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Effect of Cooking on Physicochemical and Microstructural Properties of Chicken Breast Meat

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effect of cooking on pH, juiciness, instrumental colour and microstructural properties of chicken breast meat was investigated. Industrial skinless chicken breast meat samples were purchased, frozen and sliced into dimensions , thawed and cooked by air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR) at 170, 180 and 190^{0}C for 0, 4, 8, 12 and 16 min. The pH value of the cooked samples increased from 6.05 to 6.25. Cooking methods, temperatures and times each resulted to increase in pH. The results of objective sensory instrumental analyses showed that cooking decreased significantly ($p < 0.05$) juiciness of cooked chicken breast meat. Samples cooked by BK had the highest juiciness value of 24.91%, while DF cooked samples had the least value of 13.89%.The instrumental analyses increased L*, a*, b* values and browning index. The temperature and time of cooking showed similar effects on juiciness and instrumental colour. Short cooking time (8 min) and 170^{0}C resulted in higher juiciness and best appetizing appearance to the consumers. The microstructure studies showed that raw chicken breast meat had an intact muscle fibres and bundles, but cooking caused disintegration of muscle fibres, perimysial – collagen shrinkage and it resulted to drier samples with big cracks/ voids and big surface damages, particularly in AF, BK and GR cooked products at 190^{0}C for 8 min.

Keywords: pH; juiciness; instrumental colour; microstructure; cooking method.

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1. INTRODUCTION

Meat is a nutrient- rich commodity, which is subjected to heat to improve its texture, make it edible and hygienic [1]. It has also been reported by Lawrie and Ledward [2] to be flesh of animal suitable for use as food. It is composed of muscle fibres, which are organised into bundles held together with connective tissues with sprinkling deposits of fat as well as water held in the myofibrils, in the space between the thick filament (myosin) and thin filaments (actin) and some water located in the connective tissue. Chicken meat is an excellent supplier of high quality proteins which are needed for proper neurological development as reported by Alugwu et al. [3]. It is also liable to lipid oxidation and thereby the development of flavours, due to higher unsaturated fatty acids in its composition. It is also natural food, but tough and undesirable in its raw state. However, cooking results in meat structural modification and nutritional deteriorative changes [4]. It has been reported by Hassanin et al. [5] that meat with a pH below 5.8 had pale colour, while meat with higher pH had darker colour and it has a great health risk. The ideal pH of meat is between 5.8 and 6.3 as reported by Pearson and Gillette [6]. The decrease in meat pH could be attributed to breakdown of glycogen with the formation of lactic acid and increase in meat pH could be due to partial proteolysis leading to increase of free alkaline groups depending on the conditions of such change. The water binding nature of proteins and physical structure are affected by meat pH. Meat proteins have been reported by Lynch and Young [7] and Murphy and Marks [8] to undergo oxidation at extremes of pH. Muscles become stiff few hours after stoppage of blood circulation, but become tender by postmortem conditioning or aging process by endogenous enzymes or natural enzymes proteolytic such as cathepsins as well as proteases which act on muscle proteins [9].

Heat energy generated during meat cooking results in denaturation and coagulation of proteins, thereby reducing the space of myofibrils and finally forming texture of the product [10]. It has also been reported by Yarmand et al. [11] to cause structural changes such as the destruction of cell membranes, shrinkage of meat fibers, aggregation and gel formation of myofibrillar and sarcoplasmic proteins and shrinkage and solubilisation of the connective tissue and muscle fiber breakage in cooked meat. Myoglobin is responsible for the primary colour of meat, but there are other colouring categories such as deoxymyoglobin, oxymyoglobin, metmyoglobin and etc., which contribute to colour changes during the cooking of meat.

During frying the surface water in the substrate changes into steam, dehydrates and diffuses into the frying oil and frying oil diffuses into the food. The amount of oil absorbed in the substrate depends on frying time, meat surface area, meat moisture content, meat size and frying oil temperature [12]. The absorbed oil caused an increased pressure, structural, textural and chemical changes in the product [13,14], thermal decomposition of nutrients, interaction between frying food components and oxidation products of frying oil [15].The changes in meat processed by heat can be assessed by electron microscope which has been reported by Mir et al. [16] in revealing the details of the structural changes of muscles subjected to different treatments. It also offers direct view of how meat structure changes when cooked at different temperatures. There is no much literature information on the physicochemical and microstructure changes on cooking methods of chicken breast whose consumption has greatly increased among individuals as well as in further processing of other meat products. Hence, the aim of this study was to ascertain the effect of air frying (AF), baking (BK), deep-fat frying (DF) and grilling (GR) methods on pH, juiciness, instrumental colour and microstructural properties as indices of chicken breast meat quality characteristics.

2. MATERIALS AND METHODS

2.1 Sample Preparation and Cooking Process of Chicken Breast Meat

Nine packs of skinless, boned chicken breast (pectoralis major) muscles were randomly selected from (a local grocery store) in St. Anne – de -Bellevue, Montreal, Canada. These were transported to the Food and Bioprocess Laboratory of the Dept. of Bioresource Engineering, Macdonald Campus of McGill University within 30 min under cooled conditions. In the Laboratory, samples were frozen at -80^{o}C for 2 h to harden the muscle for easy slicing into 3.0 x 3.0 x 2.0 cm. Thereafter, the cut samples were divided into four cooking methods (air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR)). Each portion of the cooking method was further subdivided into three different cooking temperature regimes (170, 180 and 190^{o}C) and each temperature portion was

subdivided further into five different time intervals (0, 4, 8, 12 and 16 min). Samples were then weighed before cooking. Samples for deep fat frying were cooked with four (4) litres of canola oil, which was previously preheated for 170°C for 2 h before its application. Thereafter, each sample was allowed to cool for 30 min at room temperature. Subsequently each sample was subjected to juiciness, pH and colour determinations and stored in refrigerator for microstructural studies.

2.2 Cooking Methods of Chicken Breast Meat

The four cooking methods evaluated in the study were air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR). The cooking conditions used were temperature (170, 180 and 190°C) and time (0, 4, 8, 12 and 16 min). Fifty grams of broiler chicken breast meats measuring 3.0 x 3.0 x 2.0 cm were employed for each cooking experiment. The uncooked breast meat was used as the control sample. Samples for air frying was carried out with Philips Air fryer (Model HD 9225), baking and grilling were done using a Black and Decker digital 4-in-1 oven (SKU: TO1303SU/ FABRICADO EN/ CHINA) and Deep fat frying was conducted with Delonghi (Type: D24527 DZ, Made in China) equipment. All samples after cooking were allowed to cool for 30 min at room temperature, before analyses, wrapped in aluminum foil and packaged in Ziploc bag. The cooked and uncooked samples were kept in freezer awaiting subsequent analysis. All the cooking experiments were performed in duplicates.

2.3 Determination of pH Values of the Samples

The pH value of the samples was determined according to standard methods of AOAC [17] using pH meter 7060 (Kent Electronics). The ground samples (3 g) was homogenized with 30 mL of distilled water in a 250 mL beaker and the pH value taken with universal (Calomel reference) electrode after allowing 1- 2 min for stabilization. The pH meter was first standardized using pH 9 and pH 4 buffer solutions before determining the samples.

