousness, initial juiciness, overall juiciness, stickiness, crunchiness, sweetness, sourness, saltiness, bitterness, umami, brothiness, chickeny, cardboardy, metallic, and off-flavor, which are similar to those that have been used previously to evaluate WB meat (Sanchez Brambila et al., 2018; Aguirre et al., 2018).

Consumer sensory analysis

Three consumer panels with 50 different panelists in each panel ($n = 150$ total panelists) were completed at Mississippi State University's James E. Garrison Sensory Evaluation Laboratory (Institutional Review Board 19-015). The chicken breast samples were cooked the same way as described in the section "Descriptive sensory analysis." Consumer panelists evaluated six 2.5 cm × 2.5 cm × 2.5 cm samples for appearance, aroma, taste, texture, and overall acceptability on 9-point hedonic scale, where 1 represents "dislike extremely" and 9 indicates "like extremely." Samples were labelled with a 3-digit random code, and the order of sample tasting was randomized by Compusense Cloud (Guelph, Ontario, Canada) software. Both descriptive and consumer panel results were obtained using the Compusense Cloud.

Statistical analysis

A 3 × 3 factorial structure within a randomized complete block design with 3 replications (blocks) was used to evaluate the impact of marinade (control, traditional, clean label) and WB severity (NOR, MOD, SEV) on pH, color, tumble loss, thaw loss, and cook loss.

A 3 × 3 × 2 factorial structure within a randomized complete block design with 3 replications was used to evaluate the impact of marinade (control, traditional, clean label), WB severity (NOR, MOD, SEV), and position (top, bottom) on texture attributes including TPA and SF measurements.

A 2 × 3 factorial structure within a randomized complete block design with 3 replications was used to determine the impact of marinade (traditional, clean label) and WB severity (NOR, MOD, SEV) on descriptive sensory attributes and consumer acceptability.

All statistical analysis was evaluated using SAS version 9.4 (SAS Institute Inc., Cary, NC). When significant differences occurred, marinade × severity treatments were separated using Tukey's honestly significant difference test. For consumer sensory analysis, agglomerative hierarchical clustering using XLSTAT Wards Method (New York, NY) was performed to group panelists in clusters based on their liking of broiler breast meat samples. The number of clusters used to group panelists was determined based on a dendrogram and a dissimilarity plot. A randomized complete block design was used within each cluster, and Tukey's honestly significant difference test was used to separate treatment means within each cluster ($P < 0.05$). A principal components analysis (PCA) (XLSTAT, New York, NY) was used to group treatments together based on sensory flavor and textural attributes.

Results and Discussion

pH

When averaged over marinade, the pH of SEV breast meat was greater ($P < 0.05$) than MOD and NOR (Table 1), and MOD was greater than NOR ($P < 0.05$). These results are consistent with previous research, in which it was reported that SEV WB had a higher pH than NOR (Kuttappan et al., 2017; Xing et al., 2017; Cai et al., 2018; Dalgaard et al., 2018). In contrast, other researchers reported that there were no differences in pH between NOR and SEV chicken breasts (Mudalal et al., 2015; Soglia et al., 2016; Wold et al., 2017). When averaged over WB severity, no differences existed ($P >$ 0.05) in pH among marinated chicken treatments. This was unexpected, since phosphates and potassium carbonate both increased the pH of marinated meat in previous research (Young and Lyon, 1997; Smith and Young, 2007; LeMaster et al., 2019).

Instrumental color

When averaged over marinade, NOR breast meat was darker (CIE L*) and redder (CIE a*) than MOD and SEV breast meat ($P < 0.05$), and MOD breast meat

Table 1. pH ($n = 4$ breasts per treatment per rep), lightness (L*), redness (a*), yellowness (b*) ($n = 10$ breasts per treatment per rep), and tumble loss ($n = 1$ per treatment per rep) of normal, moderately woody, and severely woody broiler breasts that were vacuum tumble marinated with control marinade of water; traditional marinade of water, salt, and phosphate; and clean label marinade of water, salt, and potassium carbonate

Analysis	Treatment	pH	L*	a*	b*	Tumble Loss (%)[1]
WB Severity[2]	NOR	5.8^{c}	60.6^{c}	6.7^{a}	15.5^{a}	6.6^{b}
	MOD	5.9^{b}	62.7^{b}	6.2^{b}	15.6^{a}	9.4^{a}
	SEV	6.0^{a}	64.1^{a}	6.1^{b}	14.4^{b}	10.0^{a}
	P value	<0.0001	<0.0001	0.0023	0.0256	<0.0001
	SEM	0.03	1.4	0.4	1.2	0.003
Marinade	Control	5.9	66.1^{a}	5.1^{b}	14.8	10.6^{a}
	Traditional	5.9	60.4^{b}	6.9^{a}	15.5	8.7^{b}
	Clean label	5.9	60.7^{b}	6.9^{a}	15.2	6.7^{c}
	P value	0.0571	<0.0001	<0.0001	0.3420	<0.0001
	SEM	0.03	1.4	0.4	1.2	0.003

[1]Tumble loss defined as ([weight of meat + brine] – [weight of brine leftover]) ÷ (weight of meat + brine) × 100%.

