Relationships between instrumental texture measurements and subjective woody breast condition scores in raw broiler breast fillets[1]

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ABSTRACT The objective of this study was to compare the relationships between instrumental texture measurements and subjective woody breast (**WB**) scores in raw broiler breast fillets. A total of 181 broiler breast fillets were scored based on palpable hardness and rigidity ranging from 1.0 to 3.0 in 0.5 increments. Texture properties of raw fillets were measured with 3 different instrumental methods: compression force, blunt Meullenet-Owens Razor Shear (**BMORS**), and Meullenet-Owens Razor Shear (**MORS**). Compression force was measured based on % of fillet height (30%) and distance (10 mm). Blunt Meullenet-Owens Razor Shear and MORS measurements included peak force, energy, and peak counts. One-way ANOVA of instrumental texture measurements were performed. Spearman correlations between WB scores and instrumental texture measurements and Pearson correlations between 3 instrumental measurements were analyzed. ANOVA results showed that the best means separations between WB scores were found with the compression method. The weakest means separations were observed with MORS force and BMORS peak counts. Spearman correlation coefficients showed that there were significant relationships between WB scores and instrumental measurements. The strongest correlations were found between subjective WB scores and compression force measurements (r = 0.58–0.73, $P < 0.0001$), followed by BMORS force and energy (r = 0.55–0.56, $P < 0$ 0.0001), MORS energy and peak count (r = 0.47–0.50, $P < 0$ 0.0001), and BMORS peak count (r = −0.18, $P = 0.015$). The weakest correlation was found between the WB scores and MORS force (r = 0.17, $P = 0.023$). Pearson correlation coefficients between 3 different instrumental texture methods were also significant ($P < 0.0001$). These results demonstrate that there are significant correlations between subjective WB scores and instrumental texture measurements but that correlation strength varies with the instrumental method. Instrumental texture measurements can be used as references for subjective WB scores. Compression force method has the best potential for assessing subjective WB condition scores.

Key words: BMORS, chicken, compression force, MORS, wooden breast

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INTRODUCTION

The woody breast (**WB**) condition is an emerging muscle disorder in broiler breast meat (Bilgili, 2013; Owens, 2014; Sihvo et al., 2014; Petracci et al., 2015). The key characteristic of the WB meat distinguishing it from normal breast meat is palpable hardness throughout the raw broiler breast fillet (pectoralis major). Sihvo et al. (2014) reported that fillets with the WB condition are macroscopically hardened to the touch. Bilgili (2016) described WB fillets as either completely hardened (dense) to the touch or as exhibiting hardened "ridges" along the ventral portion of the breast. Kuttappan et al. (2016) and Tijare et al. (2016) defined WB fillets by hardness and rigidity.

For both commercial and research purposes, subjective scoring is still the predominant method used to categorize chicken fillets with the WB condition. For example, Tijare et al. (2016) and Sun et al. (2018)

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categorized broiler breast fillets into 4 different WB groups based on palpable hardness and flexibility: 0 = normal (fillets that were flexible throughout), 1 = mild (fillets that were hard mainly in the cranial region but flexible otherwise), 2 = moderate (fillets that were hard throughout but flexible in the mid to caudal region), 3 = severe (fillets that were extremely hard and rigid throughout from the cranial region to caudal tip). Chatterjee et al. (2016) classified broiler fillets into normal, moderate, and severe WB groups based on the incidence of diffuse hardened areas throughout the fillets and the severity of palpable hardness. Dalgaard et al. (2018) grouped broiler breast fillets into no WB, moderate WB, and severe WB based on palpable hardness using plastic materials as references. Bowker et al. (2019) scored WB fillets using a 3-point scale (1.0 to 3.0) in 0.5 score increments (normal = 1, mild = 1.5, moderate = 2 and 2.5, and severe = 3).

Because tactile properties of raw chicken breast meat are considered as the criterion for WB identification, several instrumental texture measurements, such as compression force (**CF**), Meullenet-Owens Razor Shear (**MORS**), and blunt MORS (**BMORS**), have been tested for assessing the degree of the WB condition in raw chicken fillets. Published data have shown a positive relationship between these measurements and the severity of the WB condition. Dalgaard et al. (2018) and Sun et al. (2018) found that there was a significant difference in CF between WB and normal fillets. With small muscle portions, Mudalal et al. (2015) and Soglia et al. (2017) also demonstrated that CF values of raw broiler breast meat with the WB condition were consistently greater than those of the normal meat. Chatterjee et al. (2016) reported that MORS force and energy of fillets with the WB condition were significantly greater than those of normal fillets regardless of the meat state. Similarly, using the BMORS method, Bowker and Zhuang (2019) observed greater shear values with increased severity of the WB condition in raw fillets.

