CHAPTER II

LITERATURE REVIEW

2.1 Broiler Chicken (*Gallus gallus domesticus*)

A broiler chicken is a class of chicken bred and raised specifically for their meat. The broiler chickens grow much quicker than laying or any other traditional dual purpose breeds. They are distinguished for having excellent feed conversion ratio, low levels of activity, and fast growth rates reaching market weight of 1.8-2.3 kg within 5-6 weeks. (Beutler, 2007).

2.1.1 Taxonomy of Broiler Chicken

Kingdom:	Animalia
Phylum:	Chordata
Class:	Aves
Sub Class:	Neornithes
Order:	Galliformes
Family:	Phasianidae
Sub Family:	Phasianinae
Genus:	Gallus
Species:	Gallus
Sub Species:	G. g. domesticus

Figure 1: A typical Broiler Chicken

Source: http://www.indiamart.com, May 2014

2.1.2 Nutrient Requirements of Broiler Chicken

The broiler chicken nutritional requirement is affected by several factors. Some of these factors are:

- Environment (temperature, weather, housing and competition for feed).
- Breed, sex and genetic background of the chickens.
- Health status of herd.
- Energy concentration of the diet.
- Level of feeding, such as limited feeding versus *ad libitum* feeding.
- Availability and absorption of dietary nutrients.

For broilers, the formulation of the feed is done to enhance rapid growth and such feeds are usually high in energy (3000 kcal) and high protein (22 - 24%) for the first 5 - 6 weeks to obtain early rapid growth. After the first 5-6 weeks, the protein can be reduced to 19 - 20% with the energy still 3000 kcal per kg of feed for fattening

(Banerjee, 1998). McDonald *et al.* (1988) argued that growing poultry are normally fed *ad libitum* (fed to satisfaction) and feeding standards for them are expressed not as amounts of nutrients but as the nutrient proportions of the diet. The nutrients worth of feed ingredients for poultry depends on many factors such as variety, the source, processing and storage conditions, species, season and the class of poultry being fed.

Table 1: Nutrient Requirements of Broiler chicken

Nutrients	Units	Starter 0-10 days	Grower 11-24 days	Finisher >25 days
Protein	%	22-25	21-23	19-21
Metabolisable energy	Mj/Kg	12.60	13.30	13.50
	Kcal/kg	3010	3175	3225
Total Arginine	%	1.48	131	1.11
Digestible Arginine	%	1.33	1.18	1.00
Total Lysine	%	1.44	1.25	1.05
Digestible Lysine	%	1.27	1.10	0.92
Total Methionine	%	0.51	0.45	0.39
Digestible Methionine	%	0.47	0.42	0.36
Total Methionine +Cystine	%	1.09	0.97	0.83
Digestible Methionine +Cystine	%	0.94	0.84	0.72
Total Threonine	%	0.93	0.82	0.71
Digestible Threonine	%	0.80	0.70	0.61
Total Trypophan	%	0.25	0.22	0.19
Digestible Tryptophan	%	0.22	0.19	0.17
Total Valine	%	1.09	0.96	0.81
Digestible Valine	%	0.94	0.83	0.70
Calcium	%	1.0	0.90	0.85
Available Phosphorous	%	0.50	0.45	0.42
Sodium	%	0.16	0.16	0.16

Source: http://www.poultryhub.org/nutrition/nutrient-requirements/nutrient requirements-of-meat-chickens-broilers/, April, 2015

2.1.3 Broiler Chicken Meat Industry in Malaysia

The Malaysian livestock industry is basically dominated by the poultry industry which supplies more than 80 percent of the total meat requirements/consumption of the country. This industry is regarded as the most important sector of the livestock industries and perhaps has the highest output value per worker in the agriculture sector (DVS, 2011). Malaysia has one of the highest per capita consumption of chicken in the world. Per capita consumption of chicken/duck meat per person is about 35 kg in 2010 (DVS, 2011; Jayaraman et al., 2013). Chicken meat is the most popular and cheapest source of meat protein among Malaysians, largely because there are no dietary prohibitions or religious restrictions against chicken consumption. Over the years, quick service restaurants (QSR) such as Kentucky Fried Chicken (KFC), McDonald's, Nando's etc. have propelled the growth of chicken consumption in Malaysia. Malaysian consumers today demands safe and high quality food at a reasonable price from the industry. They are very sensitive towards issues related to food safety and halal matters. It is important to note that the majority of the Muslim consumers will not accept poultry products that are not certified halal by the Department of Islamic Development Malaysia (JAKIM). The Malaysian consumers are also price-sensitive and look for value-for-money products. The poultry industry is increasingly challenged to produce new innovative products at lower costs without compromising on the quality.

