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(Research Article)

Development of a Hydraulic Based Meat Shear Force Testing Device and Prediction of Water Holding Capacity as an Indicator of Meat Quality

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Abstract

Meat quality is determined by tenderness and water holding capacity, which are important parameters in quality evaluation. This study aims to develop a meat shear force device to measure meat tenderness and to integrate a compression technique for predicting water-holding capacity (WHC) into a single device unit. The study employed an experimental method with a comparative device-testing approach, using chicken breast meat and beef thigh meat as test samples. Meat tenderness was measured using the Warner Bratzler Shear Force (WBS) as the reference instrument and a hydraulics-based Meat Shear Force (MSF) as the newly developed testing device. The observed variables included meat breaking force (tenderness) and wet area as indicators of water-holding capacity. The results showed that the breaking force values of chicken and beef measured using the MSF device were not statistically different ($P > 0.05$) from those obtained using the WBS device. In contrast, the wet area of beef measured using the hydraulic press method was significantly greater than that measured using the manual press method ($P < 0.05$). The shear force values of chicken meat measured using both the WBS and MSF methods were consistent, whereas for beef, the MSF tended to produce slightly higher shear force values with better precision than the WBS.

Keywords: Meat Tenderness; Meat Shear Force; Warner Bratzler Shear Force; Water-Holding Capacity; Wet Area

1. Introduction

Meat is an important commodity in the food industry with high nutritional value and serves as a major source of protein for humans. Meat quality is influenced by various factors, including tenderness and water-holding capacity. Meat tenderness reflects the texture of the meat and is one of the main indicators used to determine its quality. In contrast, water-holding capacity is an important parameter for predicting the ability of meat to retain moisture and flavor during processing or cooking. Meat commonly consumed and marketed in Indonesia includes beef, lamb, goat, pork, chicken, duck, fish, and other products [1]. Technological advances in the field of food science continue to develop to improve food quality and safety. In this context, the development of methods that can accurately measure meat tenderness and water-holding capacity is essential to support the management and improvement of meat product quality. [2] Reported that measurements obtained using a texturometer with a 1 mm blade thickness were not significantly different from those obtained using the Warner Bratzler shear force method. [3] evaluated beef tenderness using the Warner Bratzler method with two cross-sectional shapes, namely round and square. Longissimus dorsi samples with square cross-sections tended to exhibit higher shear force values than those with round cross-sections. [4] Conducted measurements on raw beef and beef heated to specific temperatures. The measurements were performed using the Warner Bratzler (WB) method. The tenderness values of raw meat tended to be lower than those of heated meat.

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Water-holding capacity (WHC) is a meat quality parameter that is closely associated with the presence of water in meat; therefore, it is directly related to overall meat quality. [5] Reported that water-holding capacity increases with increasing meat pH. This occurs because low pH values cause the meat structure to become more open, thereby reducing water-holding capacity, whereas high pH values result in a more compact structure, leading to increased water-holding capacity [6 , 7]. Although several techniques have been used to measure meat tenderness and water-holding capacity separately, challenges remain in integrating information from these two parameters to comprehensively predict meat quality. Therefore, this study aims to address this issue by integrating a Meat Shear Force device for measuring meat tenderness with a compression technique for predicting water holding capacity into a single device.

2. Materials and methods

2.1. Materials

Fresh beef thigh meat and chicken breast meat were used as samples to evaluate the meat shear force and water-holding capacity of the device. The samples were obtained from a licensed slaughterhouse (RPH).

2.2. Equipment

The equipment used included a Lakoni IGBT 450-W welding machine, a Bosch GSB550 drill with a 6-mm Nachi drill bit, a spin dynamo, an SMF capacitor, a Bosch G10SS angle grinder, and a Wipro 6-inch vise. Additional equipment consisted of a Wipro DS 500 vertical drill stand, M10×25 bolts, M10 pipe clamp bolts, a DLE-75 digital hanging scale, AA alkaline batteries, 5×3×3-mm angle iron, 3×25-mm steel strip, RD 260 welding electrodes, red and white gloss paint, a single-phase alternating-current dynamo (750 W, 220 V) with a maximum pressure of 700 bar (10,000 psi), an oil tank, oil pump, oil hose, actuator, blade, and load cell.

2.3. Research Procedure

The design and drawings were developed using AutoCAD in the form of three-dimensional models by integrating components such as an alternating-current dynamo, a hydraulic pressure kit, a table or plate serving as a meat sample holder, oil hoses, cutting blades, and load cells. This process aimed to determine the dimensions, components, and overall configuration of the device visually. The Warner–Bratzler shear force (WBS) apparatus was used as a reference instrument for performance comparison, while the Meat Shear Force (MSF) device developed in this study was evaluated. Additionally, a 35-kg weight and two flat glass plates were used as manual compression tools for comparison with the hydraulic pressure measurement method.

