QUALITY ANALYSIS OF MEATS USING FTIR SPECTROSCOPY, COLOUR SPECTROPHOTOMETER, TEXTURE ANALYSER AND PHYSICAL IMAGE ANALYSIS

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Abstract: Assessment methods of meat such as physicochemical analyses and microbial techniques are laborious and time-consuming. A rapid and non-destructive quality analysis method of meat is needed and important to satisfy consumer demand. This study aims to implement FT-IR spectroscopy, colour spectrophotometer, texture analyser and physical image analysis to analyse the quality of raw, boiling and roasting meat. The FT-IR analysis revealed the functional group for proteins, triglycerides, fatty acids and carbohydrates with different intensities mostly focused at 3300 cm⁻¹, 2967 cm⁻¹, 1639 cm⁻¹, 1546 cm⁻¹, 1453 cm⁻¹. Colour parameters showed slight alterations and partial degradation of some proteins in meat was observed. L*, a* and b* for raw meats decreased, L* and b* for boiled and roasted meats increased, and a* decreased. The texture analysis shows significant different tenderness of meats and even cooking methods. Tenderness of raw meats decreased while the cooked meats increased from the first until the fifth day. The image analysis shows no significant changes in the meat textural surface. The findings show that the quality of cooked meats was better than raw meats. The assessment methods applied can evaluate the quality of meats and provide additional information on the physical changes of meat composition and structure.

Keywords: Beef, chicken, FTIR, colour spectrophotometer, texture analyser, physical image analysis.

Introduction

Meat quality has become more significant in meat industries as the rapid growth of pathogenic bacteria within meats may form surface slime, degradation of structural components, cause off-odours, off-flavours and change in meat appearance (Chen *et al.*, 2020). Spoilage and contamination of vulnerable meats can subsequently have effects on both producers and consumers. For instance, contamination from pathogenic bacteria as well as fungal may cause foodborne illnesses among consumers. According to Mutawakil (2011), the quality of meats can reduce quickly due to contamination that may be caused by oxidation and enzymatic autolysis.

Analysis of meat is much needed to ensure the compliance of the legal quality assurance standard. The previous study has shown that

traditional quality assessment methods of meat are always implied such as by sensory evaluation of meats and microbial techniques (Zhou *et al.*, 2010). The most common detection method on quality assessment of meat is by using physicochemical analyses and microbial techniques (Herrero *et al.*, 2017). Nevertheless, these methods have a major limitation such as being very laborious and time-consuming with high cost needed as in requiring a tremendous amount of samples. Therefore, it is required to introduce a fast, cost-effective, reagent-free and non-destructive methods to detect meat spoilage effectively. In the last year, alternative approaches based on vibrational spectroscopy have been developed.

In this regard, Fourier Transform Infrared Spectroscopy (FT-IR) is used as a quick and non-invasive method for detecting meat spoilage.

FT-IR spectroscopy has shown its potential to predict any functional group changes in meat substrates and might extract valuable data regarding the muscle decomposition and substance generation due to the onset of spoilage (Rahman *et al.*, 2016). Hence, FT-IR spectroscopy is believed to be one of the most effective methods for meat characterisation. The previous study showed the FT-IR analysis reveals the presence of absorbance bands of proteins, triglycerides, fatty acids, and others with different intensities according to meat type and processing (Dixit *et al.*, 2017).

Apart from that, meat quality is closely related to its colour and texture. Colour plays a vital role in determining the quality of meat products (Jackman *et al.*, 2011). Accordingly, the colour spectrophotometer can be used to examine the quality of meat which will give wavelength spectra analysis of the transmitted characteristics of the samples directly. It can provide enough data on colour values for any colour differences under a different light source. Standard meat colour measurement performed by colorimeter gives the direct benefit of tristimulus data (L^* for lightness, a^* for redness and b^* for yellowness).

Besides, the texture analyser can evaluate and distinguish the texture and tenderness of all types of meats according to processing types. Tenderness of meat also is one of the most essential quality parameters that must be taken seriously as too tough and soft meats may cause lower quality. Texture analysis of meats focused on evaluating the tenderness or toughness differences of meats with different types. Meanwhile, the study on the physical image analysis can differentiate the texture and surface appearances of meat samples.

This study implements FT-IR, colour spectrophotometer, texture analyser, and physical image methods to analyse beef (*m.longissimus dorsi*) chops and chicken (*m.pectoralis major*) breast and their shelf-life at freezing temperature storage (0 °C) for five days. Two examples of the cooking method

also were chosen: the boiling process represents moist heat treatment and the roasting process represents dry heat treatment to identify the effect of cooking and processing with freezer storage on the quality of the meat. This study aims to use FTIR, colour spectrophotometer, texture analyser and physical image analysis to analyse the quality of raw meat and cooked meat (beef and chicken) by different cooking methods i.e., boiling and roasting processes.