2.4 Determination of Juiciness

The juiciness of the samples was measured using pressing method by Texture Profile Analyzer (TPA-Stable Microsystems Texture Technologies Corp) as described by Gujral et al. [18]. One-millimeter cubed pieces were cut from the center of the raw, air fried, baked, deep-fat fried and grilled samples. Two grams of the diced samples (W_1) was placed between a pair of previously weighed filter papers (Whatman No.40) (W_2) and all enclosed in aluminum foil. The foil was placed on the instrument's sample platform and subjected to a force of 250 N. The probe employed was the 5 cm cylinder probe on a 25 kg load cell and holding time of 1 min. Thereafter, the aluminum foil and the filter papers were removed from instrument, the filter papers and their content weighed. Subsequently, the sample was removed and the filter papers on which the extracted juice adhered was weighed again (W_3). The percent juiciness was determined using the expression shown in equation 1.

$$\text{Juiciness } (\%) = \frac{W3-W2}{W1} \text{ X } 100 \qquad \text{Eqn. 1}$$

Where:

w_1 =weight of sample
w_2 = weight of filter paper
w_3 = weight of filter paper with juice

2.5 Colour Properties Measurement

The colour values of the samples (control and cooked) were evaluated with Colorimeter (Minolta Chroma CM -3500d) with a D 65 light source and an observation angle of 10^0 . Prior to utilization, the colorimeter was standardized using a black and white coloured calibration tiles. The colour changes of the samples were identified using the CIE (Commission International Éclair age) system. Each of the sample was directly placed on the instrument and reading was performed at the surface of the samples, for parameters L* (lightness), a* (redness) and b* (yellowness) and recorded. The colour of the samples was measured at four different locations on the surface from each sample and an average obtained for each sample. Additionally, browning index (BI) was evaluated using Equations (2) to (4).

$$\Delta E = [(L_o - L_1)^2 + (a_o - a_1)^2 + (b_o - b_1)^2]^{0.5} \qquad \text{Eqn.2}$$

$$\text{Browning Index (BI)} = \frac{[100\,(x-0.31)]}{0.17} \qquad \text{Eqn.3}$$

Where

$$X = \frac{(at+1.75\,Lt)}{(5.645Lt+at-3.012\,bt)} \qquad \text{Eqn. 4}$$

Lt, a_t and b_t are values at cooking time Lt

2.6 Microstructure Observation

The microstructure of the samples was determined using a scanning electron microscope (SEM) as described by Wattanachant et al. [19] with slight modification. Samples were examined using a low vacuum scanning electron microscope (mini SEM Hitachi 370) with a constant voltage of 15 kV. The samples were prepared by freeze drying to preserve the structural identity at -50 ^{o}C for 48 h in a (Thermos Vacuum Freezer). Thereafter, the samples ground into flour. The powdered samples were placed on the sticker stamped on an aluminum stub, unstick samples were discarded. The stacked samples on aluminum stub were inserted in the SEM machine. The machine was adjusted to proper directions for turning and locating the samples. Thereafter, put on the vacuum to build the machine pressure for actions. The air frying (AF), baking (BK), deep fat frying (DF), grilling (GR) and uncooked samples were examined and photographed using a transmission electron microscope (Hitachi LTD, Tokyo, Japan).The microphotographs and video prints were captured at a magnification of 3000x for longitudinal section. The video prints were used to visualize the qualitative difference between samples.

2.7 Statistical Analysis

The research study was a 4 x 3 x 5 factorial experiment as described by Obi [20] in completely randomized design (CRD). All experiments were performed in duplicate. The results are expressed as mean ± standard deviations and analysed using the General linear model procedures of IBM Statistical Package of Social Sciences [21] version 23. 0. Data subjected to two- way analysis of variance (ANOVA) and mean comparison was performed ($p < 0.05$) using Duncan's New Multiple Range Test (DNMRT).

3. RESULTS AND DISCUSSION

3.1 Changes in pH of Chicken Breast Meat

The pH results of chicken breast meat cooked with different methods each at 170, 180 and 190^{0}C for 0, 8 and 16 min are shown in Table 1. The pH value of raw chicken breast meat sample was 6.05. This showed that raw meat belongs to low acid food. This value was lower compared with the previous pH value of 6.87 reported by Ergonul [22]. Cooking increased significantly ($p < 0.05$) pH value of chicken breast meat samples. On average, the pH rose to 6.25 after cooking. This finding agrees with findings of Menon et al. [23], Oz and Zikirov et al. [24] and Ergonul who reported significant increases in pH value with increasing cooking temperature and time. The increased in pH value of cooked chicken breast meat could be attributed to cleavage of bonds relating to sulphuryl and hydroxyl as reported by Girard [25]. However, Medynski et al. [26] reported the increases of pH of cooked meat was probably caused by the reduced amount of available carboxylic group of proteins and also by the liberation of calcium and magnesium ion proteins.

Cooking methods significantly ($p < 0.05$) affected pH values of chicken breast meat. Table 1 showed that air frying (AF) cooked samples had mean pH value of 6.26, samples cooked by baking (BK) had 6.18, deep fat frying (DF) had 6.31and grilling(GR) cooked samples had mean pH value of 6.26. These values of meat products were still in low acid range. The table showed that BK cooked samples had significantly ($p < 0.05$) lower pH values than other cooking methods. There were no significant ($p > 0.05$) differences between AF, DF and GR cooking methods. The lower pH value of BK cooked chicken breast meat could be attributed to less cleavage of bonds of sulphuryl and hydroxyl bonds of the proteins.

The results of mean pH values for cooking temperatures showed that samples cooked at 170^{0}C gave mean pH value of 6.28, at 180^{0}C, mean pH value of 6.23 and at 190^{0}C, mean pH value of 6.25. There were no significant ($p > 0.05$) differences in pH between cooking temperatures. However, interaction between cooking methods and cooking temperatures was significant ($p < 0.05$) showing that the differences in pH caused by the cooking methods were significantly ($p < 0.05$) different at different temperatures. The mean pH values for the cooking times were 6.05, 6.30 and 6.40, respectively for 0, 8 and 16 min. The raw sample had significantly ($p < 0.05$) lower pH (6.05) compared to samples cooked for 8 min (6.30) and 16 min (6.40). The interaction between cooking methods and cooking times was found to be significant ($p < 0.05$), suggesting that the differences in pH caused by different cooking methods were not the same at different cooking times. The results of interaction between cooking temperatures and cooking times were not found

to be significant ($p > 0.05$) and overall interaction (cooking methods x temperatures x times) was also not significant ($p > 0.05$).

3.2 Changes in Juiciness of Chicken Breast Meat

The juiciness content of chicken breast meat cooked at different methods each at 170, 180 and 190 ^{0}C for 0, 4, 8, 12 and 16 min are shown in Table 2. Table 2 showed that cooking method significantly ($p < 0.05$) reduced juiciness value of chicken breast meat to 20.17%. Samples cooked by air frying (AF) had an average juiciness value of 17.74%, baking (BK) cooked had an average of 24.91%, deep fat frying (DF) had 13.89% and grilling (GR) had mean juiciness value of 24.15%. The differences in juiciness due to cooking methods were significant ($p < 0.05$) and BK cooked samples had significantly ($p <0.05$) higher juiciness than others. The higher juiciness of BK cooked samples could be attributed to mild heat effect of BK method on moisture evaporation and melting of fat from the samples. Whereas the lower juiciness value of DF cooked samples could be attributed to its highest moisture loss of 49.47%, which could be attributed to dehydration effects of heated cooking oil. The findings of research concur with reported findings of Pathare and Roskilly [27]. These variations of percentage juiciness with cooking methods were statistically significant ($P < 0.05$). This finding also confirmed an earlier reported statement by Hung and Carpenter [28] who stated that increase in moisture level increases juiciness in frankfurters. It also agrees with reported findings by Hernandez et al. [29] who stated that moisture loss, which occurred by evaporation in dry cooking and exudation and diffusion in moist heat cooking has an influence on juiciness. The quantity of water squeezed and retained in meat prior and after cooking affect the juiciness, palatability and selling weight. Moreover, water has been reported by Huff-Lonergan and Lonergan [30] to exist in three forms in muscle such as water bound to proteins, water entrapped or held by steric effects or attracted to bound water and free water. It is free water that is most affected by cooking. Cooking temperature significantly ($p < 0.05$) affected juiciness of cooked chicken breast meat. Samples cooked at 170^{0}C gave average juiciness value of 22.33%, at 180^{0}C average juiciness value was 19.71% and at 190^{0}C, average juiciness value was 18.47%. Thus, juiciness value significantly ($p < 0.05$) reduced with increase in cooking temperature. This findings agree with general statement that juiciness decreased with increasing cooking temperatures. The differences in juiciness caused by cooking temperatures were significant ($p< 0.05$). Heat emanating from the cooking induced stripping action of juiciness from the substrates into the cooking medium. The reduction of juiciness with increasing temperature could be attributed to thermal reduction. The results agreed with similar result conducted by Aaslyng et al. [31] and Bejerholm and Aaslyng [32].

