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Research Article

Quality assessment of broiler meat using Computer vision technology

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Abstract

The paper presents the application of image analysis and computer vision technology in quality evaluation of broiler meat. Computer vision is a rapid, non-destructive, economic and objective inspection technique, which has expanded into many diverse industries. In this experiment, images were captured from *pectoralis major* muscle in broiler at 24 hours post-mortem. The software Matlab (R2015a) has been used for image analysis. The physicochemical, proximate, biochemical and microbiological tests were followed to determine different reference values of the sample. Reference color values were measured with the help of a colorimeter. Different color value (L*,a*,b*), pH, drip loss, cooking loss, dry matter, moisture, crude protein, ether extract, ash, Thiobarbituric acid reactive substance (TBARS), Peroxide value (POV), Free fatty acid (FFA), Total coliform count (TCC), Total viable count (TVC) and Total yeast-mould count (TYMC) were measured for this experiment. All determination was done in triplicate and the mean value was reported. Data analysis was carried out using the programme Stat graphics Centurion XV.I. Calibration and validation model were fitted using the software Unscrambler X version 9.7. A higher correlation was found in pH (r=0.64) with L* value obtained from imaging analysis and cooking loss (r=0.60) with 'a*' value obtained from imaging analysis and the highest calibration and prediction accuracy was found in pH (R^2_c =0.64, R^2_p=0.56) in broiler breast meat. Results of this work indicate the probability of using computer vision technology in predicting quality of meats in the meat processing plant.

Introduction

Broiler meat is a source of high-quality protein and other nutrients which is necessary for human health. It contains significant amount of high- quality and easily digestible protein, vitamins and minerals. Therefore, it is recommended for consumption by all age groups. Broiler meat is a nutritionally valuable foodstuff for its low content of fat in which there are more desirable unsaturated fatty acids than other types of meat (Ali et al., 2022; Islam et al., 2019). It is well accepted to all communities of people. More importantly, broiler meat is available at affordable prices. In recent years, the poultry market has increased significantly because of problems in the beef sector and the trend of consumption of low-calorie foods (Petracci et al., 2009). The main edible parts of a broiler are the skeletal muscles, especially the pectoralis major and minor. Important components of these muscles are their external features, size, nutritional profiles, and histological and chemical properties. Now a days, consumers and meat industry stakeholders are very much conscious about product quality because it affects their profitability (Hocquette & Chatellier., 2011). Meat quality usually depends on physical, chemical and biological properties. The production performance and stress levels of livestock can also have a significant impact on meat quality. Optimal growth rates, proper nutrition, and efficient feed conversion contribute to well-marbled, tender, and flavorful meat. However, stress factors such as improper handling, transportation, environmental fluctuations, and overcrowding trigger physiological responses that negatively affect meat quality (Hashem et al., 2020; Sarker et al., 2017) Stress-induced release of cortisol and catecholamines depletes glycogen stores in muscles, leading to issues like pale, soft, and exudative (PSE) meat or dark, firm, and dry (DFD) meat. Proper animal welfare practices, stress management, and optimized production conditions are crucial for ensuring high-quality, nutritious meat with desirable texture, color, and flavor (Hashem et al., 1999; Hossain et al., 2016). In food production, many information applying to the material or final product are obtained by visual evaluation made by employees. However, it is often an inaccurate subjective evaluation. Human visual inspection and chemical or biological determination experiment for quality evaluation of broiler meat is time- consuming, sample destructive and tedious. But the meat processing companies need fast, real-time, accurate, low-cost and non-destructive technique for quality assessment of meat. Meat quality assessment is crucial for ensuring consumer safety, nutritional value, and overall eating satisfaction. Various techniques, ranging from physical and chemical analyses to microbiological and advanced imaging methods, help evaluate key attributes like tenderness, color, flavor, and shelf life (Rana et al., 2014; Murshed et al., 2014). These attributes are significant to assess the quality and for improvement of meat on various perspective (Islam et al., 2018; Siddiqua et al., 2018).