[2]Wooden breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[a,b,c]Means within a column lacking a common superscript differ ($P < 0.05$) by analysis. There was no WB severity × marinade interaction effect ($P > 0.05$) for these attributes.

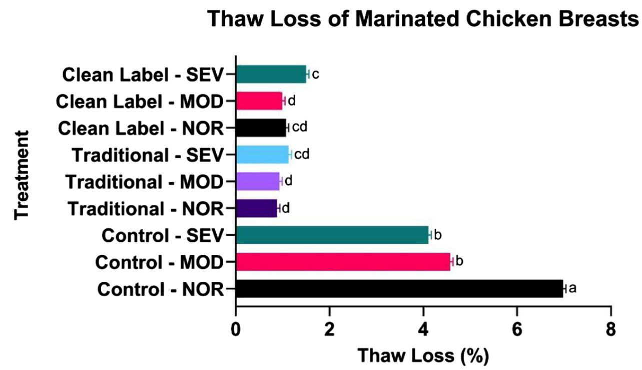
was darker than SEV breast ($P < 0.05$) (Table 1). This is consistent with previous research in which SEV WB was lighter and less red than NOR breast meat (Wold et al., 2017; Cait et al., 2018). When averaged over WB severity, use of traditional and clean label marinades decreased lightness and increased redness ($P < 0.05$) of chicken breast samples (Table 1) in comparison to the control marinated treatments. In addition, SEV WB samples were more yellow than both NOR and MOD samples when averaged over marinade ($P < 0.05$), and when averaged over WB severity, there were no differences in yellowness (CIE b*) among marinades ($P > 0.05$).

Tumble loss

When averaged over marinade, both MOD and SEV treatments did not differ in tumble loss ($P > 0.05$), but both had more tumble loss than NOR breast ($P < 0.05$) (Table 1). These findings are in agreement with previous literature in which marinade uptake of SEV and MOD WB is less than that of NOR chicken breast (Mudalal et al., 2015; Soglia et al., 2016; Tijare et al., 2016; Bowker et al., 2018; Maxwell et al., 2018). Thus, regardless of traditional or clean label marinade, the use of SEV WB leads to significant yield losses in marinated, ready-to-cook products compared to NOR breast meat. In addition, when averaged over WB severity, the control marinade had the most tumble loss ($P < 0.05$), followed by the clean label marinade ($P < 0.05$), which had more tumble loss than the traditional marinade ($P < 0.05$) (Table 1). This can be attributed to the functionality of potassium carbonate and sodium tripolyphosphate at opening the protein structure due to the addition of negative charges that increase both the ionic strength and the overall negative charge of the product (Young and Lyon, 1997; Smith and Young, 2007; LeMaster et al., 2019).

Thaw loss

Thaw loss was affected by the combination of marinade and WB severity ($P < 0.05$). All control samples, with only water added, experienced greater thaw loss than both traditional and clean label marinades ($P < 0.05$) (Figure 2). Surprisingly, the control marinated NOR samples had more thaw loss than both MOD and SEV breasts ($P < 0.05$). This may have been partially due to greater marinade uptake in the NOR meat. Among clean label and traditional marinated samples, the clean label SEV had more thaw loss than both MOD samples and traditional NOR samples ($P < 0.05$) (Figure 2). However, clean label NOR and traditional