2.4. Experimental Design

The functionality and accuracy of the instruments were evaluated by comparing the results of meat sample measurements obtained using four types of instruments, namely the Warner Bratzler Shear Force (WBS) as a reference instrument for measuring meat shear force, the Meat Shear Force (MSF) device, and a 35 kg weight and glass plates were used to measure water holding capacity. Each measurement was performed 20 times.

2.5. Observed Variables

The variables observed in this study were meat shear force (tenderness) and water-holding capacity. Meat tenderness was measured using the Warner Bratzler Shear Force (WBS) method as a reference method and the hydraulics-based Meat Shear Force (MSF) method as a test method. Water holding capacity was determined using a compression method based on the wet area formed on filter paper, with manual pressure and hydraulic pressure used as comparative methods.

2.6. Data Analysis

The measurement data were analyzed using a paired *t*-test in Microsoft Excel.

3. Results and Discussion

Table 1 Results of shear force measurements of chicken and beef measured using the Warner–Bratzler Shear Force (WBS) and Meat Shear Force (MSF)

No.	Sample	Measured Values (kg/cm^2)	Mean (kg/cm^2)	Standard Deviation (kg/cm^2)
1	WBS	3.5, 2.1, 1.3, 1.1, 3.4, 1.0, 1.3, 3.1, 1.3, 2.2, 2.2, 1.7, 1.9, 2.6, 1.6, 2.5, 3.0, 3.6, 2.2, 2.5, 1.5	2.185	0.804
2	WBS	6.0, 5.0, 4.5, 8.0, 3.5, 7.3, 5.3, 6.4, 7.1, 8.0, 5.0, 6.5, 5.7, 7.7, 5.5, 7.0, 6.7, 7.7, 8.0, 7.1	6.350	1.272
3	MSF	1,3 3, 2.1, 1.3, 1.1, 3.4, 1.2, 1.3, 3.5, 1.3, 2.2, 1.6, 3.6, 2.6, 1.7, 2.5, 3.0, 1.9, 1.5, 2.5, 2.2	2.185	0.804
4	MSF	7.0, 6.0, 4.5, 8.0, 6.7, 7.3, 5.3, 6.4, 7.1, 7.0, 6.7, 6.5, 6.1, 7.7, 7.5, 7.0, 6.7, 7.7, 8.0, 7.8	6.895	0.929

Notes: Warner–Bratzler Shear Force (WBS): measurement using chicken meat samples; Warner–Bratzler Shear Force (WBS): measurement using beef samples; Meat Shear Force (MSF): measurement using chicken meat samples; Meat Shear Force (MSF): measurement using beef samples

The standard deviation value for beef was 1.272 kg/cm^2, whereas that for chicken was 0.804 kg/cm^2, indicating that the variability in tenderness among beef samples was greater than that among chicken samples. This result suggests that the differences in tenderness between individual beef samples within the test group were larger, while chicken meat exhibited more consistent tenderness across samples. The greater variability observed in beef may be attributed to factors such as the muscle portion sampled, the age of the livestock, or variations in post-mortem handling. [8] Reported that livestock age is an important factor influencing meat tenderness, whereby increasing age leads to changes in collagen properties that result in greater variation in tenderness. In addition, post-mortem handling factors, including the aging process and storage conditions, play a crucial role in determining the extent of muscle proteolysis, which ultimately affects meat tenderness [9].

Overall, the results of the WBS test quantitatively confirm the differences in tenderness between chicken and beef that are commonly recognized qualitatively. Chicken meat was shown to be more tender, with less variation in tenderness, compared with beef.

3.1. Similarity of Test Results Between the Warner–Bratzler Shear Force (WBS) and Meat Shear Force (MSF) Instruments

Testing of chicken meat shear force showed that the mean and standard deviation values obtained from the WBS and MSF measurements (2.185 kg/cm^2 and 0.804 kg/cm^2, respectively) were not significantly different ($P > 0.05$). This indicates that, for the chicken meat samples, both datasets produced identical tenderness characteristics. Both the WBS and MSF instruments yielded highly consistent results for the chicken meat tested, demonstrating excellent agreement and indicating similar performance of both instruments on these samples.

In beef sample testing, a noticeable difference was observed in the measurement data. The mean breaking force measured using the WBS was 6.350 kg/cm^2, whereas the MSF measurement showed a mean value of 6.850 kg/cm^2; however, this difference was not statistically significant ($P > 0.05$). The MSF device recorded a slightly higher mean breaking force for beef (approximately 0.5 kg/cm^2 higher) compared with the WBS device. This higher value suggests that, based on the MSF measurements, beef tended to be slightly tougher. Overall, the WBS and MSF methods produced identical results for chicken meat, indicating very high consistency, whereas for beef, the MSF device tended to yield slightly higher and more consistent breaking force values, as indicated by a lower standard deviation, compared with the WBS device.