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The choice of assessment technique often depends on the type of meat processing involved, as different methods—such as chilling, curing, high-pressure processing, and modified atmosphere packaging—can significantly influence meat quality. For the Purpose of eliminating human mistake from the visual evaluation process, the computer vision system may be the alternative technique (Rahman et al., 2023; O'Sullivan et al., 2003). Making a photograph of inspected material and performing the image analysis with the use of appropriate computer applications, enables to make a decision about direction of its application. Computer vision system has found a wide application in meat industry. It is used for the evaluation of meatiness and classification of carcasses of big slaughter animals both pork and beef (Cannell *et al*., 2002; Fortin *et al*., 2003). Previously conducted results also applied to the evaluation of color and marbling of pork (Lu, Tan, Shatadal and Gerrard, 2000; Mendoza, Dejmek and Aguilera 2006) for the purpose of detection of PSE in Pork (Chmiel, Slowinski and Dasiewicz, 2011). In case of chicken and turkey carcasses, computer vision system was mostly often used to determine the weight of chickens, detect fractures, bruises and discolorations on carcass skin (Chao, Park, Chen, Hruschka and Wheaton, 2000; Mollah, Hasan, Salam, and Ali, 2010). One previous research reported that frozen breast meat with low water-holding capacity had more flatter in shape during extended storage time (Lee *et al*., 2008).Basically, computer vision is an RGB color vision method by which external features of the product can be assessed (Tan, 2004). Computer vision system can obtain reliable and reproducible data (Yagiz, Balaban, Kristinsson, Welt, & Marshall, 2009). It can replace human vision and perception of images. Furthermore, machine vision can create accurate descriptive data, which decreases the human intervention and accelerates the process. It is capable of constant recording which is suitable for further analysis (Brosnan & Sun, 2004). Fatih *et al*. (2016) used Computer vision system for colour measurement in meat. Computer vision technology has been used for assessing water holding capacity in meat by researchers (Qiao *et al*., 2007; Monroy *et al*., 2010; ElMasry *et al*., 2011). Direct measurements are inconvenient and time-consuming when used in the continuous processing of meat. Several high-performance techniques such as the hyperspectral imaging technique (Qiao *et al*., 2007), near-infrared (NIR) imaging (ElMasry *et al*., 2011), and nuclear magnetic resonance (NMR) (Bertram *et al*., 2001) have been used for determining the quality characteristics of meat. However, these techniques require costly equipment, whereas imaging analysis using a digital camera is inexpensive. Thus, imaging analysis with a digital camera may provide an alternative method for assessing the quality attributes by establishing correlation between image value and chemical composition of broiler meat.

Materials and methods

Sample preparation

A total of 40 breast muscle (*pectoralis major*) was collected from 40 carcasses of commercial broilers. All samples were collected from local wet market of Mymensingh town. Broilers were around 28 days of age with live weight ranges from 1200 to 1300 gm. Each steak was 2.5 cm thick and weight was around 100 gm. Samples were areal-packed and stored in the refrigerator for 24 hours at 4 °C. After 24 hours' samples were removed from refrigerator and then kept in trays for about 10-12 minutes to allow moisture appearance on sample surface. Then the surface of the samples was soaked gently with the help of blotting paper which subsequently used for better color value estimation.

Image acquisition

Image acquisition of the sample was performed with the help of imaging system (Computer Vision System, Fig. 1) developed locally following the information reported by Iqbal *et al*. (2010) and Valous *et al*. (2009). The main components of the developed system are: an illumination source, a color digital camera (Canon IXUS, Model No. 190, Tokyo, Japan), and a computer-supported with an image acquisition software package (Matlab 2015a, The Mathworks, Natick, MA, USA). Images of the samples were captured using the camera of imaging system and were stored in the computer for further processing. An image processing software (Matlab 2015a, The Mathworks, and USA) was applied for image analysis.

Reference analysis

Surface color evaluation

The surface color of the samples was measured in terms of L* (lightness), a* (redness) and b* (blueness) values using a Chroma meter (CR-400, Konica Minolta, Osaka, Japan) following the guidelines provided by CIE (Commission International de I'Eclairage) system (CIE, 1976).