2.2 Overview of Current Slaughter Practises of Animals

Animal production deals with rearing of animals while processing deals with the slaughtering, distribution and storage of animals to produce finished products called meat. Processing of animals has a key role to play because badly processed meat can

adversely affect the quality of the end product. Undesirable defects that can occur if a meat is badly processed include; haemorrhages, broken bones, bruising, Pale Soft Exudative (PSE) and Dark Firm Dry (DFD) meat, short shelf life and even condemnation of the meat (Anil, 2012).

Slaughtering procedures are controlled by rules and codes of practise of National and International Councils relating to ritual and conventional slaughtering of animals. The suitability of the method used is dependent on the guidelines that have been set by these domestic and International councils.

2.3 Religious Slaughter Methods

In recent times, the guidelines used in the ritual slaughtering of animals before it can be deemed fit for consumption in some faiths has been very controversial. The most common ritual/religious slaughter methods are the Halal (Muslim) and Kosher (Jewish method) which are usually done with or without stunning before sticking is actually done.

Poultry slaughtered for domestic consumption in accordance with Shari'a law is usually slaughtered manually by a slaughterer who has been certified by competent authorities on Halal slaughtering and if stunning is to be used, electric head stun or electrified water bath is recommended for poultry (MS 1500:2009). However, Halal slaughtering of poultry for commercial purpose may require the use of mechanical slaughter due to the numbers of chickens slaughtered daily. For chickens slaughtered using the mechanical slaughter to be Halal, the following conditions must be strictly followed;

- The operator of the mechanical knife shall be a Muslim.

- The slaughterer shall recite "Bismillah Wallahuakbar" prior to switching on the mechanical knife and shall not leave the slaughter area.
- Should the slaughterer leave the slaughter area, he shall stop the machine line and switch off the mechanical knife. To restart the operation he or another Muslim slaughterer shall recite "Bismillah Wallahuakbar" before switching on the line and mechanical knife.
- The knife used shall be of single blade type and shall be sharp.
- The slaughter act shall sever the trachea, oesophagus, both the carotid arteries and jugular veins to hasten the bleeding and death of the animals
- The slaughterer is required to check that each bird is properly slaughtered and any birds that missed the mechanical knife shall be slaughtered manually.
- A backup slaughterer with knife shall be ready to check any neck not cut well during mechanical slaughtering and rapidly cut it manually.
- Bleeding period shall be minimum 60 seconds but during winter this period shall be increased by 5-10 seconds (OIC Standards, 2009)

2.3.1 Halal Slaughter Method

Halal slaughter method is a type of religious slaughter practised by people following the Islamic faith. It is a method prescribed in the Quran and Hadith (sayings of Prophet Mohammed). It involves pronouncing the name of Allah (God) before actual slaughtering is performed. Animals are restricted but there is no rule guiding how the animal should be restricted. Slaughtering is done as quickly as possible by severing the neck at one stroke using a sharp knife (OIC Standards, 2009).

A maximum blood loss is essential during halal slaughtering process in order to make the meat fit for Muslim to consume because consumption of blood is forbidden for

Muslims (Al-Ma'idah 5:3). Complete blood loss causes occulsions which delayed bleed out rate and consciousness was observed in ruminants (Anil et al. (a), 1995; Anil et al. (b), 1995). Stunning the ruminants before the Halal slaughtered was reported to hinder blood loss. However, this statement was disputed in 2004 where the researchers observed no significant difference ($P<0.05$) in blood loss between stunned and non-stunned sheep and cattle (Anil et al., 2004).

2.3.2 Rules of Halal slaughter

Halal slaughter method is guided by rules and regulations. These rules are clearly stated in the Quran and Hadith for permissible and forbidden foods as well as the rules and practices of slaughter. Animals forbidden for Muslims consumption are pigs, carnivorous animals and carrions (Al Baqara 2:173). Hence, Muslims must ensure that the slaughtering rules are adhered to. If the treatment and slaughter of meat animals do not meet the criteria then the meat may be regarded as unlawful.

Halal slaughter rules are based on:

i) The Holy Quran

ii) Sunnah and Hadith

iii) Views of religious scholars.