Materials and Methods

Samples Preparation

Two types of meat samples were used, are beef chops and chicken breast meat with three different analyses involving raw meats, boiled meats and roasted meats. Beef chops (*m. longissimus dorsi*) and chicken breast meat (*m. pectoralis major*) were freshly bought from the slaughtermen. The preparation method was inspired by Sinanoglou *et al.*, (2018). For raw meat analysis, the raw meat was packed and stored at -18 °C of frozen storage. The boiled meats were prepared by boiling in hot water (100 °C) for 30 minutes (25±5) for beef chops and 15 minutes (10±5) for chicken breasts. At the end of every five minutes the extractive substances produced by meats were removed from boiling water (Oz *et al.*, 2016). The roasted meats were cooked by using a kitchen type oven. The meat samples were cooked when the oven temperature reached 200 °C for 15 minutes and 9 minutes respectively. All cooked meat samples were processed until the internal core temperature of beef and chicken reached 77 °C (well-done) and 70 °C respectively using a digital thermometer (Oz *et al.*, 2016; Utama *et al.*, 2018). The meat samples were packed and stored in a sealed vacuum-packed and moisture impermeable polyethylene plastics and stored at -4 °C in a freezer for a five-day period. The meat samples were analysed for five days in a row using FT-IR, colour spectrophotometer, texture analyser, while the physical image analysis was used to study raw meat samples.

FTIR Characterisation

All meat samples were cut into approximately 0.001 g and were characterised by using UATR Two-FTIR spectrometer (Perkin Elmer) in the absorbance mode of 4000 to 400 cm^{-1} at room temperature (24 °C). The spectra were triplicated and recorded. Meat samples were analysed every day in the five-day period. The characterisation by FT-IR spectra was studied in two parts: (1) differentiate types of meat samples based on main functional groups existence, (2) interpret major and minor intensities of the obtained FT-IR spectra based on increasing storage period (Sinanoglou *et al.*, 2018).

Colour Measurement

All meat samples were weighed to approximately 5-10 g in individual sample cups. Meats were minced and compressed to obtain a smooth surface inside the cup and evaluated using a colour spectrophotometer (Hunter Lab 4500L). Colour spectrophotometer gave direct tristimulus of L^* (lightness), a^* (redness) and b^* (yellowness) values. L^* signifies the lightness of the color, a^* represents a measurement from red (+) to green (-) colour, and b^* represents a measurement from yellow (+) to blue (-) colour. The obtained tristimulus data were triplicated and expressed in mean $\pm$ standard deviation.

Texture Analysis

All meat samples were cut into small cubes with measurement of 2 cm $\times$ 2 cm $\times$ 2 cm (height $\times$ width $\times$ length) and analysed using a texture analyser (Stable Micro System TA.XT Plus). The texture analyser was calibrated first and the meats were loaded in the T.A. System Software. The meat samples were placed parallel to the surface of the penetration point. The probe chosen was flat-faced cylindrical probe 5 mm, with pre-test speed of 10 mm/sec, test speed of 2 mm/sec and post-test speed of 10 mm/sec. The data of hardness or force required to compress samples were triplicated (Peleg, 2019). The results of texture profile analysis (TPA) were triplicated and averaged with standard deviation.

Physical Image Analysis

Physical image analysis was determined by using a Canon digital camera by placing 3 cm $\times$ 2 cm (length $\times$ height) of raw meat samples (beef and chicken meat) (Sinanoglou *et al.*, 2018).

Results and Discussion

FTIR Characterization

All meat samples were analysed using FT-IR spectroscopy in the mid-infrared region and wavelength of 4000 to 400 cm^{-1} . Figures 1(a), 1(b) and 1(c) (in Appendix) show the FT-IR spectra of raw meats (beef and chicken), boiled meats (beef and chicken) and roasted meats (beef and chicken), respectively. The purpose is to determine the main functional groups that existed and related to the compositional changes of meats. Similar FTIR spectra showing a similar compositional of the nutritional content of meat samples was observed. The wide absorption band at the range of 3500 to 3000 cm^{-1} are due to O-H and N-H symmetric stretching vibration of alcohols and amide or proteins, respectively. Besides, a strong band at 3300 cm^{-1} is referred to as amide A and amide B bands. The amide A band is contributed to the N-H vibration, and the amide B band is the first overtone of amide II vibration. The changes in this range of wavelengths are related to changes in structural secondary protein within meats. These findings are similar to Sinanoglou *et al.* (2018), Petracci & Berri (2017) and Barth (2007).