Physico-chemical analysis

pH value recording

The pH value in broiler meat was measured by meat pH meter (Model no. HI99163, Hanna Instruments, Woonsocket, RI, USA). The pH meter was adjusted with pH 7.01 buffer solution before the measurement. The electrodes were rinsed with cleaning solution after use.

Drip loss (DL) measurement

For DL measurement 30 g sample was hung with a wire and kept in an air tight plastic container for 24 h. After 24 h the sample was weighed and calculated the difference. It was expressed as percentage (%).

Cooking loss (CL) measurement

30 g beef sample was taken in a poly bag and boiled it in water bath until the temperature rises to 71℃ in sample. Beef with 71℃ was taken out from the water bath and soaked it with tissue paper. Weight loss of the sample was measured during cooking beef. CL was calculated using following formula:

$$\text{CL\%} = \frac{\text{Wt.before cooking} - \text{Wt.after cooking}}{\text{Wt. before cooking}} x100$$

Proximate analysis

Moisture, protein, fat, and ash was determined as per the Standard procedures of Association of Official Analytical Chemists (AOAC, 2005).

Biochemical analysis

Three types of biochemical analysis were carried out in this study: (i) Thiobarbituric acid reactive substance (TBARS), (ii) Free fatty acid (FFA) and (iii) Peroxide value (POV) measurement. Three types of analysis are discussed below:

Thiobarbituric acid values measurement

Lipid oxidation was assessed in triplicate using the 2-thiobarbituric acid (TBA) method described by Schmedes *et al*. (1989). Samples (5 g) was blended with 25 mL of 20% trichloroacetic acid solution (200 g/L of tricholoroacetic acid in 135 mL/L phosphoric acid solution) in a homogenizer (IKA) for 30 seconds. The homogenized sample was filtered with Whatman filter paper number 1 and 2 mL of the filtrate was added to 2 mL of 0.02 M aqueous TBA solution (3 g/L) in a test tube. The test tube was incubated at 100℃ for 30 minutes and cooled with tap water. The absorbance was measured at 532 nm using a UV-VIS spectrophotometer (UV-1200, Shimadzu, and Kyoto, Japan). The TBA value was expressed as mg malonaldehyde per kilogram of sample.

Peroxide value (POV) analysis (meq/kg)

POV was determined according to Sallam *et al*. (2004). The sample (3 g) was weighed in a 250-mL glass stopper Erlenmeyer flask and heated in a water bath at 60℃ for 3 min to melt the fat, then thoroughly agitate for 3 min with 30 mL acetic acid-chloroform solution (3:2 v/v) to dissolve the fat. The sample was filtered under vacuum through Whatman filter paper number 1 to remove meat particles. Saturated potassium iodide solution (0.5 mL) was added to filtrate and continue with addition of starch solution. The titration was allowed to run against standard solution of sodium thiosulfate (25/1). The formula is expressed as:

$$\text{POV (meq/kg)} = \frac{SxN}{\text{W}} x100$$

Where, S is the volume of titration (mL),

N is the normality of sodium thiosulfate solution (n=0.01) and

W is the sample weight (g).

POV was expressed as milliequivalent peroxide per kilogram of sample.

Free fatty acid (%) analysis

FFA value was determined according to Rukunudin *et al*. (1998). 5 g sample was dissolved with 30 mL chloroform using a homogenizer (IKA T25 digital Ultra-Turrax, IKA, Königswinter, Germany) at 10.000 rpm for 1 min. The sample was filtered under vacuum through Whatman filter paper number 1 to remove meat particles. After five drops of 1% ethanolic phenolphthalein was added as indicator to filtrate, the solution was titrated with 0.01N ethanolic potassium hydroxide. The formula is expressed as:

$$\text{FFF(\%)} = \frac{Titrate\ required\ (ml) x\ Normality\ of\ KOH\ x\ 28.2}{Sample\ weight\ (g)}$$

Microbiological analysis

Microbiological analysis was determined by Ikhlas *et al*. (2012). The procedures which were followed for microbial assessment of total viable count (TVC), total coliform count (TCC) and total yeast-mould count, are described below:

Enumeration of total viable count

For the determination of total bacterial counts, 0.1 mL of each ten-fold dilution was transferred and spread on triplicate PCA agar using a sterile pipette for each dilution. The diluted samples were spread as quickly as possible on the surface of the plate with a sterile glass spreader. One sterile spreader was used for each plate. The plates were then kept in an incubator at 35℃ for 24–48 h. After incubation, 30–300 colonies were counted with the aid of a colony counter. The average number of colonies in a particular dilution was multiplied by the dilution factor to obtain the TVC. The results of the total bacterial count expressed as the number of organism of colony forming units per gram (CFU/g) of sample.