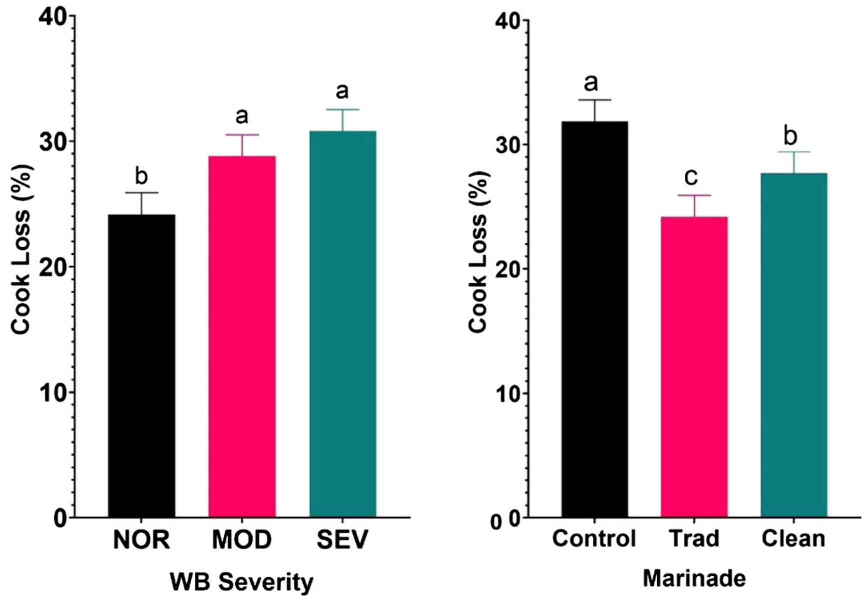
[a,b,c]Means lacking a common superscript differ ($P < 0.05$) for the treatment combination of marinade × WB severity.

Figure 2. Thaw loss (percent) of normal, moderately woody, and severely woody broiler breasts that were vacuum tumble marinated with a traditional marinade of salt and phosphate and a clean label marinade of salt and potassium carbonate.

SEV did not differ from all other traditional and clean label samples ($P > 0.05$) (Figure 2). Results indicate that both marinades improved water-holding capacity during the thaw process as indicated by the thaw loss of less than 2% for both marinades in comparison to 4%–7% thaw loss for the control marinade treatments.

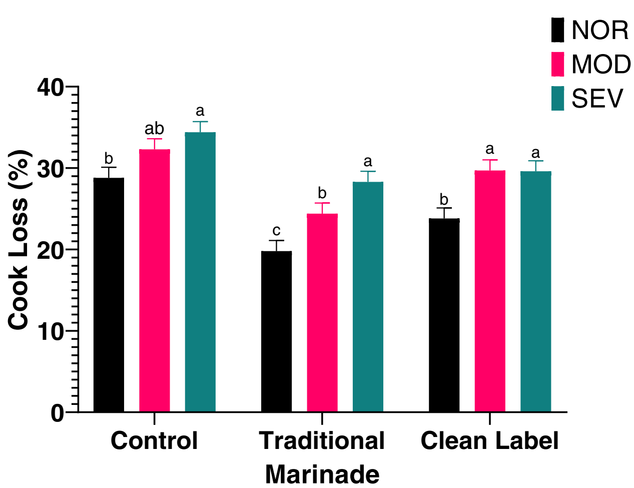
Cook loss

There was no interaction effect ($P > 0.05$) between WB severity and marinade with respect to cook loss. The traditional marinade had the least cook loss ($P < 0.05$), followed by the clean label marinade, which had less cook loss ($P < 0.05$) than the control treatment (Figure 3). Even though no significant interaction existed ($P = 0.115$), means were separated for WB severity within each marinade using Tukey's honestly significant difference test (Figure 4). For the control marinade, the NOR breast meat had less cook loss ($P < 0.05$) than SEV WB meat, but neither NOR nor SEV differed ($P > 0.05$) from MOD. In contrast, NOR meat had less cook loss for the traditional marinade than both MOD and SEV, and MOD had less cook loss than SEV. For the clean label marinade, the NOR breast meat had less ($P < 0.05$) cook loss than MOD and SEV, but there was no difference between MOD and SEV. This indicates that the traditional marinade is needed to improve cooking yields of MOD WB, but that the traditional and clean marinades can both effectively increase the yields of NOR broiler breast meat. However, neither marinade was effective at increasing the yields of the SEV WB, which is consistent with previous research findings that marination has minimal improvements on the quality of SEV WB meat (Mudalal et al., 2015; Kuttappan et al., 2016;



a,b,cMeans lacking a common superscript differ ($P < 0.05$) for marinade or WB severity. There was no interaction between WB severity and marinade for cook loss ($P > 0.05$).

Figure 3. Cook loss (percent) of normal, moderately woody, and severely woody broiler breasts that were vacuum tumble marinated with control marinade of water; traditional marinade of water, salt, and phosphate; and clean label marinade of water, salt, and potassium carbonate.



a,b,cMeans lacking a common superscript differ ($P < 0.05$) for within each marinade treatment.

Figure 4. Cook loss (percent) mean separation of normal, moderate woody, and severe woody within control, traditional, and clean label marinades.

Soglia et al., 2016; Xing et al., 2017; Cai et al., 2018; Dalgaard et al., 2018).

