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Influence of Heat on Protein Degradation, Histology and Eating Quality Indicators of Chicken Meat

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ABSTRACT

The experiments were carried out during February–July, 2021 at the Department of Livestock Products Technology (Meat science), Veterinary College and Research Institute, Namakkal, Tamil Nadu Veterinary and Animal Sciences University, India to assess the influence of heat on protein degradation, histology and eating quality indicators of chicken. Meat samples were taken from the broiler breast and cooked for the targeted end point temperature (75°C, 83°C, 89°C and 94°C) then assessed pH, colour, cooking loss, shear force value, protein degradation (SDS PAGE) and structure of muscle fibers. The heating temperature had a significant effect on pH and shear force value (p<0.01) at 94°C. Colour L^* decreased significantly (p<0.01) and a^* and b^* value increased significantly (p<0.01) of cooked chicken breast at increasing end point cooking temperature. Progressive increasing (p<0.01) trends of cooking loss were noticed during the rising of end point cooking temperature. There were no significant differences between muscle fiber diameters. But significant (p<0.01) differences were observed in the sarcomere length of cooked chicken meat, showing decreasing trends during increasing temperature. Analysis of SDS-PAGE showed that the intensity of the myofibrillar protein band gradually decreased during chicken meat cooking at a higher endpoint temperature and inferring that the meat protein had changed. The heating temperature had a significant effect on sensory quality of cooked chicken breast at increasing end point cooking temperature. This study revealed that meat cooking at high-end point temperatures affects the meat quality by degradation of muscle proteins and changes in muscle structure.

KEYWORDS: Chicken meat, temperature, sensory quality, protein degradation, histology

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1. INTRODUCTION

Raw meats are cooked to make them palatable to potential consumers. It is well known that cooking is an essential process to achieve palatable and safe meat and meat products Tornberg (2005). According to Choi et al. (2016), boiling, grilling, panfrying, and microwave cooking methods are generally used for cooking meat. The choice of cooking methods depends on the composition and characteristics of the meat cuts and the effects of cooking time and temperature on the meat product (Lee et al., 2005). Grilling adds a peculiar flavour, aroma and smell to the meat, attributed to various complex reactions and many volatile compounds such as carbonyls, aldehydes, and Maillard intermediates (Arena et al., 2014). However, the cooking of meat also leads to a decrease in its nutritional value, mainly resulting from vitamin and mineral losses (Hosseini et al., 2014, Polidori et al., 2021, Karimian-Khosroshahi et al. (2015)). Since meat is subjected to a high temperature during grilling, it induces several modifications in muscle proteins, such as denaturation, carbonylation, disulfide bond formation, and cross-linking (Silva et al., 2016), which have the potential to affect the digestibility of muscle proteins. It is well documented that the final internal temperature has a great effect on ultimate palatability, as assessed by a combination of colour, tenderness, flavour, water-holding capacity and juiciness (Barbera and Tassone, 2006, Sen et al., 2016, Lorenzo et al., 2015, Kim et al., 2018). These changes are dependent on protein denaturation and water loss. Additionally, the quality characteristics of meat products are affected by the composition and characteristics of the muscle, cooking method, and cooking time and temperature. Further, the final temperature is considered to be important for structural changes such as transverse and longitudinal shrinkage of muscle fibers due to meat protein denaturation during the cooking process. Heat-induced alteration in the 3-dimensional structure of meat proteins has been shown to cause many of the quality changes in meat, including those of colour (Suman and Joseph, 2013), tenderness (Christensen and others, 2000) and gelation (Sun and Holley, 2011).

Dry heat causes thermal denaturation and chemical modification of the proteins in meat and leads to their aggregation (Traore et al., 2012). During the cooking of meat, the thermal denaturation of different muscle proteins such as myosin, sarcoplasmic protein, collagen, and actin occurs at different temperatures. Myosin and actin, which are the major components of myofibrillar protein, start to denature at ~40–60°C and ~80°C, respectively (Ishiwatari et al., 2013). SDS–PAGE gel band intensities of proteins band decreased, as the internal temperature of pork cooked at 60, 65, 70, and 100°C (Wen et al., 2015). It is widely accepted that shrinkage of sarcomeres due to the denaturation of myofibrillar proteins could cause an increase in toughness. Cooking at high temperatures for a long time led to the degradation of muscle proteins, causing the decreasing trend of texture and quality deterioration in Bighead carp (Jiang et al., 2017). Sous vide cooked chicken meat showed a marked increase in the denaturation of proteins at 100°C at 60 min and 120 min compared to 30 min (Naveena et al., 2017).