Enumeration of total coliform count

For the determination of TCCs, 0.1 mL of each ten-fold dilution was transferred and spread on triplicate MA agar using a sterile pipette for each dilution. The diluted samples were spread as quickly as possible on the surface of the plate with a sterile glass spreader. One sterile spreader was used for each plate. The plates were then kept in an incubator at 35℃ for 24– 48 h. After incubation, 30–300 colonies were counted with the aid of a colony counter. The average number of colonies in a particular dilution was multiplied by the dilution factor to obtain the TCC. The results of the total bacterial count expressed as the number of organism of colony forming units per gram (CFU/g) of sample.

Enumeration of yeast-mould count

For the determination of yeast and mould counts, 0.1 mL of each ten-fold dilution was transferred and spread on triplicate PDA agar using a sterile pipette for each dilution. The diluted samples were spread as quickly as possible on the surface of the plate with a sterile glass spreader. One sterile spreader was used for each plate. The plates were then kept in an incubator at 25℃ for 48–72 h. After incubation, 30–300 colonies werecounted with the aid of a colony counter. The average number of colonies in a particular dilution was multiplied by the dilution factor to obtain the yeast and mould count. The results of the yeast and mould count were expressed as the number of organism of colony forming units per gram (CFU/g) of sample.

Statistical analysis

Descriptive statistical analysis and Pearson correlations between the image data and reference data were both determined using the statistical package, Statgraphics Centurion XV.I. STATPOINT TECHNOLOGIES. Warrenton, Virginia, USA with a significance level of p<.05. The calibration and validation model were fitted using the software Unscrambler X version 9.7.

Results and discussion

Color value estimation

The CIE L*a*b* model consists of L* a* and b* color lightness parameter, in which L*=0 and L*=100 are taken to be black and white respectively and a* is used to represent negative values for green and positive values for red and at last negative values for blue and positive values for yellow are displayed by b* (Zheng, Sun, and Zheng, 2006). Color value obtained from imaging analysis in broiler were 51.72±3.62, 5.95±2. 71, 15.9±3.14 for L*, a*, b* respectively (Table 1). Kaewthong *et al* (2017) found 51.92±0.57 for L* in broiler breast meat from imaging analysis which was very close to the present finding. The L*, a*, b* values from direct measurement using colorimeter were 45.57±5.37, 3.96±1.24 and 7.41±2.97 respectively and shown in table 1 where Garcia *et al* (2010) found 47.38 and 3.78 for L*and a* respectively and Souza *et al* (2011) found 46.76 and 7.87 for L* and b* respectively in broiler breast fillet which were almost similar to the present study. Qiao *et al* (2002) found 4.38±0.22 for a* and Janisch *et al* (2011) found 3.69±0.17 for a* in broiler breast meat which were near to the finding of present study.

Physicochemical properties

The pH value found in broiler breast meat was 6.14±0.17 which is similar to the findings of Janisch *et al (*2011) and Qiao *et al* (2002). They found pH values for broiler breast meat were 6.19±0.42 (Janisch *et al*, 2011) and 5.96±0.03 (Qiao *et al*, 2002). Garcia *et al* (2010), Souza *et al* (2011) and Aziz *et al* (2020) determined the pH values for broiler breast fillets were 5.89, 5.80 and 5.79±0.07 respectively which are near to the findings of present study. Drip loss and cooking loss obtained from the sample were 4.95±1.09 and 21.32±3.58 respectively where Garcia *et al* (2010) found 1.37% and 19.45% for drip loss and cooking loss in broiler breast meat respectively. The variation in drip loss value with present study may be due to strain difference.