The weak absorptions bands at 2950 to 2850 cm^{-1} are related to methyl and methylene groups' asymmetric and symmetric stretching of the carbonyl group of triglycerides' ester bond. These bands were the most significant in roasted meats and slightly intense in boiled meats. It shows that higher heating treatment causes more intense at 2950 to 2850 cm^{-1} as roasting used higher temperatures during the cooking process. The strong and sharp absorption band at the range of 1640 to 1634 cm^{-1} can be described as C=O stretching vibration of amides I. This peak is correlated with proteins adopting with β -sheets conformation and strong water absorption

which will significantly overlap the amide I band (Herrero *et al.*, 2017; Papadopoulou *et al.*, 2011). The strong water absorption indicates the high moisture content of meat that influences the protein structure. The strong water absorptions will cause the meat to dehydrate to prevent the protein structural changes. Despite the amide I band, the amide II band can determine the protein structural changes due to the intrusion of water bending at 1640 cm^{-1} . The amide I absorption band which characterises the protein secondary structure is located in the region of 1648 to 1658 cm^{-1} and 1620 to 1640 cm^{-1} are associated with the α -helix and the β -sheet protein structure, respectively (Yu., 2005). Therefore, the major protein structure content of both beef and chicken samples is β -sheet. Another sharp absorption band can be identified in the range of 1546 to 1550 cm^{-1} . This is the combined vibration of the amino group (N-H) bending with the C-N stretching of proteins. The peak at 1543 cm^{-1} represented C=O stretching band and the scissoring band of CH_2 groups. A similar result was observed by Herrero *et al.* (2017), where the strong absorption bands are affected by the amino group and the carbonyl group of proteins.

The weak absorbance bands at 1453 to 1399 cm^{-1} are related to the C-H bending of alkyl chain methylene of lipid moieties. It also corresponds to C-H asymmetric and symmetric stretching vibrations of protein moieties, respectively. Additionally, bands appearing in 1400 to 1200 cm^{-1} region can be attributed to bending vibrations of CH_2 and CH_3 aliphatic

groups (Herrero *et al.*, 2017). Ammor *et al.*, (2009) found that the minor intensity peaks observed at 1458 cm^{-1} are related to scissoring of CH_2 of fats. Moreira and co-workers (2018) proved that absorption bands at 1458 cm^{-1} are due to C-H bending and stretching of methylene (CH_2) and methyl (CH_3) groups present in fats within the meat. Minor peaks at 1398 cm^{-1} and the peak at 1315 to 1303 cm^{-1} are related to stretching of C-N and C-O, bending of N-H and O=C-N bending of amide III. The minor intensity peak observed at 1170 to 1154 cm^{-1} is attributed to the C-O stretching of proteins and triglycerides. The region can also be associated with C-O and C-C stretching vibrations due to the presence of carbohydrates. At 1240 and 1083 cm^{-1} , there are P=O symmetric and asymmetric which contributed to phospholipids and nucleic acids. The absorption band at 1080 cm^{-1} contributed as carbohydrate moieties and in the case of meats, it can represent glycogen (Sinanoglou *et al.*, 2018). Table 1 tabulated the summary of functional groups corresponding to the FTIR spectra for all meat samples.

Furthermore, the spectra of meat samples showed the absorbance bands of higher intensities at 3500 to 3000 cm^{-1} , 2950 to 2920 cm^{-1} , 2852 and 1744 cm^{-1} . It seems that beef meat has a higher lipid content compared to chicken meat as the beef spectra show higher intensities than chicken meat spectra. Moreover, the band at 3500 to 3000 cm^{-1} is associated with the vibration of the olefin group, which is characterised by the higher content of unsaturated fatty acids (Guntarti *et al.*, 2015). Additionally,

Table 1: Summary of functional groups in meat samples

Wavenumber (cm^{-1})	Functional groups
3500-3000	O-H, N-H symmetric stretching vibration of alcohols & amide of proteins, strong water absorption, O-H
3300	Amide A and amide B
2950-2850	Methyl & methylene of C=O of triglycerides
1634-1640	C=O stretching vibration of amides
1546-1550	C=O stretching & scissoring band of CH_2
1240	P=O symmetric & asymmetric of phospholipids & nucleic acids

beef meat has higher protein content than chickens, as the spectra of beef showed higher intensities at 1450, 1395, and 1170 to 1154 cm^{-1} than the ones of the chicken meat samples. In this sense, the adsorption bands at 1627 and 1541 cm^{-1} , which are characteristics of the protein exhibited a higher signal in the spectra of beef meat than in those of the chicken ones. A similar observation was found by Sinanoglou *et al* (2018) who studied on turkey and pork hams. The spectra of the chicken obtained significantly higher intensities at 1040 to 1020 cm^{-1} than the beef, which is indicative of higher carbohydrate content.