However, the majority of the reported researches were focused on a few changing traits of meat separately induced by heating and little work has been done on relationships among characteristics of eating quality and between eating quality and protein degradation and structure of muscle fibers. The objectives of this study were to evaluate the effect of heat treatment on pH, colour, cooking loss, shear force value, protein degradation and structure of muscle fibers in chicken breast muscle.

2. MATERIALS AND METHODS

The experiments were carried out at the Department of Livestock Products Technology (Meat science), Veterinary College and Research Institute, Namakkal, Tamil Nadu Veterinary and Animal Sciences University, India during February–July, 2021. Meat samples were taken from the broiler breast (approximately 200 g, each piece weight 10±12 g) cooked in a grilling oven (Model Bajaj Majesty 1603 TSS 16 L Oven Toaster Griller, Bajaj Electrical Ltd.) with different time and temperature combination. The cooking treatment started when the meat samples reached 75°C at their thermal center and the Changes in core temperature of each sample were monitored with digital thermometer and the required cooking times to reach the target core temperature. When the sample reached the targeted end point temperature (75°C, 83°C, 89°C and 94°C) were removed from the cooking device and held at room temperature for 5 min. Each sample was analysed for pH (Digital pH meter -Model 361, Systronics, India), colour (HunterLab-ColorFlex), cooking loss, shear force value (G. R. Electric manufacturing company, Model No.04347, Manhattan, U.S.A), Water holding capacity Wardlaw et al. (1973), Thiobarbituric acid reactive substance (TBARS) Witte et al. (1970) SDS-PAGE (Laemmli, 1970) and structure of muscle fibers (Sen and Sharma, 2004). Sensory evaluation of cooked breast meat was conducted by semitrained panellists at the Department of Livestock Products Technology (Meat Science), Veterinary College and Research Institute, Namakkal, Tamil Nadu-637 002 by using the eight-point hedonic scale. Panellists were instructed to cleanse their palates with water between analysis of samples. Then, mean data were subjected to suitable transformation for the temperature and analysed using Duncan significance test at five percent level of probability.

3. RESULTS AND DISCUSSION

3.1. pH

Means for the pH of cooked chicken breast at different end point cooking temperature are shown in Table 1. As internal temperatures increased, pH values increased consistently. Heating temperature had a significant effect on pH (p<0.01) at 94°C, Which is in agreement with previously reported results (Dal Bosco et al., 2001; Huang et al., 2011). The increase in pH for cooked meat is due to the reduction of free acidic groups as the meat temperature increases during heating (Lawrie, 2006). In contrast to current study, Sen et al., 2014 reported that after 65°C end point temperature on pH remains almost constant at 71°C and 79°C. However, Li et al., 2017 reported that the pH increased from 5.53–5.60 to 5.74–6.09 during increasing internal temperature.

3.2. Colour

Means for the colour L^*, a^* and b^* value of cooked chicken breast at different end point cooking temperature are shown in table 1.

Heating had a great impact on the colour of meat. As the core temperature increased from 75 to 94°C, values for L^* decreased (p<0.05), reaching a (59.76) at 94°C. Further above 89°C, L^* values decreased considerably. Huang et al. (2011) reported as the core temperature increased from 25 to 60°C, values for L^* increased (p<0.05), reaching a peak (77.89) at 60°C. Above 60°C, L^* values decreased slightly in pork. Choi et al. (2016) studied five different cooking methods (boiling, steaming, grilling, microwaving, and superheated steaming) on the L^* value of prepared marinated chicken steak and the values were 93.43, 90.90, 82.21, 91.38 and 95.15, and reported that the L^*-value was higher in superheated steam cooked chicken steak than that of the other cooking treatments such as boiling, steaming, grilling and microwaving cooking. With increasing temperature, a^* and b^* values increased significantly up to 94°C (p<0.05). These results are in line with those reported by Jeon et al. (2013), wherein lightness and redness values were lower for beef ribs subjected to grilling than those treated by boiling, pan frying, and steaming. The meat color was closely related to the degree of browning reaction that occurs during cooking. Christensen et al. (2011) studied the effect of sustained heat treatment from 48°C to 63°C on the color of Longissimus dorsi (LD) muscle of pigs. They reported that lightness (L^* values) increased with rising temperatures while increasing time did not impact L^* values and a^* values decreased in LD from sows (p<0.05) at 63°C. Sen et al., 2014 reported increasing b^* values during increasing end point temperature of mutton chops. Jeon et al. (2013) and Kim et al. (2001) observed that the color of meat products after cooking varies according to cooking method. Li et al., 2019 reported that L^* value decreased and a^* values increased significantly (p<0.05) as the prolonged microwave cooking time in yak meat.