A consistent correlation between the WB condition and instrumental texture measurements has been widely demonstrated. However, there is a lack of comparisons of commonly used instrumental texture methods for predicting the palpable evaluation of severity of the WB condition in raw chicken breast meat. Therefore, the objective of this study was to compare different instrumental texture measurements of raw meat for means separation between WB categories and for assessing the severity of the WB condition. In addition, the relationships between the different instrumental texture measurements were assessed. For each method, the effect of expressing the data in various forms was also explored.

MATERIALS AND METHODS

Sample (Broiler Breast Fillets) Preparation

A total of 181 breast fillets (pectoralis major) were collected from the deboning line of a commercial processing plant at approximately 3 h postmortem. The birds were slaughtered at 8- to 9-week-old. Fillets were placed in plastic bags on ice and transported to the US National Poultry Research Center (45 min) where they were trimmed to remove skin, connective tissue, and mucoid exudate. Fillets were weighed and scored on a 3-point scale (normal = 1.0; moderate = 2.0; severe = 3.0) in 0.5 score increments for in-between samples based on palpable hardness and rigidity (Chatterjee et al., 2016; Bowker et al. 2019). Fillets were also scored for white striping (**WS**) condition using a 3-point scale based on the prevalence and thickness of white striations on the ventral (skin-side) surface of the muscle (Kuttappan et al., 2012). Fillets were then individually packed and stored overnight at 4°C before instrumental measurements were collected.

Measurements of Raw Fillet Texture

Breast fillets were compressed using a 12-mm diameter probe with a 50-kg loading cell on a texture analyzer (model TA-XT-Plus; Texture Technologies Corp., Hamilton, MA). The trigger force was set at 20 g, and the test speed of the probe was 1 mm/s. For each fillet, 3 CF measurements were conducted on the middle portion of the ventral side of the muscle (Figure 1). Data for CF measurements were calculated based on either % of fillet height (30%) or distance (10 mm).

Blunt Meullenet-Owens Razor Shear and MORS were measured using a texture analyzer (Xiong et al., 2006; Lee et al., 2008; Morey and Owens, 2017). The distance between shears was at least 2 cm, and the test speed of the blade was 10 mm/s. The trigger force was set at 10 g. Fillets were sheared perpendicular to the fiber direction. For each fillet, 3 shear measurements of BMORS and MORS were conducted (Figure 1). Force (peak), total energy, and peak counts were derived from the shear curves using the default macro in Exponent (version 6.1, 7.0; Stable Micro Systems, Godalming, UK). For MORS measurements, the razor blade was changed every 100 shears.

Statistical Analysis

Fillet weight, WS scores, and texture measurements (CF, BMORS, and MORS) were analyzed using the PROC MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC). Significant differences ($P < 0.05$) between the WB groups were identified using the Tukey's means separation method. For each texture method, triplicate measurements within a fillet were averaged before analysis. The relationships between WB scores and texture measurements were analyzed by calculating Spearman correlation coefficients (r_s) using the PROC CORR procedure of SAS. Similarly, the relationships between the various instrumental texture measurements were analyzed by calculating Pearson correlation coefficients (r). For the purposes of discussion, the following descriptors were used to describe the relative strength of the correlations: very weak ($r < 0.20$), weak ($r = 0.20$–0.39), moderate ($r = 0.40$–