Effect of Frozen Storage Towards Meat Quality by FT-IR Interpretation

To monitor the quality of all meat in frozen storage, a comparative analysis was carried out where the meat samples were analysed every day in a five-day period. The analysis comprises of the selected range of wavelengths consisting of significant intensity peaks for all types of different samples that were used.

Based on Figures 2(a) and 2(b) (Appendix), it can be observed that the FTIR spectra of raw meat samples (beef and chicken) showed a significant decrease at 3500-3000 cm^{-1} . The bands are correlated with olefin group vibration which indicates unsaturated fatty acid contents (Sinanoglou *et al.*, (2018). The decrease in those absorbance bands confirmed that there is a partial reduction of unsaturated fatty acids within meat samples. The slightly increased intensities at 2990-2880 cm^{-1} from Day 1 to Day 5 in raw meat samples correspond to methyl and methylene groups' asymmetric and symmetric stretching of fatty acids. These changes may suggest that there is a degradation of triglycerides and an increase in the hydrolysis process resulting in the accumulation of free fatty acids. The freezing storage may suppress triglycerol acyl hydrolases that activate lipid hydrolysis, arising to free fatty acids, dimonoglycerides and monoglycerides (Liu & Kokare, 2016).

Moreover, the decrease at the intensity peaks of 1634-1630 cm^{-1} followed with the

other intensities peak at 1550-1540 cm^{-1} is probably due to the presence of partial protein rupture representing the stretching vibration of C=O and bending vibration of N-H (Yu, 2005). The decreasing of minor intensities peaks between 1450-1440 cm^{-1} and 1399-1395 cm^{-1} within five days corresponds to the reducing of C-H bending of alkyl chain methylene of lipid moieties and C-H asymmetric and symmetric stretching vibrations of protein moieties respectively. Meanwhile, the reducing intensities at 1245 to 1240 cm^{-1} marginally throughout freezing storage indicates that P=O absorption of nucleic acids reluctantly decreased due to freezing storage (Rahman *et al.*, 2018) and followed with slightly reducing intensities peak at 1174 to 1165 cm^{-1} and 1082 to 1075 cm^{-1} as an increasing storage period. The intensity of 1174 to 1165 cm^{-1} decreased from day 1 to day 2 but remained constant in the next remaining three days. The intensities are associated with C=O and C-O stretching of carbonyl and ether bonds of triglycerides and the decrease probably means lessening of the triglyceride content in meat samples (Sinanoglou *et al.*, 2018).

Figures 2(c) and 2(d) (Appendix) show the difference of FTIR spectra interpretation for boiled meats. It shows that as days of frozen storage increased, boiled meat samples did not experience any significant changes in their chemical properties. Most of the intensity peaks from 3500 to 3000 cm^{-1} , 1634 to 1630 cm^{-1} and 1550 to 1540 cm^{-1} in both meat samples showed stagnant in those five days of storage where all of the chosen intensity peak range did not show any extreme differences or changes in those five days. This can also be seen in the FTIR spectra interpretation of roasted meats in Figures 2(e) and 2(f) (Appendix) where it exhibited a stationary intensity peak within five days of frozen storage. However, at 2990-2880 cm^{-1} , roasted meats exhibit a higher absorbance than in the boiled meats. In this case, there was a higher chance for a high amount of carbonyl group methyl and methylene stretching in roasted meats. There were no previous findings for this comparative analysis of boiled meat and roasted meat in frozen storage. However, it

can be concluded that frozen storage of cooked meat does not give any effects to its chemical properties. The cooking of meats would retain the quality of meats by un-disturbing the chemical composition of meats thus maintaining the shelf life of meats compared to the unprocessed meats. Table 2 tabulated the summarisation of intensity peak changes towards the frozen storage effect.