Table 1: Mean±SE physico-chemical and histological quality of cooked chicken breast meat at different end point cooking temperatures

Parameters	T_1 (75°C)	T_2 (83°C)	T_3 (89°C)	T_4 (94°C)	Level sign
pH	6.01±0.04^a	6.06±0.05^a	6.09±0.04^a	6.21±0.02^b	**
L^*	71.76±0.01^d	69.02±0^c	66.75±0.01^b	59.76±0.01^a	**
a^*	4.2±0.00^a	5.73±0.00^b	6.47±0.01^c	7.53±0.00^d	**
b^*	21.96±0.01^a	22.05±0.01^b	25.55±0.01^c	29.94±0.01^d	**
Cooking loss %	24.75±0.27^a	31.5±0.73^b	34.08±0.21^c	36.63±0.41^d	**
Shear force value (kg)	3.87±0.04^a	4.04±0.09^a	4.16±0.17^a	6.03±0.21^b	**
Water holding capacity (per cent)	54.25±0.46^d	46.88±0.14^c	41.88±0.14^b	39.87±0.13^a	**
TBARS (mg malonaldehyde kg^{-1})	0.27±0.03^a	0.30±0.03^{ab}	0.35±0.02^{bc}	0.40±0.01^c	**
Muscle fiber diameter (µm)	44.25±1.23^b	41.17±2.31^a	39.07±1.99^a	37.64±2.28^a	NS
Sarcomere length (µm)	1.02±0.02^d	0.86±0.02^c	0.78±0.01^b	0.71±0.01^a	**

*: p< 0.05; **: p< 0.01; NS: Not significant

3.3. Cooking loss

Means for the cooking loss of cooked chicken breast at the different end point cooking temperature are shown in table 1. The final core temperature of the meat had a significant effect on CL (p<0.01), which increased significantly with increasing core temperature and reached approximately 36.63% at 94°C. This study concurrence with the results of Huang et al. (2011) reported at 100°C 41.37% cooking loss of pork muscle fibers. Moreover, Sen et al. (2014) reported the same trends in mutton chops. Further, Chumngoen et al. (2016) studied the influences of end-point heating temperature (50, 60, 70, 80, 90 and 95°C) on the quality attributes of chicken meat. In that study, cooking losses increased with increasing temperature and were considerable at temperatures exceeding 80°C. Li et al. (2018) reported higher cooked internal temperature resulted in higher cooking losses due to the prolonged cooking time, causing extra moisture loss via evaporation and the release of excess juice inside the meat samples. The chicken breast meat was separately placed in commercial plastic oven bags and tied, cooked in an electric oven at 200°C for 20 min. Also, the observed cooking loss was 24.09% in cooked meat (Taskiran et al., 2019). Li et al., 2019 reported that cooking loss increased significantly (p<0.05) as the prolonged microwave cooking time in yak meat.

3.4. *Shear force value*

Means for the Shear force value of cooked chicken breast at different end point cooking temperature are shown in table 1. The final internal temperature of the meat also had a large impact on shear force value. As the core temperature increased, shear force value of meat increased significantly (p<0.05). Garcia-Segovia et al. (2007) observed toughness increases with cooking from 60 to 80°C, in beef muscle (M. pectoralis). Huang et al. (2011) reported the same trends in pork. Choi et al. (2016) noted the lowest hardness value for samples subjected to superheated steam cooking as compared with those cooked by other methods; the highest hardness value was reported for boiled and grilled samples. At a heating temperature of above 60°C, a combined effect of the denaturation of myofibrillar proteins, shrinkage of intramuscular collagen and shrinkage and dehydration of actomyosin probably increased meat toughness (Wattanachant et al., 2005; Li et al., 2013). Chumngoen et al. (2016) results agreed with this study with steady but less progressive increases occurred in the shear force values between 70 and 90°C.

3.5. *Water holding capacity (per cent)*

Water holding capacity progressively decreased with a parallel increase of cooking temperature. Lonergan (2005), during heating, the meat proteins denature, the cellular structures are disrupted, which leads to the release of water and decreases the WHC of meat and the mechanism of WHC relies on the proteins and structures that bind and entrap water among them. Lorenzo et al. (2015) reported the roasting, grilling, microwave baking, and frying on the WHC of foal meat were about 39, 40, 30.9 and 30 percentage and opined that the microwave and grilled treatment caused different degrees of actin denaturation due to the different heating rates and thus, the different extent of protein aggregation and cross-links may have led to different amounts of water expulsion by myofibril. Further, Angel-Rendon et al. (2020) reported that the WHC of pork meat is more dependent on the final temperature reached by the meat than on the cooking method used.