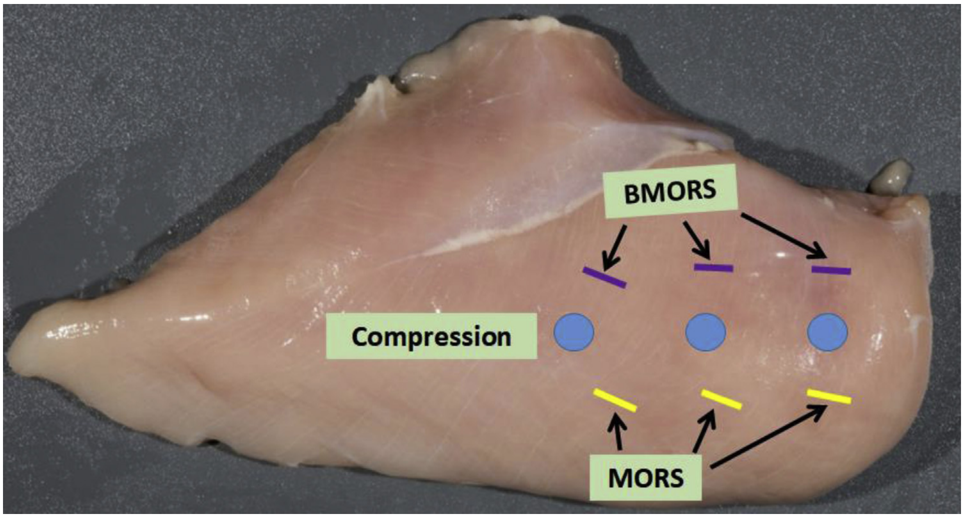

Figure 1. Diagram of locations where compression force, BMORS, and MORS were measured on broiler breast fillets. For each fillet, measurements with each instrumental method were performed at 3 different locations on the ventral side. Abbreviations: BMORS, blunt Meullenet-Owens Razor Shear; MORS, Meullenet-Owens Razor Shear.

0.59), strong ($r = 0.60$–0.79), and very strong ($r = 0.80$–0.99) (Bowker and Zhuang, 2019).

RESULTS AND DISCUSSIONS

Table 1 shows the average weight and WS scores of broiler breast fillets with different WB scores. Compared with the normal fillets (WB score = 1 or fillets without the WB condition), broiler breast fillets with the WB condition (WB score $\geq$ 2.0) showed significantly greater weight ($P < 0.05$). There were no significant differences ($P > 0.05$) in weight between WB scores 1.5, 2.0, and 2.5 or between WB scores 2.0, 2.5, and 3.0. Similarly, WS scores of breast fillets with the WB condition were also significantly greater than that of the normal fillet. There were no significant differences between WB scores 1.5, 2.0, and 3.0 or between WB scores 2.0, 2.5, and 3.0. Overall, average fillet weights and WS scores increased with increasing WB scores. Positive relationships between fillet weight and the WB condition and between WS severity and the WB condition have been previously reported. Kuttappan et al. (2017) found that WB scores increased as fillet weights increased regardless of the bird age. Chatterjee et al. (2016), Livingstone et al. (2019), Mudalal et al. (2015), and Sun et al. (2018) showed that the weights of normal fillets were consistently lower than those of fillets with the WB condition. Bowker et al. (2019) published data showing that increases in fillet weight were associated with increases in WB scores in broiler fillets and that there was a greater probability of observing WS in fillets with greater WB scores.

Descriptive statistics of subjective WB scores and instrumental texture measurements are shown in Table 2. For WB scores, the coefficient of variation (**CV**) was 32%. For the instrumental measurements, the most variation was observed for BMORS force with a CV of 56%. The least variable measurement was MORS force with a CV of 15%. For the compression method, CF measured as a % of fillet height had a higher CV (51%) than CF determined with distance (38%). For BMORS, the CV of force (56%), energy (54%), and peak counts (48%) were similar. For MORS, the force (15%) and energy (17%) had similar CV, which were lower than the peak count (35%). These results indicate that the fillet samples collected for this experiment exhibited a broad enough range of texture characteristics to allow for meaningful correlation analysis. Owing to the sharpness of the MORS blade, the MORS values primarily reflect muscle shearing forces, whereas BMORS values reflect both muscle compression and shearing forces owing to the bluntness of the blade. Thus, the lower CV observed with the MORS method compared with the BMORS method suggest that a texture methodology that focuses solely on raw shearing forces may not be as strong of an indicator for WB severity as a method that encompasses meat hardness and CF.

Means separations of instrumental texture measurements of broiler breast fillets based on WB severity

Table 1. Weight and white striping scores of broiler breast fillet samples by WB scores (means ± SD).

	WB score				
Characteristic	1.0	1.5	2.0	2.5	3.0
Weight (g)	375 ± 59^{c}	466 ± 73^{b}	491 ± 74^{a,b}	496 ± 68^{a,b}	516 ± 52^{a}
WS score	1.35 ± 0.37^{c}	1.75 ± 0.54^{b}	2.03 ± 0.57^{a,b}	2.15 ± 0.57^{a}	2.06 ± 0.51^{a,b}

$^{a–c}$Means within a row lacking a common superscript differ ($P < 0.05$).
Abbreviations: WB, woody breast; WS, white striping.