Colour Measurement

The colour measurement of meat samples was analysed using a colour spectrophotometer. Table 3 shows the values of the tristimulus of L^* (lightness), a^* (redness) and b^* (yellowness) of meat samples within a five-day period frozen storage. It shows that the values of L^* in all raw meat samples were significantly higher in Day 1 compared to Day 5. The L^* values in Day 1 of raw beef and chicken meats are 38.63 ± 0.230 and 63.35 ± 0.044 , respectively. Eventually, both samples exhibit a slight decrease in L^* values until Day 5 of frozen storage, where the L^* values are decreased to 34.79 ± 0.089 (raw beef) and 58.99 ± 0.116 (raw chicken), respectively. A decrease of a^* values of meat samples was from Day 1 which exhibited 11.71 ± 0.026 (raw beef) and 8.91 ± 0.021 (raw chicken), and on the 5th day exhibited 10.36 ± 0.120 (raw beef) and 7.3 ± 0.050 (raw chicken). Likewise, the b^* values showed a similar trend with a slight reduction

from Day 1 where 6.82 ± 0.015 (raw beef) and 14.90 ± 0.021 (raw chicken) until Day 5 where 4.08 ± 0.046 (raw beef) and 11.56 ± 0.090 (raw chicken), respectively.

Besides that, the L^* values of boiled meat showed an increase from Day 1 to Day 5. The L^* values of boiled meats are 43.98 ± 0.030 (boiled beef) and 72.41 ± 0.040 (boiled chicken) in Day 1 and increased to 44.83 ± 0.020 (boiled beef) and 74.64 ± 0.040 (boiled chicken) in the Day 5. The increase was also shown in b^* value of both boiled meat samples, where 10.30 ± 0.300 (boiled beef) and 15.95 ± 0.040 (boiled chicken) in Day 1 to 10.66 ± 0.010 (beef boiled) and 16.47 ± 0.290 (chicken boiled) in Day 5, respectively. However, a^* values for boiled meats decreased from Day 1, with values of 6.96 ± 0.006 (boiled beef) and 2.35 ± 0.010 (boiled chicken) to 5.84 ± 0.010 (boiled beef) and 1.63 ± 0.020 (boiled chicken) at Day 5. The roasted meats also showed an increase of colour parameters L^* with 40.74 ± 0.060 (roasted beef) and 70.32 ± 0.090 (roasted chicken) in Day 1 to 42.30 ± 0.040 (roasted beef) and 71.12 ± 0.040 (roasted chicken) in Day 5. There are decreases in a^* values from Day 1 to Day 5 with values of 0.35 ± 0.010 to 0.022 ± 0.010 for roasted beef, and 1.54 ± 0.020 to 1.10 ± 0.050 for roasted chicken, respectively. While b^* values of roasted meats showed a slight increase from Day 1 to Day 5

Table 2: Changes in intensity peak in a five-day storage

Wavenumber (cm ⁻¹)	Functional groups	Interpretation
3500-3000	O-H, N-H	Decrease in unsaturated fatty acid contents; partial reduction of unsaturated fatty acids within meat samples
2990-2880	Methyl & methylene of C=O	Increase in the?? represents fatty acids Degradation of triglycerides & increase of hydrolysis process resulting in the accumulation of free fatty acids
1634-1630	C=O	Represent partial protein rupture
1550-1540	C=O	Represent partial protein rupture
1450-1400	C-H	Decrease in lipid moieties
1399-1395	C-H	Decrease in protein moieties
1245-1240	P=O	Decrease of nucleic acids
1174-1165	C=O	Decrease of triglycerides
1082-1075	C-O	Decrease of triglycerides

with 10.93 ± 0.050 (roasted beef) and 13.12 ± 0.090 (roasted chicken) to 11.73 ± 0.007 (roasted beef) and 13.72 ± 0.030 (roasted chicken). It can be simplified that the L^* , a^* and b^* values of raw meats decreased from Day 1 until Day 5. The boiled and roasted meats exhibited an increase in L^* and b^* values but a decrease in a^* values within five days of storage. It can be revealed that the L^* and b^* values of raw meats are lower than boiled and roasted meats, while a^* values of raw meats were significantly higher than the boiled and roasted meats. The results and findings for cooked meat correspond to the findings of Oz, *et al.* (2016).

The reduction L^* , a^* and b^* values of raw meats from Day 1 until Day 5 are correlated with myoglobin content in meat muscle. Meat colour in both white meat and red meat is mostly determined by the amount of myoglobin, haemoglobin and cytochrome C catalase in skeletal muscle (Nathan *et al.*, 2016; Yu *et al.*, 2017). However, 80 to 90 % of meat colour depends on myoglobin content. Frozen storage and increasing shelf life of meat samples may give an impact on the stability of myoglobin content. It can also be described that after freezing storage meat for a long time, a high concentration of metmyoglobin gives the meat an undesirable brown colour and lessens the red colour of meat. This is the cause of changes of both a^* and b^* values of meat samples. Similar results have been found with frozen storage of fresh beef (Pietrasik & Janz, 2009), poultry meat (Leygonie *et al.*, 2012) and fresh lamb (Belles *et al.*, 2018). The colour changes that occur are caused by the deterioration of the globin moiety of myoglobin during storage. Myoglobin will be more susceptible to autoxidation when deterioration occurs, leading to a subsequent amount of discoloration within the meat. The accumulation of metmyoglobin within meat during storage can explain the reduction of a^* value of meat samples (Bekhit *et al.*, 2007). Changes in b^* values are mostly caused by the metmyoglobin content as well and lipid oxidation (Xiong, 2000), while the decreasing L^* value is caused by decreased water retention,

resulting in lower surface light reflectivity (Hughes *et al.*, 2014).