3.6. *TBARS values*

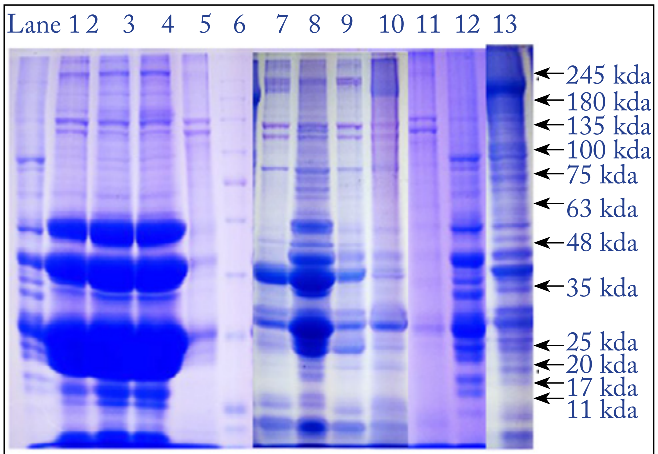
Measures of TBARS values were used to assess the degree of lipid oxidation. Lipid oxidation can cause rancidity and warmed-over flavour (WOF) in meat products. However, moderate lipid oxidation during the initial cooking of meat contributes to desirable aromas (Song et al., 2011). In the present study, the results of the TBARS value of cooked chicken breast meat samples noticed a significant variation among the different end point cooking temperatures. The corresponding increase in cooking temperature and duration was found to have a progressive increase in the TBARS values of cooked meat samples. The present findings agree with the Gok et al. (2019) reported that increasing trends of the TBARS value of beef meat cooked by sous vide and convection oven method with various cooking times. Further, the current TBARS values are within the prescribed limits (0.09) by Egyptian Organization for Standardization (Hassanin et al., 2017).

3.7. *Muscle fiber diameter and sarcomere length*

Means for the muscle fiber diameter and sarcomere length of cooked chicken breast at different end point cooking temperature are shown in table 1. The core temperature increased changes in the structure of muscle fibers and sarcomere length occurred progressively. A significant difference was noticed in muscle fiber diameter of 75°C and other endpoint temperature. There were significant (p<0.01) decreasing trends of sarcomere length observed in all endpoint temperature. Increasing holding time has a relatively has a smaller effect than increased temperature on diameter changes and thus in pork longissimus heated at 53, 55, 57 or 59°C, there were no clear differences in fibre diameter as cooking time was increased from 3 to 20 hrs (Christensen et al., 2011). Kong et al. (2010) concluded that the significant decrease in sarcomere length were obtained for both salmon and chicken muscle during high temperature thermal processing, with salmon muscle exhibiting more shrinkage parallel to the muscle fiber than chicken. Moreover, Huang et al. (2010) revealed that the visual appearance of the muscle fibre structure changed significantly on heating, with sarcomeres contracting transversely and longitudinally and becoming condensed, but there was no occurrence of breakage within fibres. Palka and Daun (1999) reported vacuum-packed slices of bovine semitendinosus (ST) muscle were retorted to internal temperatures of 50, 60, 70, 80, 90, 100 and 121°C. The sarcomere length decreased continuously in the range 50-121°C and also Supaphon et al. (2021) reported the shrinkage of muscle fiber in sousvide cooked muscle.

3.8. Protein degradation

The SDS-PAGE electrophoresis analysis on chicken breast meat with the different heating intensities was conducted to estimate the changes in the protein composition. Figure 1 show the SDS-PAGE electrophoretic analysis under different end point temperature 75°C, 83°C, 89°C, and 94°C, respectively.



Lane 1 Raw meatwsp, Lane 2: TIWSP; Lane 3: T2WSP; Lane 4: T3WSP; Lane 5: T4WSP; Lane 6: Marker; Lane 7: TISSP; Lane 8: T2SSP; Lane 9: T3SSP; Lane 10: T4SSP; Lane 11: Raw meatwsp; Lane 12: Raw meatwsp; Lane 13: Raw meatwSSP; WSP: water soluble protein; SSP: salt soluble

Figure 1: SDS-PAGE of cooked chicken breast at different end point cooking temperature.