Proximate components

Dry matter, moisture, crude protein, ether extract and ash content of the sample shown in Table 1. The values were 27.55±2.64, 72.45±2.64, 23.87±1.46, and 2.06±0.52, 1.42±0.13 for dry matter, moisture, crude protein, ether extract and ash respectively. Kaewthong *et al (*2017) determined the crude protein% and fat% in broiler breast meat were 23.64±0.25 and 2.70±0.17 respectively which were almost similar to the present findings. Qiao *et al* (2002) found crude protein and ash in broiler breast meat were 22.96±0.17 and 1.31±0.04 respectively which is close to the present study But Oliveira *et al* (2016) reported the value of ether extract and ash were 3.3±0.52 and 1.4±0.08 respectively.

Biochemical properties

Fresh meat undergoes major undesirable changes during storage at both refrigerated and freezing temperature. Lipid peroxidation is one of the primary mechanisms of quality deterioration in stored foods, especially in muscle tissues. The changes in quality can be manifested by deterioration in flavor, color, texture and nutritive value and the production of toxic compounds (Pearson *et al*., 1983). In the current study, peroxide value, TBARS and free fatty acid values were chosen as representative of primary and secondary lipid oxidation and lipid hydrolysis, respectively. High peroxide values are definite indication of rancid fat, but moderate values may be the result of depletion of peroxides after reaching a high concentration. In highly unsaturated fats, even after extensive oxidation, the amount of peroxide remains low. This is because the peroxides initially formed from unsaturated fats are themselves highly unsaturated and thus unstable and react quickly to form secondary oxidation products. Low peroxide values may also be obtained for any extremely rancid products, again because the peroxides initially formed have all undergone further oxidation reactions (Levemore, 2004; Gotoh and Wada, 2006).

Free fatty acid content is a measure of the extent to which hydrolytic rancidity has occurred in a sample. Free fatty acid content is used extensively as a general indication of the condition and edibility of pure oils and fats and the fat extracted from food products, including meat (Lovemore, 2004; Ogunsola and Omojola, 2008). The extent of oxidative rancidity in a fat may also be determined by its TBA number. The 2-thiobarbituric acid (TBA) test is believed to measure the breakdown products of unsaturated fatty acid oxidation. Typically, the TBA number of a sample shows a steady increase as it becomes more rancid.

In this study, broiler breast meat showed average TBARS, per oxide value and free fatty acid values were 0.11±0.02, 2.26±0.3 and 0.03±0.01 respectively. Islam *et al* (2019) found 0.06±0.01 mg-MDA/kg TBARS, 0.83±0.02 meq/kg POV and 0.33±0.03% FFA in indigenous chicken meat whereas Rima *et al* (2019) reported 0.18±0.02 mg-MDA/kg TBARS, 0.55±0.02 meq/kg POV and 0.24±0.02% FFA in broiler meat. These findings are almost similar to the present study. Gheisari (2011) stated that peroxide and TBA values can be used as lipid quality indices in chicken during 4 days storage in refrigerator.

Microbiological analysis

The microbiological safety and quality of poultry meat are equally important to producers, retailers and consumers and both involve microbial contaminants on the processed product. Two different groups of microorganisms are relevant, one is certain foodborne pathogens and other is the organisms that are generally harmless for human health but, being psychrotrophic, are able to multiply on the product during chill storage. Microbiological traits measured by laboratory method are presented in table 1. The average values with standard deviations were 5.08±0.05 log CFU/g, 5.88±0.08 log CFU/g and 7.67±0.09 log CFU/g for TCC, TYMC and TVC respectively where Aziz *et al* (2020) found 5.07 ±0.87 log10 coliform of pectoralis major muscle in broiler chicken in a study. Islam *et al* (2019) investigated microbial population in indigenous chicken meat that were 1.56±0.05 log CFU/g for TCC, 1.63±0.03 log CFU/g for TYMC and 4.61±0.16 log CFU/g for TVC. Rima *et al* (2019) reported 1.92±0.07 log CFU/g for TCC, 1.55±0.05 log CFU/g for TYMC and 3.69±0.10 log CFU/g for TVC.