The colour of meat samples can be also affected by the cooking method. The boiling method is one of many cooking methods preferred by meat consumers. The colour of the boiled sample did not show any significant difference within five days of storage. However, it can be seen that the L^* and b^* parameters for boiled and roasted meats are higher than the raw meats (Table 3), while a^* values of boiled and roasted meats are lower than the raw meats. During the time of cooking the meat, the globin gives the colour to fresh meat denatured forming haemoglobin (Aberle *et al.*, 2001). This leads to subsequent decrease in a^* values. Besides, a lower average of L^* values in roasted meat was correlated with dry heat treatment applied while a higher average of L^* values in boiled meat represents moist heat treatment (Oz and Zikirov, 2015; Utama *et al.*, 2018). The decrease in a^* value of roasted and boiled meat indicates the denaturation of myoglobin content as it is usually correlated with the amount of oxymyoglobin. Therefore, a decrease in a^* value also indicates the denaturation the myoglobin pigments. Similar findings were obtained by Sanchez del Pulgar *et al.* (2012) as their research also obtained a decrease in a^* values of beef. Choi *et al.*, (2016) also obtained similar results for boiled chicken breast meats. The increased b^* values of boiled and roasted meats are noted more than raw meat samples and this indicates yellow colour intensity. The yellow colour on meat is still unexplained. However, findings by Wei *et al.*, (2017) also have shown similar results, where the b^* value increased and was correlated with increased lipid oxidation.

Based on the findings, it shows that the value of L^* , a^* and b^* of raw meat samples decreased from Day 1 of frozen storage until Day 5. These changes were caused by the effect of frozen storage on the raw meat samples. The L^* , a^* and b^* values of boiled meat samples during the five days of storage did not give any significant difference. This shows that the colour measurement of boiled and roasted meat

Table 3: Colour measurement values (L^* , a^* , b^*) of raw, boiled and roasted beef and chicken meats

Raw Beef			
Time (day)	L^*	a^*	b^*
1	38.63 ± 0.230	11.71 ± 0.026	6.82 ± 0.015
2	37.79 ± 0.220	11.37 ± 0.015	5.03 ± 0.017
3	37.18 ± 0.046	11.24 ± 0.034	4.91 ± 0.023
4	36.79 ± 0.075	10.87 ± 0.110	4.72 ± 0.026
5	34.79 ± 0.089	10.36 ± 0.120	4.08 ± 0.046
Raw Chicken			
Time (day)	L^*	a^*	b^*
1	63.35 ± 0.044	8.91 ± 0.021	14.90 ± 0.021
2	62.53 ± 0.100	7.72 ± 0.050	12.88 ± 0.040
3	61.56 ± 0.030	7.66 ± 0.005	12.64 ± 0.010
4	59.03 ± 0.006	7.45 ± 0.04	11.82 ± 0.060
5	58.99 ± 0.116	7.30 ± 0.05	11.56 ± 0.090
Boiled Beef			
Time (day)	L^*	a^*	b^*
1	43.98 ± 0.030	6.96 ± 0.006	10.30 ± 0.300
2	44.00 ± 0.140	6.79 ± 0.006	10.66 ± 0.010
3	44.47 ± 0.050	6.68 ± 0.050	11.01 ± 0.150
4	44.71 ± 0.020	6.49 ± 0.020	11.12 ± 0.040
5	44.83 ± 0.020	5.84 ± 0.010	11.66 ± 0.010
Boiled Chicken			
Time (day)	L^*	a^*	b^*
1	72.41 ± 0.040	2.35 ± 0.010	15.95 ± 0.040
2	72.47 ± 0.120	2.24 ± 0.050	16.12 ± 0.030
3	72.94 ± 0.050	2.06 ± 0.030	16.44 ± 0.006
4	73.88 ± 0.020	1.66 ± 0.006	16.46 ± 0.020
5	74.64 ± 0.040	1.63 ± 0.020	16.47 ± 0.290
Roasted Beef			
Time (day)	L^*	a^*	b^*
1	40.74 ± 0.060	0.350 ± 0.010	10.93 ± 0.050
2	41.77 ± 0.050	0.032 ± 0.010	10.87 ± 0.010
3	41.81 ± 0.010	0.029 ± 0.030	11.38 ± 0.030
4	41.80 ± 0.030	0.025 ± 0.010	11.69 ± 0.040
5	42.30 ± 0.040	0.022 ± 0.010	11.73 ± 0.070
Roasted Chicken			
Time (day)	L^*	a^*	b^*
1	70.32 ± 0.090	1.54 ± 0.020	13.12 ± 0.090
2	70.51 ± 0.070	1.49 ± 0.010	13.57 ± 0.010
3	70.75 ± 0.020	1.35 ± 0.010	13.62 ± 0.030
4	70.87 ± 0.050	1.27 ± 0.030	13.67 ± 0.010
5	71.12 ± 0.040	1.10 ± 0.050	13.72 ± 0.030