Cooking time affected juiciness of chicken breast meat. Samples cooked at 4, 8, 12 and 16 min had average juiciness of 19.99%, 16.15%, 13.67%, and 9.39%, respectively. Thus juiciness significantly ($p < 0.05$) reduced as cooking time increased. The differences are attributed to long time exposition of the products in the cooking medium. The interaction between the cooking methods and cooking times are significant ($p < 0.05$). This suggests that the juiciness due to the cooking methods were different at different cooking times. The results showed that the interaction between cooking temperatures and cooking times was significant ($p < 0.05$). This suggests that the differences in juiciness values between 170 and 180^{0}C (170 – 180^{0}C), 170 and 190^{0}C (170 – 190^{0}C) and 180 and 190^{0}C (180 – 190^{0}C) were decreasing with increased in cooking times. However, the overall interaction (Method x Temperature x Time) was found to be significant. This significant ($p < 0.05$) overall interaction confirmed why the products deep fat fried (DF) at 190^{0}C and 16 min had the least juiciness value (4.95%), while the products obtained by baking (BK) at 170^{0}C for 4 min had the highest juiciness value (32.75%).

3.3 Changes in Instrumental Colour of Chicken Breast Meat

3.3.1 Changes in L* value of chicken breast meat

The results of colour values of lightness (L*), redness (a*) and yellowness (b*) as well as browning index (BI) of chicken breast meat cooked at different methods each at 170, 180 and 190^{0}C for 0, 4, 8, 12 and 16 min are shown in Tables 3,4,5 and 6, respectively. The results in Table 3 showed that cooking increased L* values of cooked chicken breast meat. On the average, L* value of chicken breast meat increased to an overall mean of 58.78. Cooking methods significantly ($p < 0.05$) affected Lightness (L*)

colour of chicken breast meat. The results in Table 3 showed that samples cooked by air frying (AF) had an average L* value of 57.28, while samples cooked by baking (BK) had 64.55, deep fat frying (DF) had 66.80 and grilling (GR) had mean L* value of 46.48. Cooking produced higher values of L* and it indicated that cooked meats became darker due to reduction of deoxymyoglobin and oxymyoglobin (reddish colour) and increase intensity of metmyoglobin (brownish-red). This finding agrees with reported findings by Liu et al. [33], Gracia-Segovia et al. [34] and Yancey et al. [35]. The differences in L* value due to cooking methods were significant ($p < 0.05$). The increased L* or lighter colour of cooked meat could be attributed to oxidation of meat pigment (myoglobin) by cooking.

Cooking temperature significantly ($p < 0.05$) affected L* value of cooked chicken breast meat. Samples cooked at 170^0C, 180^0C and 190^0C gave average L* values of 56.89, 58.42 and 61.03, respectively. Thus, L* value significantly ($p < 0.05$) increased with increase in cooking temperature. The differences in L* value caused by cooking temperatures were significant ($p< 0.05$). Cooking at 190°C resulted to significantly ($p < 0.05$) higher L* value than cooking at 170°C and 180°C. The increase in darkness with increasing cooking temperature has been reported for fried food products such as potatoes and chicken nuggets by Ngadi et al. [36], Oztop et al. [37] and Mba et al. [38]. The interaction between cooking methods and temperatures were significant ($p < 0.05$), suggesting that the differences in L* value caused by the cooking methods were different at different temperatures. It could be deduced from Table 3 that the differences in L* value between AF and GR (AF – GR) were increasing with increase in cooking temperatures, but differences in L* value between AF and DF (AF – DF) and BK and DF (BK – DF) were decreasing with increase in cooking temperatures. On the other hand, the differences in L* value between AF and BK (AF – BK) or between BK and GR (BK – GR) were neither increasing nor decreasing with increase in cooking temperatures and the differences in L* value between DF and GR (DF – GR) were similar with increase in cooking temperatures.

Table 1. pH value of chicken meat at different cooking method, temperature and time

Cooking Method	Cooking Temp.^{0}C	Cooking time (min)			Mean cooking	
		0	8	16	Temp.^{o}c	Method
AF	170	6.05 ± 0.07	6.25 ± 0.07	6.35 ± 0.07	6.22 ± 0.15	
	180	6.05 ± 0.07	6.25 ± 0.07	6.35 ± 0.07	6.22 ± 0.15	
	190	6.05 ± 0.07	6.45 ±0.07	6.55 ± 0.07	6.35 ±0.24	
Mean		6.05 ±0.05	6.32± 0.10	6.42± 0.15	6.26 ± 0.19	6.26^a ± 019
BK	170	6.05 ± 0.07	6.25 ± 0.07	6.45 ± 0.07	6.25 ± 0.19	
	180	6.05 ± 0.07	6.15 ± 0.07	6.25 ±0.07	6.15 ±0.10	
	190	6.05 ±0.07	6.15± 0.14	6.20± 0.07	6.13 ± 0.10	
Mean		6.05 ± 0.05	6.18± 0.16	6.30± 0.08	6.18 ± 0.14	6.18^b± 0.14
DF	170	6.05 ± 0.07	6.45 ± 0.07	6.55 ± 0.07	6.35 ± 0.07	
	180	6.05 ± 0.07	6.35 ± 0.07	6.45 ± 0.07	6.28 ± 0.07	
	190	6.05 ± 0.07	6.35 ±0.07	6.45 ± 0.07	6.28 ± 0.07	
Mean		6.05 ± 0.05	6.38± 0.08	6.48± 0.10	6.31 ±0.20	6.31^a ±0.20
GR	170	6.05 ± 0.07	6.35 ± 0.07	6.45 ± 0.07	6.28 ± 0.07	
	180	6.05 ± 0.07	6.35 ± 0.07	6.45 ± 0.07	6.28 ± 0.07	
	190	6.05 ± 0.07	6.25 ± 0.07	6.35± 0.07	6.22 ± 0.15	
Mean		6.05 ± 0.05	6.38 ± 0.08	6.35 ± 0.10	6.26 ± 0.17	6.26^a ± 0.17
	Grand mean	6.05^c ± 0.05	6.30^b ± 0.11	6.40^a ± 0.14	6.25±0.18	6.25 ±0.05

Data are means of duplicate determinations ± standard deviations
Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$)
AF air frying
BK baking
DF deep fat frying
GR grilling

Table 2. Juiciness (%) of chicken meat at different cooking method, temperature and time

Cooking method	Cooking temp.^{0}C	Cooking time (min)					Mean
		0	4	8	12	16	C M
AF	170	41.65 ±0.49	24.00±0.41	17.50± 0.78	13. 90±0.42	7.65 ± 0.49	
	180	41.65 ±0.49	16.25± 1.06	13.25±0.92	8.15 ± 1.20	4.40 ± 0.85	
	190	41.65 ±0.49	15.00± 0.41	8.88 ± 0.18	7.90 ± 0.56	4.25 ± 1.06	
Mean		41.65 ±0.49	18.42 ± 4.48	13.21 ± 3.90	9.98 ± 3.17	5.43 ±1.84	17.74^c± 2.84
BK	170	41.65 ±0.49	32.75± 1.49	24.50±0.71	22.40 ± 0.85	14.90 ±0.14	
	180	41.65 ±0.49	26.25± 1.06	21.25± 1.06	19.40 ± 0.85	13.15±1.20	
	190	41.65 ±0.49	22.50± 0.71	20.75 ± 1.06	18.90±0.71	11.90 1.27	
Mean		41.65 ±0.49	27.17 ± 4.68	22.17 ± 1.97	20.23 ± 1.80	13.32 ± 1.56	24.91^a± 2.11
DF	170	41.65 ±0.49	11.20 ± 0.71	7.82 ± 0.05	6.45±0.35	5.70 ± 0.71	
	180	41.65 ±0.49	9.45 ± 0.35	6.70 ± 0.71	6.13 ± 0.31	5.38 ± 0.25	
	190	41.65 ±0.49	8.25 ± 0.07	5.95 ± 0.35	5.50 ± 0.28	4.95 ± 0.36	
Mean		41.65 ±0.49	9.63 ± 1.37	6.82 ± 0.91	6.03 ± 0.75	5.34 ± 0.50	13.89^d±0.65
GR	170	41.65 ±0.49	29.25 ± 1.06	26.25 ± 0.64	21.65 ± 0.50	14.15 ± 0.21	
	180	41.65 ±0.49	24.50 ± 0.71	21.50 ± 0.71	18.00 ± 0.41	13.90 ± 0.99	
	190	41.65 ±0.49	20.50 ± 0.40	19.50 ± 0.71	15.65 ± 0.49	12.40 ± 0.85	
Mean		41.65 ±0.49	24.75 ± 3.96	22.42 ± 3.15	18.43 ± 2.79	13.48 ± 1.16	24.15^b±2.18
	Grand mean	41.65^a ± 0.37	19.99^b ±7.80	16.15^c± 7.15	13.67^d ±6.38	9.39^e ± 4.29	20.17±1.97