TPA

SEV samples were harder and gummier than NOR samples ($P < 0.05$), and MOD samples were gummier than NOR samples ($P > 0.05$). Both MOD and SEV samples were chewier than NOR samples ($P < 0.05$), but they did not differ from each other ($P > 0.05$) (Table 2). These results are consistent with previous research that demonstrated that SEV WB was harder than NOR breast meat (Mudalal et al., 2015; Soglia et al., 2016; Xing et al., 2017; Dalgaard et al., 2018). When averaged over WB severity, control marinade samples were harder, more cohesive, gummier, and chewier than both traditional and clean label marinades ($P < 0.05$), but no texture differences existed ($P > 0.05$) between traditionally marinated and clean label–marinated chicken breast. This could be from the lack of a strong functional ingredient, like sodium phosphate and salt, in the control marinade. In addition, for all TPA attributes except springiness, top samples were harder, more cohesive, gummier, and chewier than the bottom samples ($P < 0.05$) (Table 2, Figure 1). This is consistent with reports that the top or cranial portion of the breast is usually more impacted by the WB myopathy than the bottom or caudal portion (Dalle Zotte et al., 2017).

SF

More SF was required ($P < 0.05$) to cut through SEV samples than NOR and MOD samples (Table 2). Differences did not exist in SF ($P > 0.05$) between traditional and clean label–marinated samples (Table 2). In addition, the top positions of the breast required a greater amount of SF to cut through the samples in comparison to the bottom positions ($P < 0.05$) (Figure 1, Table 2), which is confirmatory of previous

Table 2. Texture profile analysis attributes (*n* = 4 breasts per treatment per rep) and shear force (*n* = 10 breasts per treatment per rep) of normal, moderately woody, and severely woody broiler breasts that were vacuum tumble marinated with control marinade of water; traditional marinade of water, salt, and phosphate; and clean label marinade of water, salt, and potassium carbonate

Analysis	Treatment	Hardness[1]	Cohesiveness[2]	Gumminess[3]	Chewiness[4]	Springiness[5]	Shear Force (N)
WB Severity[6]	NOR	7.5^{b}	0.30	2.2^{c}	9.4^{b}	4.2^{a,b}	15.8^{b}
	MOD	8.0^{a,b}	0.31	2.6^{b}	11.3^{a}	4.2^{a}	15.8^{b}
	SEV	8.6^{a}	0.31	2.8^{a}	11.9^{a}	4.1^{b}	18.1^{a}
	P value	0.011	0.168	<0.0001	0.0003	0.021	<0.0001
	SEM	0.76	0.01	0.24	1.13	0.08	1.30
Marinade	Control	8.7^{a}	0.32^{a}	2.9^{a}	12.2^{a}	4.2	17.5^{a}
	Traditional	7.6^{b}	0.30^{b}	2.3^{b}	10.5^{b}	4.1	16.2^{b}
	Clean label	7.8^{b}	0.30^{b}	2.5^{b}	9.9^{b}	4.2	16.0^{b}
	P value	0.009	0.004	0.0002	0.0007	0.748	0.003
	SEM	0.76	0.01	0.24	1.13	0.08	1.30
Position	Top	8.4^{a}	0.3^{a}	2.8^{a}	11.7^{a}	4.2	17.6^{a}
	Bottom	7.7^{b}	0.3^{b}	2.4^{b}	10.0^{b}	4.2	15.6^{b}
	P value	0.031	0.002	0.0002	0.0005	0.569	<0.0001
	SEM	0.76	0.01	0.24	1.13	0.08	1.30

[1]Kg of initial force.

[2]Kg of initial force * distance of force (kg * mm).

[3]Hardnesss * cohesiveness (kg^2 * mm).

[4]Gumminess * springiness (kg^2 * mm^2).

[5]Recovery between first and second bites (compressions) (mm).

[6]Woody breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[a,b,c]Means within a column lacking a common superscript differ ($P < 0.05$) for each analysis. There was no WB severity × marinade × position interaction for texture profile analysis (TPA) attributes ($P > 0.05$).

reports that top or cranial portions of SEV WB meat are harder than NOR meat. Della Zotte et al. (2017) reported that the top or cranial portion of the WB meat is the hardest and often contains localized WB myopathy traits (Dalle Zotte et al., 2017). SF results for WB meat are highly variable in the literature. Some researchers reported no difference in SF between woody and NOR breast meat (Cai et al., 2018; Dalgaard et al., 2018). In contrast, some have determined that WB requires significantly more SF than NOR breast, such as Trocino et al. (2015), but they did not specify the severity of WB.