samples was not affected by frozen storage but mostly by the cooking method treatment. The reasons are probably due to the denaturation of myoglobin during cooking resulting in no further changes exhibited during the frozen storage of cooked meats. The slight changes are increased in L^* and b^* and decreased in a^* in both boiled and roasted meat samples, perhaps as a result of freeze burn exhibit by meats. This finding supported FTIR analysis. To summarise, the raw meats indicate the colour changes which represent the differences in meat quality freshness. The colour of raw meats decreased and this shows the reduction of raw meats quality compared to the cooked meats.

Texture Profile Analysis

The mechanical and geometrical texture attributes of meats were evaluated using a texture analyser. The TPA was carried out to analyse the tenderness of meat samples. The results of the meat samples are shown in Table 4. Force needed to compress raw meat samples in Day 1 is higher than the raw meat samples in Day 5, recorded with 8.25 ± 0.030 N (raw beef) to 7.89 ± 0.050 N (raw beef) and 7.45 ± 0.010 N (raw chicken) to 6.74 ± 0.012 N (raw chicken), respectively. This indicates that as the storage period increased, the force needed for the compression of all raw meat samples decreased. The decline in force required was due to an increase in deterioration in the protein structure of raw meats.

As reported by Rhee *et al.* (2004), tenderness of meat may result from the degradation of structural proteins or protein patterns during freezing storage. Myosin degradation within meat muscle proteins is the main factor that may affect meat tenderness. Frozen storage also caused ice crystal formation within meat muscles, thus affecting meat tenderness. When the ice crystal formed within meat muscles, desiccation of the protein cell membrane will occur (Kang *et al.*, 2014). The ice crystals may destroy the structure of meat as the water was frozen leading to a high concentration of solutes within the protein structure of meats. The ice

crystals will attract water from intracellular to intercellular spaces leading to an excessive loss of moisture during the thawing process. The damaged muscle fibres do not reabsorb water upon thawing, thus a further loss of moisture ~~to~~ occurs. Wang *et al.* (2020) stated that the tenderness of meats is affected mostly by the formation of ice crystals similar to this finding. As a consequence, the texture of meat may deteriorate due to an increase in the affluence of water-soluble nutritional components and also decrease the water holding capacity (WHC) of meat (Cho *et al.*, 2014; Lagerstedt *et al.*, 2008). In conformance with Huff-Loneragan & Lonergan (2005), as stated that water loss is directly proportional to the WHC of muscle meat.

For boiled and roasted meat samples, with increasing frozen storage, the force needed was increased. Boiled meats exhibited an increase in tenderness from Day 1 until Day 5 with 9.56 ± 0.001 N (boiled beef) to 10.12 ± 0.08 N (boiled beef) and 9.45 ± 0.030 N (boiled beef) to 9.96 ± 0.020 N (boiled chicken). Similarly, roasted meats also display similar findings with an increase in tenderness from Day 1 until Day 5. Roasted beef showed a total of 10.26 ± 0.020 N and the roasted chicken exhibited the total force of 10.21 ± 0.030 N on Day 1. Both exhibited an increase in tenderness on the last day with 11.35 ± 0.050 N for roasted beef and 10.61 ± 0.060 N for roasted chicken, respectively. These findings were comparable to findings of Choi *et al.* (2016), in that increased tenderness is obtained for dry heat than moist heat treatment of meats.