Some Quranic chapters directly or indirectly referenced food and slaughter. These chapters include; Quran chapter 2 verses 168-173; Quran chapter 5 verses 1, 3, 5, 87 and 88; Quran chapter 6 verses 118, 119, 121, 145 and 146; Quran chapter 16 verses 114-118.

Some of the Prophet's Hadith concerning humane treatment and slaughtering of animals are stated as follows:

"Allah Who is Blessed and Exalted, has prescribed benevolence towards everything; so when you must kill a living being, do it in the best manner and, when you slaughter an animal, you should sharpen your knife so as to cause the animal as little pain as possible" (Narrated by Muslim).

"A good deed done to an animal is as meritorious as a good deed done to a human being, while an act of cruelty to an animal is as bad as an act of cruelty to a human being" (Narrated by Bukhari).

When one of you slaughters, let him complete it, "meaning that one should sharpen the knife well and feed, water, and soothe the animal before killing it" (Narrated by Ibn Umar).

2.3.3 Rulings (Fatwas) on Halal Slaughter using Stunning

Decisions on halal matters are usually made by Islamic scholars on issues relating to spirituality using the Quran and hadith as guide. Debates on rulings on Halal slaughter have been controversial. For example, a ruling was issued in 1978 by a special committee consisting of representatives of the four acknowledged Schools of Thought in Islam (Shafii, Hanafi, Maliki and Hanbali) at Al- Azhar University in Cairo allowing stunning of animals before slaughter as long as it clean, do cause maximum bleeding and quick (Masri, 1989).

Also the Joint Committee of the League of the Muslim World and World Health Organisation met at the Institute of Veterinary Medicine in West Berlin in 1986 to witness two stunning demonstrations on sheep. The Joint Committee observed that the sheep made a full recovery after being electrically stunned. The Joint Committee concluded that animals being slaughtered to provide Halal meat for Muslims can be electrically stunned provided the stun does not cause death (Masri, 1989). Similarly,

electrical stunning is also acceptable by the Halal Food Authority in United Kingdom (Halal Food Authority, n.d) and by the Saudi Arabian Standards Organisation. In addition, head only electrical stunning of mammals is accepted by the Arab Gulf Cooperation Council (GCC) which is enforced in Bahrain, Kuwait, Oman, Qatar and the United Arab Emirates (The Poultry Site, 2004).

Presently, the Organisation of Islamic Cooperation (OIC) working group and Malaysian standards are the most prominent bodies that set guidelines for slaughtering animals. The following conditions have been set by the OIC before stunning can be applied to an animal;

- Poultry shall be alive and in stable condition during and after stunning (loss of consciousness) and upon slaughtering.
- The current and duration of electric shock, if it is used shall be as specified in Table 2.
- Any poultry that die before the act of slaughtering shall be considered as dead and unlawful.
- Shall be proven to be humane.
- Shall not reduce the amount blood loss during slaughtering process.

However, the Malaysian standard (MS-1500:2009) do not recommend stunning of animals, but if stunning is to be used; the permitted types are electrical and pneumatic percussive stunning.

Table 2: Guideline parameters for electrical stunning according to OIC Standard.

Type of animal	Current(Ampere)	Duration(Second)
*Chicken	0.25-0.50	3.00-5.00
Lamb	0.50-0.90	2.00-3.00
Goat	0.70-1.00	2.00-3.00
Sheep	0.70-1.20	2.00-3.00
Calf	0.50-1.50	3.00
Steer	1.50-2.50	2.00-3.00
Cow	2.00-3.00	2.50-3.50
Bull	2.50-3.50	3.00-4.00
Buffalo	2.50-3.50	3.00-4.00
Ostrich	0.75	10.00

Note: Electrical current and duration shall be validated and determined by the organization, taking into account the type and weight of the animal and other varying factors.

Source: OIC Standards (2009)

2.3.4 Effect of Halal slaughter method on Meat Quality

Effect of halal slaughter on meat quality has been extensively reported (D'Agata et al., 2009; Alli et al., 2011; Addeen et al., 2014; Nakyinsige et al., 2014 and Sabow et al., 2015). Addeen et al. (2014) reported that birds slaughtered using the halal method had a lower drip and cook loss values compared with the other methods used namely, decapitation, conventional and unbled methods. The results were similar to that reported by D'Agata et al. (2009) who observed that meat derived from halal slaughtering showed lower drip loss compared to those from conventional slaughtering methods. Additionally, Addeen et al. (2014) concluded that Islamic

slaughtering method yielded chicken meat with better quality which was stable during post-mortem storage.