Descriptive sensory analysis

NOR was more tender, less cohesive, less chewy, stickier, and less crunchy ($P < 0.05$) than MOD and SEV, and MOD was more tender, less cohesive, less chewy, stickier, and less crunchy ($P < 0.05$) than SEV when averaged over marinades. This is consistent with greater SF values for SEV than NOR in the top position ($P < 0.05$). In addition, traditional marinade samples were less crunchy than clean label marinade samples ($P < 0.05$). No difference existed ($P > 0.05$) between the traditional and clean label marinades with respect to tenderness, cohesiveness, chewiness, and stickiness. Sensory crunchiness was not different ($P > 0.05$) between the traditional and clean label marinades for the SEV treatment, which indicates that regardless of the type of commercial marinade that was used (traditional or clean label), SEV WB meat has undesirable sensory attributes that are described as cohesive, chewy, and crunchy. This further demonstrates that the SEV WB meat does not absorb marinade well and has high cooking loss, regardless of whether marinade is used or not, and its sensory properties are not substantially improved through marination. Interaction was present between breast severity and marinade for initial and overall juiciness ($P < 0.05$) (Table 3). The traditional marinated SEV samples were initially juicier than MOD and NOR samples ($P < 0.05$), and the clean label MOD samples were initially juicier ($P < 0.05$) than the SEV and NOR samples. In contrast, the traditional marinated SEV had a greater overall juiciness rating than traditional NOR and clean NOR, with no other differences ($P > 0.05$) present. When averaged over marinade, NOR samples were saltier than MOD and SEV samples ($P < 0.05$),

Table 3. Chicken descriptive analysis ($n = 8$ trained panelists, $n = 4$ breasts per treatment per rep): Responses of textural descriptive attributes[1] that were different ($P < 0.05$) between traditional and clean label marinades and woody breast severity (normal, moderate, and severe)

Analysis	Treatment	Tender	Cohesive	Chewy	Mushy	Sticky	Crunchy	Initial Juiciness	Overall Juiciness
Severity[2]	NOR	8.4^{a}	4.7^{c}	4.5^{c}	3.0^{a}	5.3^{a}	2.8^{c}	7.3^{b}	7.0^{b}
	MOD	7.6^{b}	5.3^{b}	5.3^{b}	1.8^{b}	4.4^{b}	4.9^{b}	$7.5^{a,b}$	$7.3^{a,b}$
	SEV	6.8^{c}	5.8^{a}	6.2^{a}	1.2^{c}	3.8^{c}	6.6^{a}	7.6^{a}	7.4^{a}
	P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.032	0.005
	SEM	0.063	0.153	0.063	0.068	0.075	0.085	0.048	0.051
Marinade	Trad[3]	7.7^{a}	5.3	5.2	1.9	4.5	4.5^{b}	7.4	7.2
	Clean	7.5^{b}	5.5	5.4	1.7	4.4	5.0^{a}	7.4	7.2
	P value	0.041	0.153	0.058	0.208	0.698	0.014	0.773	0.560
	SEM	0.062	0.058	0.063	0.068	0.075	0.085	0.048	0.051
Severity × Marinade	Trad NOR	8.5^{a}	4.7^{c}	$4.5^{d,e}$	2.8^{a}	5.3^{a}	2.6c	7.3^{b}	7.0^{b}
	Trad MOD	$7.8^{b,c}$	$5.2^{b,c}$	$5.1^{c,d}$	1.7^{b}	4.4^{b}	4.5^{b}	7.3^{b}	$7.1^{a,b}$
	Trad SEV	$7.0^{d,e}$	$5.7^{a,b}$	$6.1^{a,b}$	$1.1^{b,c}$	3.8^{b}	6.3^{a}	7.8^{a}	7.6^{a}
	Clean NOR	$8.4^{a,b}$	4.7^{c}	4.4^{e}	2.8^{a}	5.3^{a}	2.9^{c}	7.2^{b}	7.0^{b}
	Clean MOD	$7.5^{c,d}$	$5.4^{a,b}$	$5.5^{b,c}$	$1.3^{b,c}$	$4.3^{a,b}$	5.2^{b}	7.7^{a}	$7.4^{a,b}$
	Clean SEV	6.6^{e}	5.9^{a}	6.3^{a}	1.0^{c}	3.8^{b}	6.9^{a}	7.4^{b}	$7.2^{a,b}$
	P value	0.638	0.999	0.107	0.018	0.333	0.069	0.001	0.005
	SEM	0.059	0.056	0.059	0.061	0.064	0.068	0.048	0.053

[1]Descriptive attributor was evaluated based on a 15-point modified quantitative spectrum scale in which 0 = none and 15 = the most that can possibly be expressed within the product.

[2]Woody breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[a,b,c,d,e]Means within a column lacking a common superscript differ ($P < 0.05$) for each analysis within severity, marinade, or severity × marinade.