Table 1. Range, mean, standard deviation (SD) and coefficient of variation (CV) of broiler breast meat quality traits

Attribute	n	Range	Mean	SD	CV%
L^*_{image}	40	38.37-56.53	51.72	3.62	7.00
a^*_{image}	40	1.22-10.31	5.95	2.71	45.49
b^*_{image}	40	6.71-22.2	15.9	3.14	19.77
L*	40	34.19-56.15	45.57	5.37	11.79
a*	40	0.8-6.15	3.96	1.24	31.31
b*	40	2.19-12.92	7.41	2.97	40.04
pH	40	5.7-6.37	6.14	0.17	2.8
DL%	40	2.61-6.37	4.95	1.09	22.07
CL%	40	15.8-29.13	21.32	3.58	16.78
DM%	40	22.37-33.22	27.55	2.64	9.59
Moisture%	40	66.78-77.63	72.45	2.64	3.65
CP%	40	19.93-26.35	23.87	1.46	6.13
EE%	40	1.13-3.09	2.06	0.52	25.22
Ash%	40	1.18-1.74	1.42	0.13	8.97
TBARS	40	0.1-0.17	0.11	0.02	12.99
POV	40	1.33-2.76	2.26	0.3	13.26
FFA	40	0.02-0.05	0.03	0.01	32.69
TCC	40	4.94-5.15	5.08	0.05	1.00
TYMC	40	5.72-6	5.88	0.08	1.37
TVC	40	7.48-7.88	7.67	0.09	1.11

L*image, L*value from imaging analysis; a*image, a* value from image analysis; b*image, b* value from imaging analysis; n, sample size; SD, standard deviation; CV, co-efficient of variation; DL, drip loss; CL, cooking loss; DM, dry matter; CP, crude protein; EE, ether extract; TBARS, thiobarbituric acid reactive substance; POV, per-oxide value; FFA, free fatty acid; TCC, total coliform count; TYMC, total east-mould count; TVC, total viable count.

Correlation between computer vision technology and conventional analytical technology

Correlation between image data and reference data of broiler breast meat is presented in table 2. The L* value from imaging analysis had medium correlation with L*(0.40), DL% (0.37), DM (0.39), CP (0.35) and POV (0.29) but higher with pH (0.64) obtained from laboratory method. A higher correlation found in CL% (0.60) and medium correlation found with b* (0.40), moisture (0.43) and FFA (0.24) with 'a*' value obtained from imaging analysis. The 'b' value resulted from imaging analysis had medium correlation with L* (0.43), pH (0.5), DL% (0.48), DM (0.37), CP (0.49), EE (0.38), POV (0.28) and TVC (0.37) measured by analytical method. Kaewthong *et al. (*2017) stated the correlation between color value obtained from image analysis and drip loss obtained from direct measurement. They (Kaewthong *et al*, 2017) found correlation between L* from image analysis and drip loss was 0.36, between a* from image analysis and drip loss was 0.45 and between b* from image analysis and drip loss was 0.20 in broiler breast meat. Researchers (Monika and Marek, 2012) showed higher correlation of fat content from direct measurement and white field's area from computer vision system and also found strongest correlation of moisture content from direct measurement and white fields from computer vision system in meat batters. Chmiel *et al* (2011) made correlation between content of white spots achieved with CVS method and fat content determined using the reference Soxhlet method in chicken breast muscle. Rahman *et al* (2020) found higher correlation in a* (r=0.65) and moisture (0.56) with a* value obtained from image analysis in beef.

Table 2. Pearson correlation coefficients between image data and reference data for quality attributes of broiler breast meat

Variables	L^*_{image}	a^*_{image}	b^*_{image}
L*	0.40^{**}	-0.47^{**}	0.43^{**}
a*	-0.14	0.17	-0.33^{*}
b*	-0.23	0.4^{**}	-0.38^{*}
pH	0.64^{***}	-0.58^{***}	0.5^{***}
DL%	0.37^{*}	-0.53^{***}	0.48^{**}
CL%	-0.46^{**}	0.6^{***}	-0.49^{***}
DM	0.39^{**}	-0.43^{**}	0.37^{*}
Moisture	-0.39^{**}	0.43^{**}	-0.37^{*}
CP	0.35^{*}	-0.54^{***}	0.49^{***}
EE	0.18	-0.28	0.38^{*}
Ash	0.12	0.003	-0.04
TBARS	0.09	0.04	0.11
POV	0.29	-0.24	0.28
FFA	-0.31	0.24	-0.44^{**}
TCC	-0.02	0.03	-0.12
TYMC	-0.13	0.08	0.17
TVC	-0.10	-0.06	0.37^{*}