Significantly changes in chicken breast meat protein composition were observed along with increasing heating temperature. Slightly more intense sarcoplasmic protein bands were observed as a result of cooking temperature up to 89°C compared raw meat. Many protein bands were gradually thinner and lighter or even disappeared in myofibrillar proteins. It is noteworthy that the in cooked meat proteins bands below 63 kDa were more prominent in the both WSP and SSP samples compared to its corresponding WSP and SSP samples from raw meat. Depending on the cooking method, heat treatment alters the structure of muscle proteins due to the aggregation and coagulation in most of the sarcoplasmic proteins, protein-protein interactions of myofibrillar proteins with applied temperature, and gelation of collagen (Bircan and Barringer, 2002), which greatly affects quality properties of product (Deb-Choudhury et al., 2014). Murphy and Marks (2000) also reported same results in chicken meat patties. As the duration of cooking increased there was a drastic reduction in the quantity of protein bands in the area below 75 kDa. Intensity of certain bands lower molecular Mw increase and some new bands in low Mw area emerged. This study agreement with the results of Huang et al. (2011) studied heat on protein degradation of pork muscle fibers.

Previous studies have found that long-term heating would lead to protein denaturation, producing lower molecular weight component and thereby affecting solubility (Zhang et al., 2013). However, observed the trend of water-soluble protein in muscle was increasing. The protein content at 90°C and 100°C took a slight upward trend, while the content increased faster and then showed a relatively flat trend under 110°C and 120°C treatment. At higher heating temperatures, a greater amount of soluble protein was observed over time, reaching about 5%, much higher than the 1–2% level at the beginning of the heating period. This reflected the protein degradation and the release of low-molecular-weight compounds. Li et al., 2019 reported that the protein band disappeared in boiled yak meat. Taskiran et al. (2019) reported that the intensity of myofibrillar protein bands in the Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS-PAGE) decreased after cooking by both microwave oven (MWO) and electric oven (EO), whereas EO cooked samples demonstrated more fragmentation in both sarcoplasmic and myofibrillar proteins in comparison with MWO cooked chicken meats.

3.9. *Sensory quality*

Means for the Sensory quality of cooked chicken breast at different end point cooking temperature are shown in Table 2. There was significant difference between sensory qualities of cooked chicken breast meat at different end point cooking temperatures. Chicken head and tail fillets were grilled on a char-broiler until the inside temperature reached 73°C and the appearance scores recorded were 7.18 and 6.53 on a nine-point hedonic scale was reported by Cho et al. (2016). Dominguez-Hernandez et al. (2018) reported that the heat treatment of meat at temperatures between 50°C and 65°C, for extended periods, has increased tenderness and better appearance than when cooked at higher temperatures and is a consequence of the complex interplay between heat-induced protein denaturation and proteolysis of connective tissue and, possibly, myofibrillar structures. Interestingly, Park et al. (2020) reported the juiciness score for *sous vide* cooked chicken breast meat and the meat samples at 60°C for 1, 2 and 3 hrs had been 6.62, 5.70, 5.18 and the samples cooked at 70°C for 1, 2 and 3 hrs were 5.11, 4.25 and 3.57, respectively. The undesirable changes that occurred at internal temperatures above 80°C, *i.e.* increase in cooking losses, the meat becoming less juicy and decrease in palatability traits scores, have been associated with excessive loss of the meat fat content, soluble nutrients and dehydration was also reported by Bowers et al. (1987).

Table 2: Mean±SE Sensory quality of cooked chicken breast meat at different end point cooking temperatures

Parameters	T_1 (75°C)	T_2 (83°C)	T_3 (89°C)	T_4 (94°C)	Level .sign
Appearance	6.67±0.21[a]	7.00±0.00[a]	7.17±0.11[a]	6.67±0.21[a]	NS
Flavour	6.17±0.38[a]	6.67±0.2[ab]	7.33±0.21[b]	6.75±0.17[ab]	**
Juiciness	7.00±0.00[c]	6.50±0.18[b]	6.33±0.11[b]	5.07±0.09[a]	**
Tenderness	7.50±0.18[c]	6.83±0.28[b]	6.75±0.09[b]	5.89±0.20[a]	**
Overall Acceptability	6.96±0.03[bc]	7.17±0.28[c]	6.50±0.18[ab]	6.17±0.11[a]	**

*: $p< 0.05$; **: $p< 0.01$; NS: Not significant

4. CONCLUSION

The heating temperature has a significant effect on physico-chemical, muscle proteins degradation, histology studies and sensory quality. Analysis of SDS-PAGE showed that the intensity of the myofibrillar protein band gradually decreased during chicken meat cooking at a higher endpoint temperature and inferring that the meat protein had changed. This study revealed that meat cooking at high-end point temperatures affects the meat quality by degradation of muscle proteins and changes in muscle structure.

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