Trad = traditional.

and the traditional marinated samples were saltier than clean label samples when averaged over WB severity ($P < 0.05$) (Table 4). When averaged over marinade, NOR samples had more umami flavor than SEV samples ($P < 0.05$) (Table 4). NOR samples were also more chickeny than MOD samples ($P < 0.05$), which were more chickeny than SEV samples ($P < 0.05$). This may coincide with more cooking loss in SEV compared with NOR samples (Figures 3–4), as well as the SEV being less salty than NOR samples ($P < 0.05$). Therefore, SEV flavor was not preserved or improved from the addition of salt as well as NOR samples were.

MOD and SEV samples had more off-flavor than NOR samples ($P < 0.05$) (Table 4). In addition, when separated out, the clean label MOD and clean label SEV had more off-flavor ($P < 0.05$) than the clean label NOR samples; even though the off-flavor ratings were higher for SEV and MOD in traditional marinades, there were not any differences ($P > 0.05$) between the 3 WB severities. Tasoniero et al. (2016) determined that off-flavor is associated with white striping, but literature on the off-flavor of SEV WB is not available. SEV WB was described as a sour, raw, or uncooked flavor by our descriptive panelists. Our MOD and SEV samples exhibited more of this off-flavor attribute than NOR samples ($P < 0.05$). This off-flavor is a significant attribute of interest for WB meat. If the off-flavor of WB could be characterized, we would be able to grade WB based on a specific flavor in the final product in addition to hand palpation and textural descriptive attributes such as crunchiness.

PCA was performed, and the biplot (Figure 5) explained 89.7% of the variability for our descriptive analysis, 80.8% on the x-axis and 8.9% on the y-axis. This PCA accurately associated marinated WB samples with the descriptors that best described them. From this, we can visualize the major descriptive differences in samples. The traditional and clean label NOR samples were more tender, mushier, and stickier than both SEV samples, and traditional and clean label SEV samples were crunchier, chewier, and had more initial juiciness than the NOR samples. Meanwhile, both the traditional MOD and clean label MOD samples were in between NOR and SEV samples but just slightly more like the SEV samples.

Consumer sensory analysis

The appearance of traditional NOR, with a rating of 6.3, was preferred ($P < 0.05$) over the traditional and

Table 4. Chicken descriptive analysis ($n = 8$ trained panelists, $n = 4$ breasts per treatment per rep): Responses of descriptive taste and flavor attributes[1] that were different ($P < 0.05$) between traditional and clean label marinades and woody breast severity (normal, moderate, and severe)

Analysis	Treatment	Salty	Umami	Chickeny	Off-flavor
WB Severity[2]	NOR	3.3[a]	4.4[a]	4.8[a]	0.2[b]
	MOD	2.6[b]	4.2[a,b]	4.5[b]	0.4[a]
	SEV	2.5[b]	4.0[b]	4.2[c]	0.4[a]
	P value	0.0001	0.007	<0.0001	<0.0001
	SEM	0.086	0.046	0.043	0.030
Marinade	Traditional	2.8	4.3	4.5	0.3
	Clean label	2.5	4.1	4.5	0.4
	P value	0.051	0.131	0.498	0.168
	SEM	0.086	0.046	0.043	0.030
Severity	Traditional NOR	3.6[a]	4.5[a]	4.8[a]	0.1[b]
×	Traditional MOD	2.6[b,c]	4.2[a,b]	4.5[a,b]	0.4[a,b]
Marinade	Traditional SEV	2.7[a,b,c]	4.2[a,b]	4.3[b]	0.3[a,b]
	Clean label NOR	3.1[a,b]	4.4[a]	4.7[a]	0.1[b]
	Clean label MOD	2.5[b,c]	4.2[a,b]	4.4[a,b]	0.5[a]
	Clean label SEV	2.2[c]	3.8[b]	4.1[b]	0.6[a]
	P value	0.243	0.095	0.824	0.146
	SEM	0.069	0.05	0.049	0.04

[1]Descriptive attributor was evaluated based on a 15-point modified quantitative spectrum scale in which 0 = none and 15 = the most that can possibly be expressed within the product.

[2]Woody breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[a,b,c]Means within a column lacking a common superscript differ ($P < 0.05$) for each analysis.