Nakyinsige et al. (2014) reported a significantly higher blood loss for rabbits slaughtered using the halal method than those killed by gas stunning. The residual blood in the gas-stunned rabbits increased the microbial load since blood favours the multiplication of spoilage microorganism. However, the studies carried out by D`Agata et al. (2009) gave a contradicting report. It was observed that meat obtained from cattle slaughtered by the halal method showed higher ultimate pH values and higher petechial haemorrhages caused by the increased blood pressure and the breaking of the vasal endothelium which may be probably due to short-term excitement of cattle prior to slaughter compared to cattle slaughtered by conventional method.

2.4 Conventional Methods of Poultry Slaughter

This method of slaughter is in accordance to the standards of the European Union. It was stated clearly in the Animal Protection Act No 1099/2009 that animals to be slaughtered in the abattoirs shall either be transported or lairaged, restrained and stunned before slaughtering can be performed. Some permitted stunning methods for poultry includes; electrical stunning and gas stunning.

2.4.1 Electrical Stunning of Chickens

The electrical water bath stunning is the most common method of stunning (or stunning/killing) poultry under commercial conditions (Gregory & Wotton, 1985; Anil et al., 1997; Raj, 2006). It is done to produce a brain dysfunction and render the birds unconscious before sticking is carried out (Anil & Mckinstry, 1992; Cook et al., 1996;

Cook, 1999). Ali et al. (2011) reported the lowest weight of blood bled and an increase in the bacteria count for birds slaughtered using the electrical stunning method and concluded that this might be due to the residual blood left in the carcass of the birds which serves as an excellent medium for growth of microorganism.

Kuenzel and Ingling (1977) compared plate and water-bath stunner, A.C. (60Hz) and D.C. voltages to determine which among them gave the best bleed-out. They concluded that an A.C. water-bath stunner set at 50 volts gave the best bleed-out in broiler chickens. Also, Kuenzel and Walther (1978) reported a better bleed-out using high frequency (480Hz) current.

There has been some level of doubt in the poultry industry as regards the electrical stunning of birds leading to cardiac arrest because it is believed that it results in poor bleed-out and hence reducing the quality of the meat produced (Griffiths et al., 1985). Therefore, some researchers have found a way of stunning a bird without leading to cardiac arrest (Gregory & Wilkins, 1989; Gregory & Wotton, 1990). Gregory and Wilkins (1989) reported that currents that stimulate ventricular fibrillation in most broiler chickens can be related with downgrading defects such as deep breast muscle haemorrhages, superficial leg muscle haemorrhages, wing-tip haemorrhages, shoulder haemorrhages and broken bones in the collar region, all of which would reduce the quality of the carcass and hence the meat produced. They recommended that the defects could be reduced by using currents less than 130mA or greater than 190mA. However, Gregory and Wotton (1990) reported that a minimum of 105mA was required to provide at least 52 seconds of stunning but recommended a current greater than 120mA.

Gregory et al. (1991) concluded that high frequency, pulsed, D.C. currents will ensure a humane stunning with a minimum of carcass downgrading.

2.4.2 Gas Stunning of Chickens

Controlled Atmosphere stunning (CAS) systems kills the birds by exposing them to anoxic gas mixture (gas mixture that does not contain oxygen) which rapidly renders the birds insensible to pain or distress. The major advantage of gaseous stunning is that birds can be stunned in their transport crates thereby eliminating the handling stress associated with uncarting and shackling in the electrical stunning method (Sparrey & Kettlewell, 1994).

Carbon dioxide (CO_2) at fairly high concentrations successfully rendered both broilers and laying hens unconscious with laying hen taking a little longer to become unconscious but at concentration of 55% CO_2, both birds became unconscious in 21-22 seconds (Raj & Gregory (a), 1990; Raj & Gregory (b), 1990). Lower concentration of gas has been reported to take longer time to stun the birds. In human, a CO_2 concentration of 30-60% is considered the minimum concentration respiratory distressed is experienced. So it is recommended that a low level of about 30% should be used to stun chickens but the disadvantage of using this low level is that the birds gain consciousness rather fast and, hence cannot be used in commercial processing line. Therefore it is recommended that levels should not be less than 55% CO_2 (Raj & Gregory (b), 1990).