The results of tenderness for cooked meats are higher than raw meats due to the toughening of muscle fibres and tenderness of connective tissue. Changes can occur in actin and myosin muscle fibre protein when heating. The peptide chains of amino acids undergo deformation and then reformed or coagulate back. This results in moisture loss and toughening of muscle fibres. However, it has been shown that moist heat gave a tenderising effect on connective tissue as a result of the alteration of collagen to gelatine. When heat is applied, collagen converted into

Table 4: Texture profile analysis (TPA) of raw, boiled and roasted beef and chicken meats

Time of Frozen Storage (Day)	Force (N)					
	Raw beef	Raw chicken	Boiled beef	Boiled chicken	Roasted beef	Roasted chicken
1	8.25 ± 0.030	7.45 ± 0.010	9.56 ± 0.001	9.45 ± 0.030	10.26 ± 0.020	10.21 ± 0.030
2	8.21 ± 0.040	7.40 ± 0.012	9.67 ± 0.020	9.53 ± 0.090	10.59 ± 0.010	10.32 ± 0.010
3	8.15 ± 0.070	7.29 ± 0.012	9.85 ± 0.060	9.78 ± 0.010	10.65 ± 0.040	10.46 ± 0.050
4	8.12 ± 0.010	6.89 ± 0.012	9.96 ± 0.010	9.83 ± 0.030	10.87 ± 0.030	10.53 ± 0.010
5	7.89 ± 0.050	6.74 ± 0.012	10.12 ± 0.08	9.96 ± 0.020	11.35 ± 0.050	10.61 ± 0.060

water-soluble gel and muscle softens. A high softened connective tissue can be obtained by using moist heat treatment. Besides that, the harder texture of dry heated meat represents the denaturation of intramuscular collagen or changes in myofibrillar structure.

In conformance with that, Kaur *et al.* (2020) stated that denaturation of myofibrillar protein leads to meat toughening while tenderisation is caused by the solubilisation of connective tissue. This explained the higher average force in roasted meats than boiled meats. Freezing or frozen storage may also affect the tenderness of cooked meat. However, it is not as obvious as raw meat samples. Cooked meat has achieved its best tenderness resulting from the cooking method. Frozen-thawed cooked meats would not impact meat tenderness (Liu *et al.*, 2020). The slight changes in the tenderness of meat in Table 4 probably indicate the ice crystal formation during frozen storage. It shows different tenderness of raw and cooked meats which decreases and increases respectively due to the treatment process. In conclusion, this texture analysis is correlated with FTIR and colour measurement analysis. It inferred that the freshness of meat quality could be easily analysed.

Physical Image Analysis

Figures 3(a) and 3(b) (Appendix) show the images of raw beef and chicken meat surfaces in Day 1 and Day 5. The images were taken to analyse any significant changes in the meat muscles. There was no significant difference in meat muscles on the first day and the fifth day due to the low magnification of the digital camera used. However, according to Kim *et al.* (2015), the analysis of a meat structure using the hyperspectral image can show a significant change occurring during frozen storage. This might be due to frozen storage during those five days, indicating that ice crystal formation affects the muscle fibres in beef and chicken meat. As reported by Hong *et al.*, (2005), frozen storage can result in the destruction of muscle fibres due to the formation of ice crystals of various sizes according to the freezing rate. A faster freezing rate results in smaller ice crystals while slower freezing rate leads to a bigger size of ice crystal formation. The larger the size of ice crystal, the more damage it can do to the meat muscle fibres. A smaller ice crystal formation will cause less physical damage to meat components while larger ones interrupt the muscle cells and cause exudation. Other than freezing, thawing has been proven to give effects on muscle fibres of meats. According to Taher and Farid (2001), minimum thawing can reduce degradation in quality of meats.

Conclusion

This study was successfully implemented using the rapid and ease analysis methods, FT-IR spectroscopy, color spectrophotometer, texture analyser and physical image analysis for raw and cooked meats via boiling and roasting cooking methods throughout the five days of frozen storage. The FTIR analysis shows that there are significant changes in the composition of raw meat samples compared to cooked meat samples. The color measurement showed such substantial changes in meat samples within five days, where the freezing storage caused slight alterations for the colour parameters and partial degradation of some proteins in meat. The texture analysis shows significant difference in tenderness with different types of meat and cooking methods. However, the image analysis shows no significant changes in the textural surface of meat due to the conventional image analysis. It can be summarised that those methods applied were able to evaluate the differences in the quality of raw and cooked meats instead by of using laborious, costly and time-consuming analysis methods.

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Appendix

Figure 1: FT-IR spectra of (a) raw beef and chicken, (b) boiled beef and chicken and (c) roasted beef and chicken meats

Figure 2: The FT-IR spectra interpretation of (a) raw beef; (b) raw chicken; (c) boiled beef; (d) boiled chicken; (e) roasted beef; (f) roasted chicken within five days storage

Figure 3: Image of (a) raw chicken and (b) raw beef in day 1 (above) and day 5 (below)