Table 2. Descriptive statistics for WB scores and instrumental texture measurements (compression, BMORS and MORS) of raw broiler breast fillets.

Method	Measurement[1]	N	Min	Max	Mean	SD	CV[2]
Palpable evaluation	WB score	181	1.00	3.00	2.01	0.65	32%
CF	30% % of fillet height (N)	180	4.61	56.78	22.46	11.57	51%
	10 mm distance (N)	177	4.12	21.87	10.89	4.12	38%
BMORS	Force (N)	181	6.78	74.06	26.11	14.49	56%
	Energy (N.mm)	181	61.50	553.80	206.21	111.68	54%
	Peak count	181	1.00	9.00	4.48	2.16	48%
MORS	Force (N)	181	4.36	9.37	6.34	0.97	15%
	Energy (N.mm)	181	39.00	98.10	61.64	10.58	17%
	Peak count	181	2.00	21.00	11.20	3.97	35%

[1]Abbrevaitions: BMORS, blunt Meullenet-Owens Razor Shear; CF, compression force; CV, coefficient of variation (CV = 100 × SD/Mean); MORS, Meullenet-Owens Razor Shear; WB, woody breast.

scores are shown in Table 3. There were significant differences in CF between WB scores 1, 2, and 3 regardless of data processing method and absolute values of WB scores 1.5 and 2.5 fell between 1 and 2 and between 2 and 3, respectively. There were no significant differences between WB scores 2.0 and 2.5 or between WB scores 1.0 and 1.5 when the force was expressed as a function of % height. There were no differences between WB 1.0 and 1.5, between 2.0 and 2.5, or between 2.5 and 3.0 based on peak force of compression distance. Overall CF measurements increased ($P < 0.0001$) with increases in WB severity. Fillets scored WB 3.0 had the greatest average CF values. The mean values of fillets scored 2.0 and 2.5 were less than scored fillets 3.0 but significantly higher than those of fillets scored 1.0 and 1.5. These results are consistent with other published data. Using a compression method similar to this study, Sun et al. (2018) found that CF were different among WB categories scored subjectively by tactile evaluation and that CF increased with the severity of the WB condition (normal < mild < severe). Using a different compression method, Dalgaard et al. (2018) also found that CF increased as WB severity increased in broiler breast meat. In addition, CF measurements also separated normal and WB fillets well when the measurements were performed using a texture profile analysis–like method (Mudalal et al., 2015; Soglia et al., 2016, 2017; Tasoniero et al., 2017).

Average BMORS values of the raw fillets (force and energy) scored 2.0, 2.5, and 3.0 were greater ($P < 0.0001$) than those of fillets scored 1.0 and 1.5. There were no significant differences among WB scores 2.0, 2.5, and 3.0 or between 1.0 and 1.5 regardless of measurement expression. Peak counts for BMORS measurements did not significantly vary between the 5 WB scores. The results in this study are consistent with published data showing significant differences in BMORS force and energy among normal, moderate WB, and severe WB fillets (Bowker and Zhuang, 2019).

Similar trends were also noted for MORS force, energy, and peak count measurements. Average MORS values from fillets scored 2.0 and higher were consistently greater than those of fillets scored 1.0 and 1.5; however, the means were not significantly different among fillets scored 2.0, 2.5, and 3.0 or between fillets scored 1.0 and 1.5. These results are consistent with the data published by Chatterjee et al. (2016) and Bowker and Zhuang (2019) with fresh, never-frozen broiler breast fillets. These data indicate that any of the 3 instrumental methods evaluated in the present study can separate normal fillets from those with moderate or severe WB in the raw state. However, the CF measurements provided the most distinct separation among the fillets, indicating that CF might be a more effective method for classifying the severity of the WB condition in raw broiler breast fillets. In fact, Mudalal et al. (2015) also concluded that measurements of CF could be used as a tool to discriminate WB fillets.

With cooked WB fillets, several published studies have also indicated that the results of texture measurements vary with the instrumental method, texture measurement parameters, and raw meat state. Chatterjee

Table 3. Instrumental texture measurements of raw broiler breast fillets by WB scores (mean ± SD).