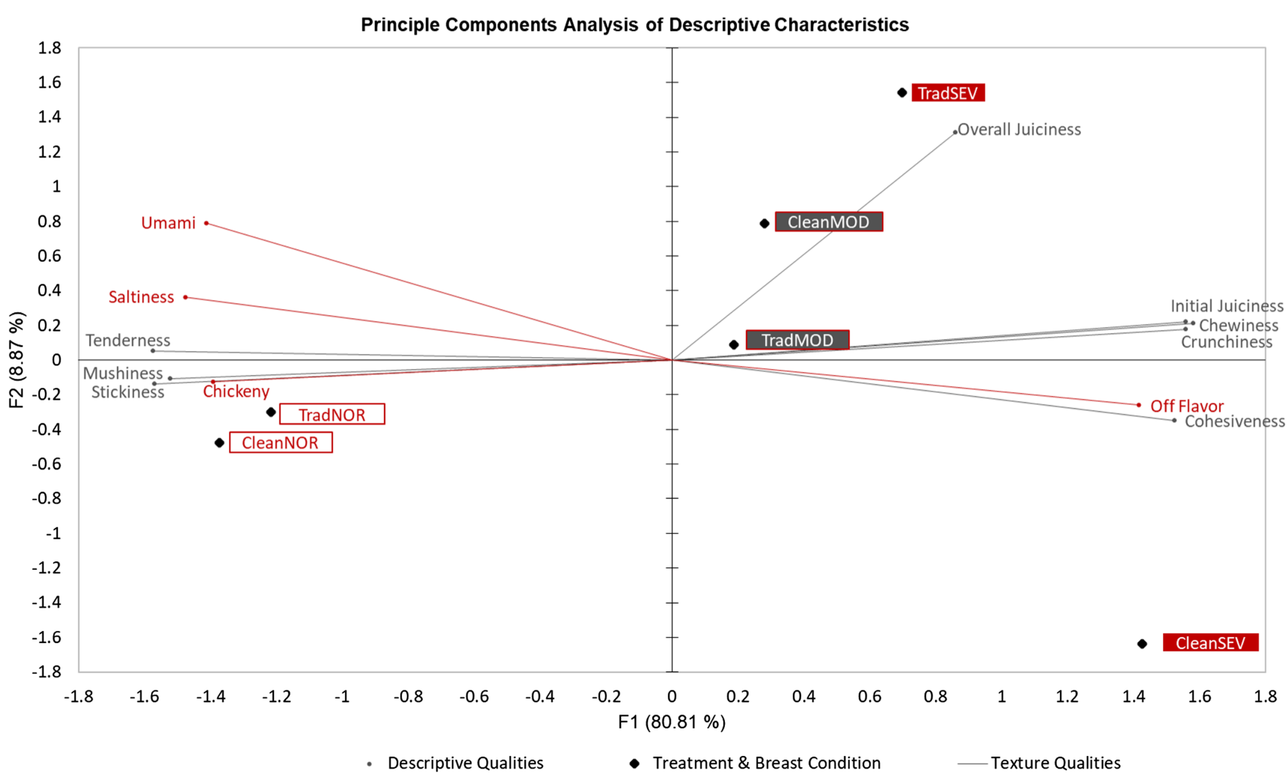


Figure 5. Principle components analysis of sensory descriptive characteristics of normal, moderately woody, and severely woody breast meat that was marinated with either a traditional or clean label marinade.

Table 5. Chicken consumer analysis ($n = 150$ total panelists): Effects of marinade treatment (traditional and clean label) and woody breast severity (normal, moderate, severe) on the appearance, aroma, texture, flavor, and overall acceptability[1] of baked broiler breast meat ($n = 155$ consumers)

Marinade	WB Severity[2]	Appearance	Aroma	Texture	Flavor	Overall Acceptability
Traditional	NOR	6.3[a]	6.4[a]	6.4[a]	6.4[a]	6.4[a]
Traditional	MOD	6.2[a,b]	6.1[a,b]	6.3[a,b]	6.0[b]	6.2[a,b]
Traditional	SEV	5.9[b]	6.1[a,b]	5.8[c,d]	5.3[c]	5.6[c,d]
Clean label	NOR	6.2[a,b]	6.2[a,b]	6.1[a,b,c]	5.9[b]	6.1[a,b]
Clean label	MOD	6.0[a,b]	6.0[a,b]	6.0[b,c]	5.8[b]	5.9[b,c]
Clean label	SEV	5.9[b]	5.9[b]	5.6[d]	5.2[c]	5.4[d]
SEM		0.11	0.10	0.13	0.17	0.13

[1]Consumer acceptability was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]Woody breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[a,b,c]Means with the same letter within each column are not significantly different ($P > 0.05$).

clean label SEV treatments, both with ratings of 5.9. No other differences existed ($P > 0.05$) in appearance acceptability among treatments (Table 5). For aroma acceptability, the only difference in treatments was that the traditional NOR aroma was preferred ($P < 0.05$) over clean label SEV with average ratings of 6.4 and 5.9, respectively (Table 5). The texture of traditional NOR treatment was preferred over ($P < 0.05$) that of traditional SEV, clean label MOD, and clean label SEV. In addition, Traditional MOD was preferred ($P < 0.05$) over traditional and clean label SEV treatments, and clean label MOD was preferred ($P <$ 0.05) over clean label SEV (Table 5).