Data are means of duplicate determinations ± standard deviations.
Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$)
AF air frying
BK baking
DF deep fat frying
GR grilling

The cooking times affected significantly ($p < 0.05$) L* value of cooked chicken breast meat as shown in Table 3. The average L* values at 4, 8, 12 and 16 min were 57.13, 60.62, 63.15 and 67.52, respectively. Thus L* value significantly ($p < 0.05$) increased as cooking time increased. The results of this research disagree with reported lightness L* results reported by Kumar et al. [39] in which lightness decreased with an increase in the level of frying temperature and time in Khaja (A traditional sweet). The differences are attributed to long time exposition of the products to heat, which caused oxidation of meat pigment. The interaction between the cooking methods and cooking times was found to be significant ($p < 0.05$), suggesting that the L* value due to the cooking methods were different at different cooking times. The significant interaction ($p < 0.05$) showed that the differences in L* value between AF and BK (AF - BK) and AF and DF (AF - DF) were decreasing with increase in cooking times, but differences between AF and GR (AF – GR) or between BK and DF (BK - DF) or between BK and GR (BK - GR) or between DF and GR (DF - GR) were neither increasing nor decreasing with increase in cooking times. There was significant interaction ($p < 0.05$) between cooking temperatures and cooking times. The differences in L* value between170 and 180^0C (170 – 180^0C) or between170 and 190^0C (170 – 190^0C) or between180 and 190^0C (180 – 190^0C) were increasing, decreasing and decreasing, respectively with increase cooking times (from 8 min to 16 min). However, the overall interaction (Method x Temperature x Time) was found to be significant. This significant ($p < 0.05$) overall interaction confirmed why the products obtained by grilling (GR) at 170°C for 4 min had the least L* value (41.94), while the products obtained by deep fat fried (DF) at 190°C and 16 min had the highest L* value (77.51). It is also observed that L* coefficient of determination R^2 is 99.8%. These values are very high, indicating treatment variables and their interactions affected the observed increases in L* value.

3.3.2 Changes in a* value of chicken breast meat

The results of a* value of chicken breast meat are shown in Table 4. It was observed from the table that a* values of chicken breast meat were significantly ($p < 0.05$) increased with cooking. However, an overall mean a* reduced to 4.11. The results in Table 5 showed that samples cooked by air frying (AF) had an average a* value of 4.18, while samples cooked by baking (BK) had 2.53, deep fat frying (DF) had 7.41 and grilling (GR) had mean a* value of 2.32. The findings of this research work are in line with similar research works conducted by Resurrecion [40] who reported increased a* value with cooking. However, it disagreed with the findings by Wattanachant [19] who reported increased a* value in Thai indigenous chicken heated to endpoint temperature of 70^0 C, but deceased when heated at higher temperatures. It has been reported that younger birds show pink colour during cooking due to their thinner skins which allows heat to reach their flesh but older birds have fats coating in their skin which prevents heat from reaching the flesh and spots of pink colour are seen in areas that lack fat. The lower a*value in GR method was due to lesser degree of heat penetration on the meat skin. This similar result was reported by Vaudagna et al. [41] in beef cooked in sous-vide. The higher a*value in DF cooking method could be attributed to meat pigment concentration by higher oil frying temperature, greater moisture loss and Maillard reaction resulting in formation of heterocyclic amines, which contribute to the development of tumour as reported by Wong et al. [42]. Samples cooked by DF were darker than other samples. This result is in line with reported findings by Ngadi et al. [36], Oztop et al. [37] and Kumar et al. [39] who observed increases in darkness in fried potatoes, chicken nuggets and Khaja (A traditional sweet). Generally, myoglobin –colour pigment in meat is expected to decrease during cooking, but increases in dull redness was observed.in this study. This increase in intensity of redness of chicken breast meat could be attributed to less sarcoplasmic protein denaturation and improved colour qualities as reported by Dai et al. [43].

The cooked a* value of chicken breast meat increased significantly ($p <0.05$) with cooking temperatures. The average a* values at 170^0C, 180^0C and 190^0C were 3.28, 4.05 and 5.00 respectively. Cooking at 190°C resulted to significantly ($p < 0.05$) higher a* value than cooking at 170ºC and 180ºC. The increased intensity of a* value of cooked samples could be attributed to denaturation of sarcoplasmic proteins. This is because myoglobin is a sarcoplasmic protein which is almost completely denatured between 80 and 85^0 C as reported by Tornberg [44]. It could also be attributed to non-enzymatic reactions especially Maillard reaction, caramelization and chemical oxidation occurring at high temperatures as reported by Kumar [45] and Xu et al. [46]. The interaction between

cooking methods and temperatures was significant ($p<0.05$), suggesting that the differences in a* value caused by the cooking methods were different at different temperatures.

The results in Table 4 showed that cooking times affected a* value. The average values of a* at 4, 8, 12 and 16 min were 2.90, 4.09, 5.95 and 7.40, respectively. Thus a* value significantly ($p < 0.05$) increased as cooking time increased. The increased in a* value with increasing cooking time of this research disagreed with reported findings by Garcia-Segovia et al. [34]; Yancey et al. [35] and Nithyalakshmi and Preetha [47] who reported decreases in a* values. The differences are attributed to intensity of denaturation of sarcoplasmic proteins and degree of penetration of heat on meat. The interaction between the cooking methods and cooking times was found to be significant ($p < 0.05$), suggesting that a* value due to the cooking methods were different at different cooking times. The significant interaction ($p < 0.05$) showed that the differences in a* value between AF and BK (AF - BK) and AF and GR (AF - GR) were increasing with increase in cooking times, but differences in a* value between BK and DF (BK – DF) were similar with increase in cooking times. On the other hand, the differences in a* value between AF and DF (AF – DF) or between BK and GR (BK - GR) or between DF and GR (DF - GR) were neither increasing nor decreasing with increase in cooking times. There was significant interaction ($p < 0.05$) between cooking temperatures and cooking times. The differences in a* value between 170 and 180°C (170 -180°C) or between 170 and 190°C (170 -190°C) or between 180 and 190°C (180 -190°C) were neither increasing nor decreasing with increase in cooking times. However, the overall interaction (Method x Temperature x Time) was found to be significant. This significant ($p < 0.05$) overall interaction confirmed why the products obtained by air frying (AF) at 170^{o}C for 4 min had the least a* value (0.80), while the products obtained by deep fat fried (DF) at 190ºC for 16 min had the highest a* value (11.42). It was also observed that a* coefficient of determination R^2 is 99.4%. These values are very high, indicating treatment variables and their interactions affected the observed increases in a* value.

3.3.3 Changes in b* changes in chicken breast meat

The results of b* value of cooked chicken breast meat are shown in Table 5. The results in Table 5 showed that cooking increased b*value of cooked chicken breast meat. On the average, b* value of chicken breast meat reduced to an overall mean of 15.59. Cooking methods significantly ($p < 0.05$) affected yellowness (b*) colour of chicken breast meat. The results in Table 5 showed that samples cooked by air frying (AF) had an average b* value of 17.26, while samples cooked by baking (BK) had 16.46, deep fat frying (DF) had 14.58 and grilling (GR) had 14.06. The increase in yellowness could be attributed to formation of metmyoglobin and further denaturation of proteins to produce brownish products. The similar results were obtained by Garcia-Segovia et al. [34], Christensen et al. [48] and Nithyalakshmi and Preetha [47].