Method	Measurement	WB score 1.0	1.5	2.0	2.5	3.0
CF	30% of fillet height (N)	9.71 ± 5.30[c]	15.20 ± 4.81[c]	28.83 ± 8.53[b]	27.85 ± 11.47[b]	33.93 ± 9.32[a]
	10 mm distance (N)	7.35 ± 2.35[c]	8.24 ± 2.55[c]	11.28 ± 3.73[b]	12.06 ± 4.12[a,b]	14.32 ± 3.53[a]
BMORS	Force (N)	14.73 ± 8.22[b]	16.76 ± 9.34[b]	29.15 ± 13.67[a]	31.97 ± 15.74[a]	34.37 ± 12.43[a]
	Energy (N.mm)	117.51 ± 54.86[b]	136.12 ± 74.39[b]	227.98 ± 104.04[a]	251.08 ± 122.30[a]	272.11 ± 100.15[a]
	Peak count	5.07 ± 2.26[a]	5.40 ± 1.90[a]	4.02 ± 2.35[a]	4.09 ± 1.91[a]	4.23 ± 1.91[a]
MORS	Force (N)	5.98 ± 1.05[b]	5.97 ± 0.95[b]	6.61 ± 0.86[a]	6.41 ± 1.05[a,b]	6.48 ± 0.84[a,b]
	Energy (N.mm)	51.87 ± 7.53[b]	55.79 ± 10.87[b]	65.35 ± 8.17[a]	64.68 ± 10.62[a]	66.71 ± 8.08[a]
	Peak count	7.70 ± 2.38[b]	9.13 ± 3.48[b]	12.19 ± 3.78[a]	12.79 ± 3.54[a]	13.10 ± 3.50[a]

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

Abbrevaitions: BMORS, blunt Meullenet-Owens Razor Shear; CF, compression force; MORS, Meullenet-Owens Razor Shear; WB, woody breast.

Table 4. Spearman correlation coefficients between subjective WB scores and instrumental texture measurements in raw broiler breast fillets.

Assessment parameter	CF % height	CF distance	BMORS force	BMORS energy	BMORS peak count	MORS force	MORS energy	MORS peak count
WB score	0.73***	0.58***	0.55***	0.56***	−0.18*	0.17*	0.47***	0.50***

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.
Abbrevaitions: BMORS, blunt Meullenet-Owens Razor Shear; CF, compression force; MORS, Meullenet-Owens Razor Shear; WB, woody breast.

et al. (2016) found that similar to the raw fillets, cooked WB fillets exhibited both greater MORS measurements (force and energy) and greater texture profile analysis hardness (or CF) than cooked normal fillets. Bowker and Zhuang (2019) reported that cooking had less impact on the ability of MORS parameters and BMORS peak counts (number of peaks) to distinguish between normal and WB fillets regardless of the raw meat state. However, in fresh fillets, cooked BMORS force and energy were similar between normal, moderate WB, and severe WB fillets. In frozen–thawed fillets, the cooked BMORS values were greater in severe WB compared with normal fillets. With Warner-Bratzler shear force method, Sanchez Brambila et al. (2018) reported that shear with cooked normal fillets was either greater than or similar to that with cooked WB fillets regardless of meat state. However, Mudalal et al. (2015) did not report any differences in Warner-Brastzler shear force between the normal fillets and the fillets with myopathies. Soglia et al. (2017) found no differences in CF values in the ventral portion of fillets between cooked normal and WB samples regardless of the CF setting.

Spearman's correlation coefficients between instrumental texture measurements and WB scores are shown in Table 4. Compression force measurements based on % of height showed the best correlation (r_s = 0.73, $P < 0.0001$). The correlation coefficient for CF measurements based on distance was 0.58 with $P < 0.0001$. For BMORS method, BMORS energy showed the best correlation ($r_s = 0.56$, $P < 0.0001$), followed by BMORS force ($r_s = 0.55$, $P < 0.0001$). Blunt Meullenet-Owens Razor Shear peak count had a weak negative correlation (r_s = −0.18), although it was still significant ($P = 0.015$), indicating that BMORS peak counts is a poor indicator of the WB condition in raw meat. For the MORS method, MORS peak count had the strongest correlation ($r_s = 0.50$, $P < 0.0001$), followed by MORS energy ($r_s = 0.47$, $P < 0.0001$). Meullenet-Owens Razor Shear force showed a significant but weak positive correlation with the WB score ($r_s = 0.17$, $P = 0.023$), indicating that MORS force measurements may not be useful for assessing the severity of the WB condition.