The flavor of traditional NOR was preferred over all other treatments ($P < 0.05$), and the flavor of traditional MOD, clean label NOR, and clean label MOD were preferred over both SEV treatments ($P <$ 0.05) (Table 5). This is consistent with descriptive analysis results that associated an off-flavor with traditional and clean label SEV samples. Thus, the consumers may have detected the raw, uncooked off-flavor that was described by trained panelists. This indicates that the traditional marinade maximizes flavor and texture acceptability in NOR meat but that flavor and texture acceptability cannot be improved in SEV meat, regardless of whether clean label or traditional marinades are used. With respect to overall acceptability, traditional NOR was preferred ($P < 0.05$) over traditional SEV and clean label MOD and SEV treatments (Table 5). In addition, traditional and clean label NOR were

Table 6. Effects of marinade treatment (traditional and clean label) and woody breast severity[1] (normal, moderate, severe) on the overall acceptability[2] of baked broiler breast meant ($N = 155$ consumers) according to different clusters of consumer segments

		Traditional Marinade			Clean Label Marinade		
Cluster	Consumer (n)	NOR	MOD	SEV	NOR	MOD	SEV
1	46	5.4[b,c,d]	6.2[a]	5.2[c,d]	4.9[d]	5.7[a,b,c]	5.9[a,b]
2	25	7.6[a,b]	7.6[a,b]	7.3[a,b]	7.0[b]	7.7[a]	7.4[a,b]
3	18	7.2[a,b]	4.8[d]	7.6[a]	7.1[a,b]	5.8[c]	6.8[b]
4	27	7.1[a]	7.1[a]	6.8[a,b]	6.9[a]	6.1[b]	3.6[c]
5	17	6.7[a,b]	6.6[a,b]	3.8[c]	7.3[a]	4.7[c]	6.1[b]
6	10	4.2[a]	2.7[a]	2.8[a]	3.6[a]	2.6[a]	3.1[a]
7	12	6.6[a,b]	6.3[b]	3.2[c]	5.9[b]	7.6[a]	2.5[c]
% of panelists that rated the sample 7 or greater		45.2%	33.5%	27.7%	38.7%	23.9%	16.1%
% of panelists that rated the sample 6 or greater		63.9%	81.9%	45.2%	56.1%	41.3%	38.7%
% of panelists that rated the sample 5 or greater		93.5%	81.9%	74.8%	63.9%	82.6%	68.4%

[1]Woody breast (WB) severity graded as normal (NOR), moderate (MOD), or severe (SEV).

[2]Consumer acceptability was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[a,b,c]Means within a row lacking a common superscript differ ($P < 0.05$).

preferred ($P < 0.05$) over both SEV treatments, and clean label MOD was preferred ($P < 0.05$) over clean label SEV (Table 5). These results demonstrate that texture was the predominant determinant of overall acceptability. Consumers rated SEV samples less acceptable than NOR meat, regardless of which marinade system was used. This is important to consider if using WB in any fresh or marinated products.

Currently, consumer acceptability research in broiler breast myopathies is limited, and the majority of its studies are focused on the consumer acceptability of white striping. Some consumer acceptability research has been completed by Xing et al. (2020), in which NOR samples were preferred over MOD and SEV samples ($P < 0.05$), and there was no difference between MOD and SEV samples ($P > 0.05$) for appearance, texture, and overall acceptability. Our consumer overall acceptability results indicated that the clean label and traditional SEV samples were less acceptable ($P < 0.05$) than traditional NOR and MOD and clean label NOR samples; no difference ($P > 0.05$) existed between MOD and NOR within each marinade (Table 5). In addition, cluster analysis revealed that more consumers rated the NOR and MOD samples with the traditional marinade as acceptable (6 or greater) in comparison to NOR and MOD with the clean label marinade (Table 6). Thus, differences in acceptability among WB SEV samples compared to NOR samples were more apparent in the clean label than the traditional marinade, which indicates that it may not be advisable to utilize the clean label formulation in place of the traditional marinade with MOD WB meat.

Conclusions

Differences existed between NOR and SEV samples in both traditional and clean label marinades with respect to sensory tenderness, crunchiness, and off-flavor that resulted in decreased sensory acceptability for SEV samples. Therefore, it is not suggested to utilize either formulation to marinate SEV WB meat because it will not mask the undesirable eating characteristics of WB and will be noticeable to consumers. In addition, it may not be desirable to use MOD WB for clean label marinades since cook-loss values are high.

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