Cooking temperature significantly ($p < 0.05$) affected b* value of cooked chicken breast meat. Cooking at 170^{0}C gave average b* value of 13.98, while cooking at 180^{0}C and 190^{0}C gave average b* values of 15.54 and 17.25, respectively. Thus, b* value significantly ($p < 0.05$) increased with increase in cooking temperature. The differences in b* value caused by cooking temperatures were significant ($p< 0.05$). Cooking at 190ºC resulted to significantly ($p < 0.05$) higher b* value than cooking at 170^{0}C and 180^{0}C. The increase in b* value could be attributed to reduction of deoxymyoglobin and oxymyoglobin intensity and an increase of metmyoglobin. This finding is in agreements with similar reported results by Garcia-Segovia et al. [34], Christensen et al. [48] and Roldan et al. [49]. The interaction between cooking methods and temperatures was significant ($p < 0.05$), suggesting that the differences in b* value caused by the cooking methods were different at different temperatures. It could be deduced from Table 5 that the differences in b* value between AF and DF (AF – DF) and AF and GR (AF – GR) were increasing with increase in cooking temperatures, whereas the differences in b* value between AF and BK (AF – BK) or between BK and DF (BK – DF) or between BK and GR (BK – GR) or between DF and GR (DF– GR) were neither increasing nor decreasing with increase in cooking temperatures.

The results in Table 5 showed that cooking times affected b* value. The average b* values at 4, 8, 12 and 16 min were 14.09, 16.24, 18.98 and 21.94, respectively. Thus b* value significantly ($p < 0.05$) increased as cooking time increased. An increase in cooking time results in diminishing intensity of deoxymyoglobin and oxymyoglobin

and increases metmyoglobin. The interaction between the cooking methods and cooking times was found to be significant ($p < 0.05$), suggesting that the b* value due to the cooking methods were different at different cooking times. The significant interaction ($p < 0.05$) showed that the differences in b* value between DF and GR (DF - GR) were similar with increase in cooking times. On the other hand, differences in b* value between AF and BK (AF – BK) or between AF and DF (AF – DF) or between AF and GR (AF – GR) or between BK and DF (BK – DF) or between BK and GR (BK – GR) were neither increasing nor decreasing with increase in cooking times.

There was significant interaction ($p < 0.05$) between cooking temperatures and cooking times. The differences in b* value between 170 and 180^{0}C (170 -180^{0}C) or between 170 and 190^{0}C (170 -190^0 C) or between 180 and 190^{0}C (180 -190^{0}C) were increasing, increasing and similar, respectively with increase in cooking times (from 8 min to 16 min). However, the overall interaction (Method x Temperature x Time) was found to be significant. This significant ($p < 0.05$) overall interaction confirmed why the products obtained by grilling (GR) at 170ºC for 4 min had the least b* value (10.42), while the products obtained by air frying (AF) at 190^{0}C for 16 min had the highest b* value (25.91). It was observed that b* coefficient of determination R^2 is 99.4%. These values are very high, indicating treatment variables and their interactions affected the observed increases in b* value.

3.3.4 Browning index (BI) of chicken breast meat

The results of browning index (BI) of chicken breast meat cooked at different methods each at 170, 180 and 190 ^{0}C for 0, 4, 8, 12 and 16 min are shown in Table 6. The results in Table 6 showed that cooking increased BI value of cooked chicken breast meat. On the average, BI value of chicken breast meat decreased to an overall mean of 37.16. Cooking methods significantly ($p < 0.05$) affected browning of chicken breast meat. The results in Table 6 showed that samples cooked by air frying (AF) had an average BI value of 42.21, while samples cooked by baking (BK) had 31.84, deep fat frying (DF) had 48.08 and grilling (GR) had mean BI value of 26.52. The higher BI value of DF cooked samples could be attributed to higher cooking oil temperature. Moreover, this higher value of browning index could be attributed to Maillard browning reaction during cooking associated with reaction of reducing sugar, denatured proteins and amino acids of cooked meat. Cooking temperature significantly ($p < 0.05$) affected BI value of cooked chicken breast meat. Cooking at 170^0 C gave average BI value of 33.70, whereas cooking at 180^{0}C and 190^0 C gave average BI values of was 37.14 and 40.64, respectively. Thus, BI value significantly ($p < 0.05$) increased with increase in cooking temperature. The differences in BI value caused by cooking temperatures were significant ($p< 0.05$). Cooking at 190^0 C resulted to significantly ($p < 0.05$) higher BI value than cooking at 170^0 C and 180^{0}C. The interaction between cooking methods and temperatures was significant ($p < 0.05$), suggesting that the differences in BI value caused by the cooking methods were different at different temperatures. It could be deduced from Table 6 that the differences in BI value between AF and BK (AF – BK) or between AF and GR (AF – GR) or between BK and GR (BK – GR) were neither increasing nor decreasing with increase in cooking temperatures, but differences in BI value between AF and DF (AF – DF), BK and DF (AF – DF) and DF and GR (DF – GR) were decreasing with increase in cooking temperatures. The higher browning index of samples cooked by DF method could be attributed to denaturation of remnant samples and oxidation of cooking oil. The results in Table 6 showed that cooking times affected BI value. The average BI values at 4, 8, 12 and 16 min were 28.02, 35.74, 46.95 and 59.04, respectively. Thus BI value significantly ($p < 0.05$) increased as cooking time increased This result agrees with an earlier finding by Mba et al. [8] who stated longer cooking time resulted in increased browning index value.

The interaction between the cooking methods and cooking times was found to be significant ($p < 0.05$), therefore the BI values due to the cooking methods were different at different cooking times. The significant interaction ($p < 0.05$) showed that the differences in BI value between AF and BK (AF – BK), AF and GR (AF – GR), BK and DF (BK – DF), DF and GR (DF - GR) were increasing with increase in cooking time, but differences between BK and GR (BK – GR) were similar with increasing cooking time. On the other hand, differences in BI value between AF and DF (AF – DF) were neither increasing nor decreasing with increase in cooking times. The results showed that the interaction between cooking temperatures and cooking times was significant ($p < 0.05$),

Table 3. Lightness (L*) of chicken breast meat at different cooking method, temperature and time

Cooking method	Cooking temp.^{0}C	Cooking time (min)					Mean cooking	
		0	4	8	12	16	temp.^{0}C	method
AF	170	45.10 ±0.79	49.68 ± 0.74	53.12±1.00	59.74± 0.15	62.28 ± 0.08	53.98	
	180	45.10 ±0.79	53.30 ± 1.64	55.04 ± 0.57	64.30 ± 0.95	68.26 ± 0.36	57.20	
	190	45.10 ±0.79	54.64 ± 0.01	65.36 ± 0.91	67.25 ± 1.03	70.93 ± 0.82	60.65	
Mean		45.10 ±0.79	52.54 ± 2.43	57.84 ± 5.92	63.76 ± 3.44	67.16 ± 3.98	57.28	57.28^c±3.34
BK	170	45.10 ±0.79	60.95 ± 0.64	66.56 ± 1.32	69.15 ± 1.02	70.87 ± 0.69	62.53	
	180	45.10 ±0.79	61.17 ± 1.06	67.14 ± 1.52	70.37 ± 1.49	74.54 ± 0.12	63.66	
	190	45.10 ±0.79	69.94 ± 0.97	73.41 ± 0.14	73.78 ± 0.02	75.15 ± 0.08	67.47	
Mean		45.10 ±0.79	64.02 ± 4.67	69.04 ± 3.52	71.10 ± 2.29	73.52 ± 2.09	64.55	64.55^b±2.59
DF	170	45.10 ±0.79	67.30 ± 0.67	69.68 ± 0.13	70.88 ± 1.15	76.00 ± 0.03	65.79	
	180	45.10 ±0.79	67.84 ± 1.08	70.64 ± 0.38	72.25 ± 1.58	76.25 ± 0.33	66.41	
	190	45.10 ±0.79	69.40 ± 0.93	72.39 ± 0.84	76.54 ± 0.01	77.51 ± 0.13	68.19	
Mean		45.10 ±0.79	68.18 ± 1.20	70.90± 1.30	73.22± 2.78	76.59 ± 0.74	66.80	66.80 ^{a}±1.25
GR	170	45.10 ±0.79	41.94 ± 0.29	43.85 ± 0.65	44.37 ± 0.35	50.95 ± 0.00	45.24	
	180	45.10 ±0.79	44.66 ± 0.70	44.85 ± 0.19	46.31± 0.63	51.09 ± 0.65	46.40	
	190	45.10 ±0.79	44.77 ± 0.28	45.84 ± 0.01	47.20 ± 0.83	56.42 ± 0.89	47.79	
Mean		45.10^e ±0.79	43.79 ±1.48	44.72 ± 0.79	45.96 ± 1.53	52.82 ± 2.83	46.48	46.48^d±1.28
	Grand mean	45.10^e± 0.00	57.13^d±10.15	60.62^c±11.17	63.51^b±11.22	67.52^a±9.67		58.78±2.09

Data are means of duplicate determinations ± standard deviations.

Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$)

AF air frying

BK baking

DF deep fat frying

GR grilling

Table 4. Redness (a*) of chicken breast meat at different cooking method, temperature and time

Cooking method	Cooking temp.^{0}C	Cooking time (min)					Mean cooking	
		0	4	8	12	16	Temp.^{0}C	method
AF	170	0.21 ±0.54	0.80±0.00	2.37±0.19	4.79± 1.32	8.03 ± 0.16	3.24	
	180	0.21 ±0.54	1.46 ±0.11	3.04 ± 0.35	7.40 ± 0.47	9.91±0.38	4.40	
	190	0.21 ±0.54	2.57 ± 0.00	3.57 ± 0.22	7.50 ± 0.62	10,69 ± 0.10	4.91	
Mean		0.21 ±0.42	1.61 ±0.80	2.99 ± 0.57	6.56 ± 1.54	9.54±1.24	4.18	4.18 ^{b}±0.86
BK	170	0.21 ±0.54	0.64 ± 0.07	1.02 ± 0.00	1.30 ± 0.16	3.47 ± 0.83	1.33	
	180	0.21 ±0.54	1.82 ± 0.04	2.36 ± 0.08	2.87 ±0.39	4.89 ± 0.28	2.43	
	190	0.21 ±0.54	2.41±0.38	3.06 ± 0.04	6.31 ± 0.21	7.09 ± 0.44	3.82	
Mean		0.21 ±0.42	1.62 ± 0.82	2.15 ± 0.93	3.49 ± 2.30	5.15 ± 1.69	2.53	2.53^c ±1.25
DF	170	0.21 ±0.54	5.31 ± 0.34	9.16 ± 0.29	9.71± 0.37	9.81 ± 0.17	6.84	
	180	0.21 ±0.54	5.86 ± 0.16	9.39 ± 0.48	9.78 ± 0.16	10.21 ± 0.06	7.09	
	190	0.21 ±0.54	9.03 ± 0.02	9.63 ± 0.67	11.24 ± 0.82	11.42 ±0.53	8.30	
Mean		0.21 ±0.42	6.73 ±1.80	9.39± 0.44	10.24 ± 0.88	10.48 ±0.79	7.41	7.41^a ±0.78
GR	170	0.21 ±0.54	1.51 ± 0.02	1.72 ± 0.01	2.43 ±0.01	2.66 ± 0.09	1.70	
	180	0.21 ±0.54	1.61 ± 0.08	1.83 ± 0.00	2.75 ± 0.17	5.04 ± 0.34	2.29	
	190	0.21 ±0.54	1.76 ± 0.09	1.96 ± 0.00	5.31 ± 0.17	5.60 ± 0.35	2.97	
Mean		0.21 ±0.42	1.62 ±0.13	1.84 ± 0.11	3.50±1.42	4.43 ±1.41	2.32	2.32^c ± 0.63
	Grand mean	0.21 ^{e} ±0.39	2.90 ^{d}± 2.47	4.09 ^{c}± 3.20	5.95 ^{b}± 3.21	7.40 ^{a}± 2.97		4.11 ±2.35

Data are means of duplicate determinations ± standard deviations.
Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$
AF air frying
BK baking
DF deep fat frying
GR grilling

Table 5. Yellowness (b*) value of chicken breast at different cooking method, temperature and time

Cooking method	Cooking temp.^{0}C	Cooking time (min)					Mean cooking	
		0	4	8	12	16	temp.^{0}C	Method
AF	170	6.70 ± 0.04	10.49 ±0.48	14.11± 1.11	20.68± 0.71	22.26 ± 0.28	14.85± 6.25	
	180	6.70 ± 0.04	16.54 ± 1.11	16.98 ± 1.09	23.38 ± 1.08	23.75 ± 0.95	17.47± 6.56	
	190	6.70 ± 0.04	18.26 ± 0.10	20.84 ± 0.93	25.55 ± 0.18	25.91 ± 0.33	19.45± 7.38	
Mean		6.70 ± 0.03	15.10 ± 3.69	17.31 ± 3.13	23.20 ± 2.26	23.97 ± 1.71	17.26^a ±6.79	17.26 ^{a} ±6.79
BK	170	6.70 ± 0.04	13.99 ± 0.45	16.35 ± 0.95	18.29 ± 0.38	19.04 ± 0.50	14.87± 4.70	
	180	6.70 ± 0.04	14.04 ± 0.40	16.98 ± 1.09	18.54 ± 0.86	20.54 ± 0.88	15.36±5.12	
	190	6.70 ± 0.04	19.23 ± 0.49	21.95 ± 1.27	23.77 ± 0.31	24.13 ± 0.28	19.16± 5.77	
Mean		6.70 ± 0.03	15.75± 2.72	18.43 ± 2.88	20.20 ± 2.80	21.23 ± 2.39	16.46^b ±5.77	16.46 ^{b} ±5.77
DF	170	6.70 ± 0.04	11.88 ± 0.52	15.30 ± 0.01	16.14 ± 0.22	17.45 ± 0.94	13.49± 4.08	
	180	6.70 ± 0.04	13.68 ± 0.16	15.55 ± 0.96	17.13 ± 1.01	20.41 ± 0.16	14.69±4.83	
	190	6.70 ± 0.04	13.75 ± 0.03	15.96 ± 0.11	17.48 ± 0.47	23.89 ± 0.87	15.56±5.89	
Mean		6.70 ± 0.03	13.10 ± 0.98	15.60 ± 0.53	16.91 ± 0.80	20.58 ± 2.94	14.58^c± 4.89	14.58^c ± 4.89
GR	170	6.70 ± 0.04	10.42 ± 0.63	12.76 ± 0.76	12.98 ± 0.46	20.62 ± 0.40	12.69± 4.82	
	180	6.70 ± 0.04	13.26 ± 0.00	14.00 ± 0.32	16.72 ± 0.15	22.53 ± 0.73	14.64± 5.42	
	190	6.70 ± 0.04	13.51 ± 0.46	14.04 ± 0.78	17.17 ± 1.01	22.78 ± 0.24	14.84± 5.54	
Mean		6.70 ± 0.03	12.39 ± 1.58	13.60 ± 0.83	15.62 ± 2.12	21.97 ±1.13	14.06^c± 5.18	14.06 ^{d}± 5.18
	Grand mean	6.70 ^{e} ± 0.03	14.09^d±2.70	16.24 ^{c} ± 2.76	18.98^b± 3.61	21.94^a ±2.39	15.59 ± 5.78	15.59± 1.64

Data are means of duplicate determinations ± standard deviations.
Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$)
AF air frying
BK baking
DF deep fat frying
GR grilling

Table 6. Browning index (BI) value of chicken breast at different cooking method, temperature and time