L*image, L*value from imaging analysis; a*image, a* value from image analysis; b*image, b* value from imaging analysis; DL, drip loss; CL, cooking loss; DM, dry matter; CP, crude protein; EE, ether extract; TBARS, thiobarbituric acid reactive substance; POV, per-oxide value; FFA, free fatty acid; TCC, total coliform count; TYMC, total east-mould count; TVC, total viable count *p<0.05, **p<0.01, ***p<0.001

Prediction of broiler breast fillet quality traits

The ability of computer vision technology to predict meat quality trait is mainly remarkable with high determination coefficient (R^2) and it indicates the accuracy of model which ranges from 0 to 1. Table 3 presents the results of calibration and prediction of color, pH, and drip loss, cooking loss, dry matter, moisture and crude protein of the broiler breast meat using image data. The range of calibration data R^2 is 0.25-0.64 and range of prediction data R^2 is 0.05-0.56. The range of root mean square error for calibration and prediction are 0.10-4.22 and 0.11-4.67 respectively. pH and cooking loss have the most association with the image data in both calibration and prediction analyses. Chmiel *et al* (2011) used computer vision system to estimate fat content in poultry meat. They found coefficient of determination (R^2) for chicken thigh muscles were 68.9 for black background and

73.9 for green background. They used two types of background under the sample because the use of various background colors was purposed for achieving maximum contrast between tested sample and background color. They (Chmiel *et al*, 2011) also calculated R^2 value in estimating fat content in turkey thigh muscles using computer vision system were 65.0 and 49.0 for black background and green background respectively. Fatahi et al. (2017) diagnosed the chicken meat freshness using computer vision technology with appropriate degree of accuracy (R^2=80.02). Researcher (Ding et al., 2016) found the accuracy of 98% in chicken wings quality obtained via machine vision method. Geronimo et al. (2019) applied computer vision and near infrared methods for recognition and classification of chicken breast as wooden breast and normal. They obtained the accuracy of 91.8% in classification of chicken breasts as wooden or normal.

Table 3. Best fitting predictions of eight quality traits on broiler breast meat using image technology

Variables	n	R^2_C	$RMSE_C$	R^2_P	$RMSE_P$
L*	40	0.37	4.22	0.22	4.67
b*	40	0.25	2.54	0.05	2.86
pH	40	0.64	0.10	0.56	0.11
DL	40	0.43	0.81	0.29	0.91
CL	40	0.52	2.43	0.37	2.81
DM	40	0.3	2.18	0.19	2.34
Moisture	40	0.3	2.18	0.19	2.34
CP	40	0.45	1.08	0.26	1.24

DL, drip loss; CL, cooking loss; DM, dry matter; CP, crude protein; n, number of samples; R^2_C, coefficient of determination of calibration; $RMSE_C$, root mean square error of calibration; R^2_P, coefficient of determination of prediction; $RMSE_P$, root mean square error of prediction

Conclusions

The goal of the work was to investigate the ability of the computer vision system in predicting quality trait of broiler meat. Different color value, physicochemical, proximate, biochemical and microbiological assessment was done following conventional analytical techniques. Computer system has been standardized for this research. Different image data has been determined using computer vision system. The correlation coefficient was determined between image data and reference data. Cross validation was applied to find the level of accuracy of the computer vision system. Highest calibration and prediction accuracy were found for pH, medium accuracy was found in cooking loss, drip loss and crude protein of the sample. By applying statistical model dealing with predicting ability of computer vision technology to determine meat chemical properties showed its good potentiality to replace analytical technology which is time-consuming, expensive and hazardous for health and environment.

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