Except for BMORS peak count, significant positive correlations between instrumental texture measurements and WB scores suggest that the larger the measurement values, the more severe the WB condition or the greater the WB score. Among the measurements, the strongest correlations were observed between compression measurements and the WB scores (r_s = 0.58–0.73) regardless of measurement parameter, followed by BMORS measurements (r_s = 0.55–0.56). The weakest correlations were found between the WB scores and MORS measurements (r_s = 0.17–0.50). These results suggest that CF measurements are a better indicator of the severity of the WB condition in broiler breast meat. With the same technique (fillets were compressed to 20% of the fillet height), Sun et al. (2018) reported r_s = 0.79 correlation coefficient between CF values and the WB scores. Our results further demonstrate that CF measurements based on % of fillet height should be used for assessment of the subjective WB scores or as a reference for WB severity.

Because the results (both force and energy) from BMORS measurements are a combination of CF and shear force and those of MORS are primarily from muscle shear, it is of interest also to investigate the relationship between different instrumental measurements of texture properties of raw broiler breast meat with the WB condition. Therefore, in addition to examining the relationships between instrumental measurements and WB scores, the Pearson correlations among different instrumental measurements as well as their various forms were also analyzed (Table 5). As expected, there were very strong correlations (r > 0.8 and $P < 0.001$) between different data forms within the same measurement method. With regards to the relationships between the

Table 5. Pearson correlation coefficients between instrumental texture measurements in raw broiler breast fillets.

Texture parameter	CF distance	BMORS force	BMORS energy	BMORS peak count	MORS force	MORS energy	MORS peak count
CF % height	0.88***	0.57***	0.59***	−0.14	0.29***	0.56***	0.54***
CF distance		0.60***	0.62***	−0.17*	0.31***	0.56***	0.52***
BMORS force			0.99***	−0.37***	0.44***	0.66***	0.55***
BMORS energy				−0.35***	0.43***	0.66***	0.54***
BMORS peak count					−0.08	−0.22***	−0.32***
MORS force						0.83***	0.33***
MORS energy							0.61***

*$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$.
Abbrevaitions: BMORS, blunt Meullenet-Owens Razor Shear; CF, compression force; MORS, Meullenet-Owens Razor Shear.

different measurement methods, compression measurements (force based on % of fillet height and force based on distance) had similar moderate correlations to BMORS force and energy (r = 0.56–0.62) and MORS force, energy, and peak count (r = 0.56–0.60). Poor correlations were found between BMORS peak counts and CF or MORS force ($r < 0.20$). Moderate or strong correlations were observed between BMORS measurements (either force or energy) and MORS force (r = 0.43–0.44), peak count (r = 0.54–0.55), or energy (r = 0.66). Blunt Meullenet-Owens Razor Shear peak counts were significantly but weakly correlated with MORS energy ($r = -0.22$, $P < 0.0001$) and peak count ($r = -0.32$, $P < 0.0001$). These results indicate that in WB meat texture assessments, 3 instrumental measurements are not strongly correlated ($r < |0.07|$) or 3 instrumental methods evaluated in this study could not be used to predict each other well in WB texture analysis. The portion due to CF in BMORS measurements plays only a minor role, and the best correlation between BMORS and MORS is in the energy form. These results also indicate that the WB condition may affect both hardness and shear force of raw broiler breast meat and suggest that the 3 instrumental methods likely reflect the same texture properties in broiler breast meat with the WB condition to some degree. These conclusions can be demonstrated by findings in published data (Chatterjee et al., 2016; Bowker and Zhuang, 2019) and in this study that any of the 3 methods can be used to separate normal broiler fillets (with no WB condition) and the fillets with the severe WB condition.

CONCLUSIONS

Data from this study show that any of the 3 instrumental texture methods (compression, BMORS, and MORS) can be used to separate normal broiler breast fillets from breast meat with the severe WB condition in the raw state. However, among these 3 methods, the CF method can better differentiate between normal and moderate WB fillets and between moderate and severe WB fillets in the raw state. Except for BMORS peak count, there are significant and positive correlations between subjective WB scores and 3 instrumental measurements. The strongest correlations are found between CF measurements and the WB scores. These results indicate that instrumental texture measurements can potentially be used as references for assessments of the WB condition in raw broiler breast meat.

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