Cooking method	Cooking temp.^{0}C	Cooking time (min)					Mean cooking	
		0	4	8	12	16	Temp.^{0}C	Method
AF	170	16.07 ± 1.31	19.24 ± 0.54	29.34±1.10	53.82± 1.06	69.96 ± 1.12	37.68	
	180	16.07 ± 1.31	29.98 ± 0.87	34.21 ± 1.17	64.88 ± 0.40	70.19 ± 0.55	43.06	
	190	16.07 ± 1.31	30.64 ± 0.71	39.63 ± 0.21	66.72 ± 1.69	76.35 ± 1.28	45.88	
Mean		16.07 ± 1.01	26.62 ± 5.75	34.39 ± 4.66	61.81 ± 6.31	72.16 ± 3.45	42.21	42.21^{b}±3.40
BK	170	16.07 ± 1.31	22.04 ± 0.49	27.06 ± 1.03	29.32 ± 0.44	39.20 ± 1.21	26.74	
	180	16.07 ± 1.31	26.23 ± 0.92	29.16 ± 1.05	34.94 ± 0.55	40.88 ± 1.14	29.45	
	190	16.07 ± 1.31	33.51 ± 0.31	44.25 ± 0.53	48.85 ± 0.72	57.00 ± 0.61	39.34	
Mean		16.07 ± 1.01	27.26 ± 5.21	33.49 ± 8.42	36.70 ± 7.53	45.69 ± 8.83	31.84	31.84^{c}±5.42
DF	170	16.07 ± 1.31	34.54 ± 0.46	48.49 ± 1.16	50.77 ± 1.52	83.08 ± 1.44	46.59	
	180	16.07 ± 1.31	35.27 ± 1.09	49.60 ± 0.91	60.84 ± 0.75	84.14 ± 1.30	49.18	
	190	16.07 ± 1.31	42.18 ± 1.21	51.38 ±0.75	65.53 ± 0.00	67.16 ±0.00	48.47	
Mean		16.07 ± 1.01	37.33 ± 3.84	49.82 ± 1.50	59.05 ± 6.79	78.13 ± 8.55	48.08	48.08^{a}±1.09
GR	170	16.07 ± 1.31	20.70 ± 0.04	23.43 ± 0.00	27.91 ± 0.57	30.93 ± 1.30	23.80	
	180	16.07 ± 1.31	20.90 ± 0.40	26.17 ±0.61	30.24 ± 0.78	40.98 ± 0.25	26.87	
	190	16.07 ± 1.31	20.98 ± 0.37	26.22 ± 1.18	32.55 ± 0.59	48.61 ± 1.36	28.88	
Mean		16.07 ± 1.01	20.86 ± 0.28	25.27 ± 1.55	30.23 ± 2.14	40.17 ± 7.98	26.52	26.52^{d}±2.09
	Grand mean	16.07^{e} ±0.94	28.02^{d} ± 7.28	35.74^{c} ± 10.16	46.95^{b} ± 15.10	59.04^{a} ± 18.13	37.16	37.16 ±3.47

Data are means of duplicate determinations ± standard deviations.
Values with different superscripts row- wise and column- wise differ significantly ($p < 0.05$)
AF air frying
BK baking
DF deep fat frying
GR grilling

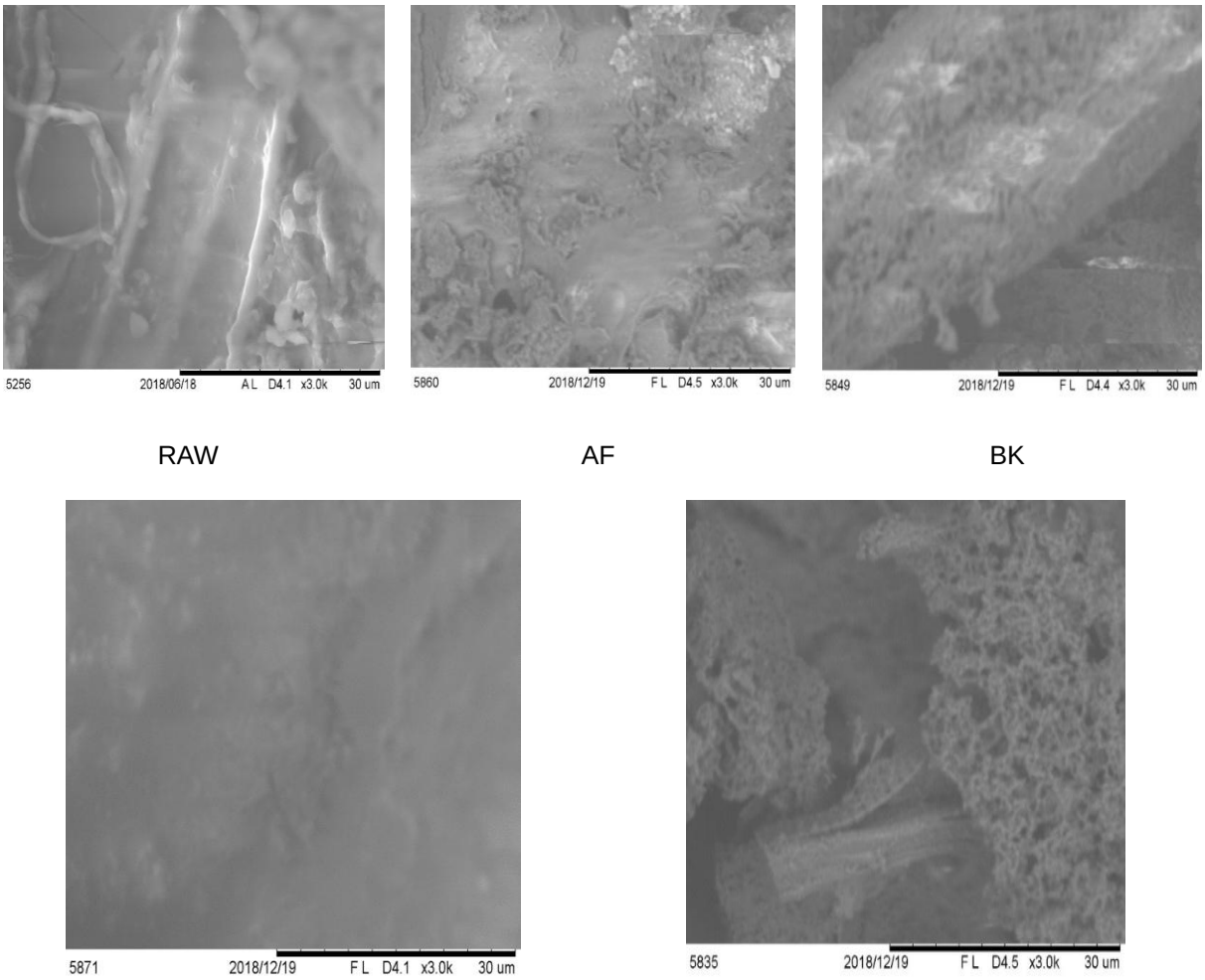
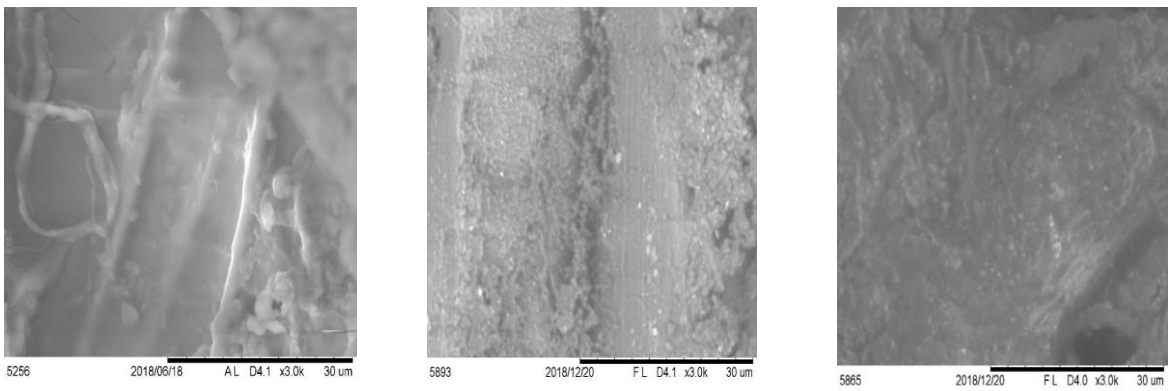
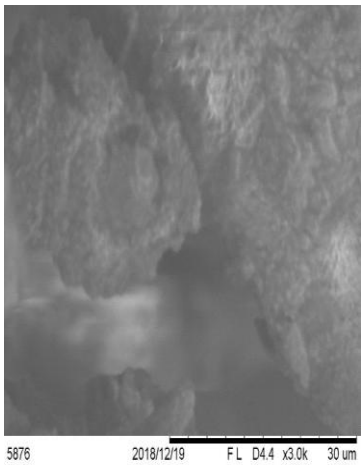
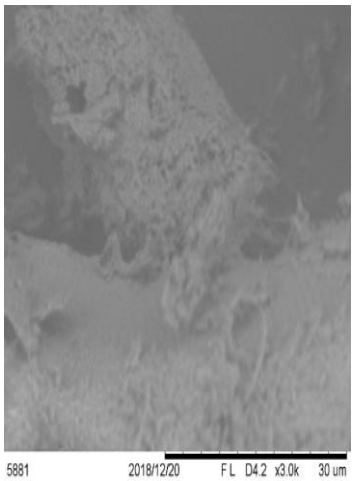