This finding is consistent with the statement of [10], who reported that meat tenderness is inversely proportional to shear force, whereby lower Warner–Bratzler shear force values indicate more tender meat, whereas higher shear force values indicate a tougher meat texture. Meat with a breaking force value of < 4.15 kg/cm^2 is categorized as very tender; values of 4.15 to < 5.86 kg/cm^2 are considered tender; values of 5.86 to < 7.56 kg/cm^2 are categorized as moderately tender; values of 7.56 to < 9.27 kg/cm^2 are classified as somewhat tough; values of 9.27 to < 10.97 kg/cm^2 are classified as tough; and meat with a breaking force value of ≥ 10.97 kg/cm^2 is classified as very tough.

Table 2 Wet area values of chicken and beef measured using manual and hydraulic compression methods

No.	Meat Type	Compression Method	Measured Values (kg/cm^2)	Mean (kg/cm^2)	Standard Deviation (kg/cm^2)
1	Chicken	Manual	3, 4, 4, 1.75, 3, 5, 2.25, 1, 1.25, 2	2.725	1.309
2	Chicken	Hydraulic	1.25, 1, 1.5, 1.5, 2.25, 1.25, 2.25, 1.25, 2, 3.25	1.75	0.707
3	Beef	Manual	1.25, 1, 1.5, 1.5, 2.25, 1.25, 2.25, 1.25, 2, 3.25	1.75	0.687
4	Beef	Hidrolis	3.25, 3.75, 4.75, 5.25, 5.25, 4.75, 2.50, 2.00, 5.25, 2.75	3.975	1.284*

Notes: Values marked with an asterisk (*) indicate a statistically significant difference ($P < 0.05$).

The average wet area (WA) of chicken meat was lower when measured using hydraulic mechanical pressure (1.75 cm^2) than when measured using manual weights (2.725 cm^2). These results indicate that the more consistent and controlled pressure applied by the hydraulic press method causes less water to be released from the meat, resulting in more precise measurements. In contrast, manual pressure may vary and can produce a slightly larger wet area due to uneven or excessive pressure applied to some samples. Although both WA values still indicated negative free water (reflecting high water-binding capacity), the lower WA obtained using the hydraulic device demonstrates that the measurements were more accurate and consistent in reflecting high water-binding capacity in the meat.

The smaller standard deviation observed with hydraulic mechanical pressure (0.707 cm^2) indicates that wet area measurements were more consistent and exhibited lower variability than those obtained using manual weights (standard deviation of 1.309 cm^2). This finding confirms that the use of a hydraulic mechanical press provides better control over test conditions, resulting in more precise and reliable data. The greater variability associated with manual weights is likely attributable to inconsistencies in the application of pressure.

3.2. Effect of Compression Method on Consistency

Hydraulic mechanical pressure produced a lower mean wet area (WA) value (1.75 cm^2) and a smaller standard deviation (0.727 cm^2) in chicken meat sample testing, and the difference was not statistically significant ($P > 0.05$). This finding indicates that the compression method using a hydraulic device with a pressure of 35 kg provides more consistent and precise measurement results compared with manual weights. In contrast, manual pressure resulted in a slightly higher mean WA value (2.725 cm^2) and a larger standard deviation (1.309 cm^2).

For beef samples, the WA measured using the hydraulic method was significantly greater than that measured using the manual method and differed significantly on a statistical basis ($P < 0.05$). This result indicates greater variability in pressure application or result interpretation, which may potentially affect data reliability if not carefully controlled. The use of a 35-kg hydraulic press has been shown to provide more consistent wet area measurements. The observed standard deviation (1.284 cm^2) is more realistic and comparable to the variability that may occur in manual measurements. This finding is consistent with the report of [11], who stated that water content measurements based on meat compression using a 2 kg load produced water traces with wet area values ranging from 1 to 143 cm^2.

4. Conclusion

The shear force of chicken meat measured using the Warner–Bratzler Shear Force (WBS) and Meat Shear Force (MSF) instruments showed identical results, indicating very high measurement consistency between the two methods. In contrast, during beef shear force testing, the MSF device tended to produce slightly higher shear force values and demonstrated better precision, as indicated by a lower standard deviation, compared with the WBS device.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there are no financial or personal relationships that could be construed as a potential conflict of interest in relation to the content of this study.

Statement of ethical approval

This research did not involve the use of live animals. Meat samples were sourced from an officially licensed slaughterhouse and were handled in accordance with applicable institutional and national regulations. Consequently, ethical approval was not required for this study.

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