Plate 1. SEM micrographs (3000 X) showing myofibers of chicken breast muscles of Raw and cooked with [air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR)] at 170 ^{0}C for 8 min

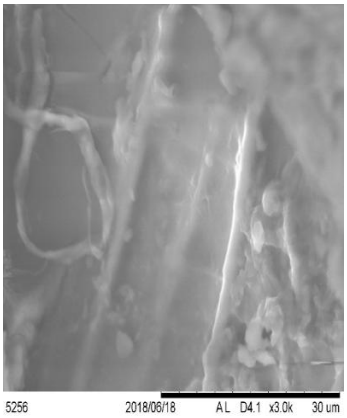


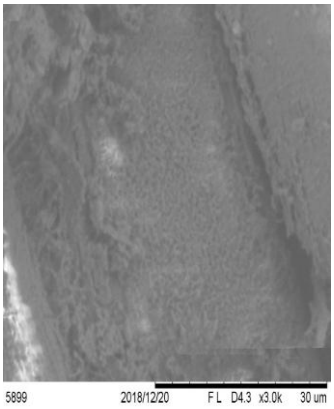


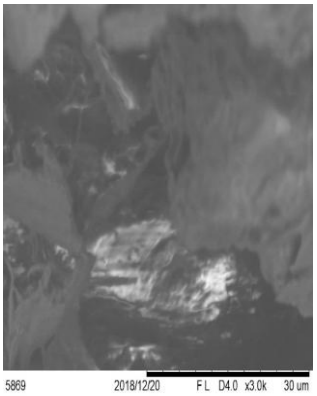


DF GR

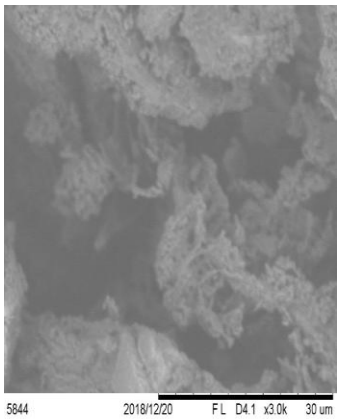
Plate 2. SEM micrographs (3000 X) showing myofibers of chicken breast muscles Raw and cooked with [air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR)] at 180 ^{0}C for 8 min

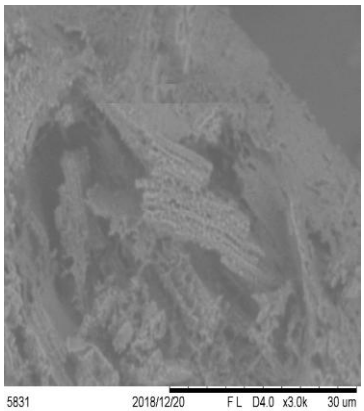






RAW AF BK





DF GR

Plate 3. SEM micrographs (3000 X) showing myofibers of chicken breast muscles Raw and cooked with [air frying (AF), baking (BK), deep fat frying (DF) and grilling (GR)] at 190 ^{0}C for 8 min

suggesting that the differences in BI value caused by the temperature were different at different cooking times. The significant interaction ($p < 0.05$) showed that the differences in BI value between 170 and 180^{0}C (170 - 180^{0}C), or 170 and 190^{0}C (170 -190^{0}C) or 180 and 190^{0}C (180 – 190^{0}C) were neither increasing nor decreasing, increasing and increasing, respectively with increase in cooking times (from 4 to 12 min). However, the overall interaction (Method x Temperature x Time) was found to be significant. This significant ($p < 0.05$) overall interaction confirmed why the products obtained by air frying (AF) at 170^{0}C for 4 min had the least BI value (19.24), while the products fried in vegetable oil (DF) at 180^{0}C and 16 min had the highest BI value (84.14). The coefficient of determination R^2 is 99.9%. This value is very high, indicating treatment variables and their interactions affected the observed increases in BI value.

3.4 Changes in Microstructure of Chicken Breast Meat

The SEM images of uncooked samples are shown in Plates 1, 2 and 3. The plates showed an intact muscle fibres and bundles, smooth and visible with different sizes in appearances. Freeze drying though resulted in the losses of free and immobilized water with minimal distortion on meat surfaces. The intact quality of control samples could be attributed to no heat application effects. Samples cooked at 170^{0}C for 8 min had SEM images with disintegration of muscle fibres, perimysial-collagen shrinkage and increased in core sizes. These structural changes could be attributed to effects of cooking which increases internal pressure, caused squeezing and migration of fluid from meat core to meat crust, resulting in drier samples with weakening myofibrils within fibres, big cracks, huge voids and big surface damages in AF, BK and GR samples. Whereas DF cooked samples had smoother surfaces, less surface damages, less cracks, less voids due to high oil uptake in the pores and build-up of denatured collagen gel within fibres for cell maintenance. This finding agrees with Kassam and Ngadi [50] who reported pore size reduction in deep fat fried samples at low temperature.

Samples cooked at 180 ^{0}C for 8 min are shown in Plate 2. The plate showed increased weakening of myofibrils and higher fluid removal from muscle fibres. Samples cooked by DF had more fluid losses and greater voids in muscle fibres than other cooking methods and cracks in descending order of arrangement of cooking methods of DF, GR, BK and AF. All samples had dried patches, surface gaps, rough surface texture and shrinkage in muscle fibres. These structural qualities could be attributed to increase evaporation of moisture from the samples due to thermal denaturation of intramuscular collagen and more surface damage. This result agrees to an earlier reported work by Wattanachant et al. [19] on chicken breast muscle.

Samples cooked at 190^{0}C are shown in Plate 3. The plate showed that samples cooked by DF, GR and BK methods had bigger cracks, bigger fibres damages, higher surface voids and rough surface textures as a result of their highly fractured and solubilized connective tissues. These cooking methods generate larger heat output and caused greater fluid removal compared to samples cooked by AF method, which had less pore sizes, less surface damages and fair smooth surface texture because it's mild heat output and fewer fluid removal from its cooked samples. Samples cooked by AF method were filled with aggregate gel formed by denatured sarcoplasmic, myofibrillar proteins and melted collagen. This findings agrees with earlier findings by Palka [51], Palka and Daun [52], Kemp et al. [53] who reported reduction in quantity of water bound in muscle with increasing cooking temperature and Christensen et al. [54] who stated that shrinking of perimysial-collagen could be attributed to fluid purging out from the muscle fibres as well Vasanthi et al. [55] who reported that higher temperatures resulted in fractured, solubilized meat connective tissues and tender meat products. It has also been reported by Dehghannya and Ngadi [56] that microstructure of the food surface changes the oil absorption behaviour as well changes the textural and sensory properties.

4. CONCLUSION

The moisture loss and oil uptake occurred during chicken breast meat cooking processes and these decreased juiciness and increased pH of the cooked products. Samples cooked at low temperature were juicer and increased cooking temperature decreased juiciness of cooked meat. The instrumental colour (L* and b*) and browning index (BI) scores were increased by DF cooking method, whereas AF cooked samples had higher a* scores than other cooking methods. Generally, frying resulted in migration of water

from meat crust into the frying oil as steam, causing increased internal pressure to move water from core meat to replace the migrated water. Heat emanating from cooking methods converted meat from viscoelastic to less elastic material, exerted increased internal pressure on muscle fibres and squeezed greater water, caused structural distortion, fracture, cracks and voids on muscle fibres. Samples cooked by DF and AF methods at 170ºC and 190ºC, respectively had smoother surfaces, less structural damages , less cracks and voids due to oil absorption and filling of aggregate gel formed from denatured sarcoplasmic, myofibrillar proteins and melted collagen.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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