Raj et al. (1990a) reported the lowest incidence of bone breakage for birds stunned with 2% oxygen in argon, followed by birds stunned in 45% $C0_2$, then birds stunned in 55% $C0_2$ and lastly birds stunned electrically. They recommended that if gas stunning is to be used, it must not exceed 50%. Also Raj and Gregory (1991) reported that gas stunned broilers bled out more slowly than electrically stunned broilers over the first 60 seconds. They however reported no difference in the blood loss after 140 seconds. They therefore recommended a time interval of between 60 and 140 between

neck cutting and scalding. There was fewer muscle haemorrhages, more tender breast meat and breast muscles free of bruises for gas stunned birds when compared to birds stunned electrically (Raj et al., 1990). The texture and eating quality of gas stunned chicken fillets 2 hours *post mortem* were rated higher by tasting panellist than the electrically-stunned chicken fillet (Raj et al., 1992). Raj et al. (1997) reported that gas stunned chickens reduces meat quality defects and allows hot filleting at 4 hours post mortem without a reduction in quality when compared to electrically stunned birds.

2.5 Conversion of Muscle to Meat

The overall mechanical and biochemical changes of the muscle after the process of slaughtering largely determines the final meat quality. The development of rigor mortis is essential in the process of muscle conversion to meat hence, important for proper meat quality (Sams, 1999). After exsanguination, the muscle cells continue to respire, producing and consuming energy in the form of adenosine triphosphate (ATP). As the remaining oxygen left in the carcass is used up, the cells produce the needed ATP anaerobically. Glycolysis is an important biochemical process in the post-mortem conversion of muscle to meat. It involves the breakdown of glycogen to glucose 6-phosphate (G6P), glucose and lactic acid using the anaerobic respiration in order to produce ATP. The ATP produced is used for muscle metabolism after killing the animal (Hartschuh et al., 2002). As blood circulation hinders the removal of the accumulated lactic acid in the system, intracellular pH drops to a level that hinders further glycolysis and hence a stop to ATP production. As the ATP level drops to about 0.1mmol/g, rigor mortis is developed (Sams, 1999).

The process of muscle conversion to meat is completed when all the energy reserves in the muscles have been used up. The length of time required before rigor mortis can

occur depends on the amount of glycogen available within the muscle at the time of exsanguination and the continued activity of glycolytic enzymes (Swatland, 1994). Rigor mortis sets in when all the energy in the muscle has been expended and a temporary toughening of the muscle is noticed. Rigor mortis is not an instant process; it begins at a certain time after slaughter because of the gradual depletion of glycogen. This lag time is called the delay phase (Lyon & Buhr, 1999; Barbut, 2002). The length of delay phase is dependent on ultimate pH and time taken to reach pH_u. However, the onset of rigor mortis is not pH dependent but occurs when over 60% of the initial ATP has been used (Khan, 1975). It has been reported that rigor in breast meat can occur within 15 minutes post-mortem, whereas it takes leg muscle about 3 minutes to come into rigor. However, full rigor occurs at 2-4 hours post-mortem in breast fillet compared to less than 2 hours in leg meat (Kijowski et al., 1982). The muscle at this time is inextensible but after a certain period of time, the muscle begins to relax again as a result of the breakage of sarcomere components which is due to the activity of proteolytic enzymes. Some of the major changes during the aging process include the degradation of the thin protein band which actin filaments are attached in a striated muscle fibre (Z-line) and degradation of the protein nebulin, titin and desmin. The major proteolytic enzymes calpains and cathepsin are calcium dependent and this calcium is released from the sarcoplasmic recticulum and mitochondria during the process of post-mortem aging.

2.6 Meat Quality Attributes of Broiler Chicken Meat

Meat quality can be described as the qualitative characteristics that make up the meat. These include physical, chemical, nutritional, microbial, biochemical, sensory and cooking properties of the meat. Physical attributes such as appearance (colour),

texture, juiciness, tenderness, odour and flavour are mostly used by consumers to determine the quality of the meat prior or after purchase but a processor is more concerned about the shelf life, cook loss, drip loss, pH, shear force, water holding capacity, protein solubility and fat content of the meat (Allen et al., 1998). All these attributes are essential in order to reduce downgrading of the meat product. Grading of poultry product is usually based on the physical attributes without considering the functional properties of the meat which is the bases for further processing of meat by food and meat industries (Barbut, 1996). pH, colour, water holding capacity and tenderness are the major quality parameters usually used to assess meat quality (Dadgar et al., 2010).

2.6.1 Meat pH

Meat pH is the most important factor responsible for meat quality and protein functionality. There is a strong relationship between muscle pH and other meat quality attributes such as colour, WHC, tenderness, juiciness and shelf life due to its effect on protein structure and hydration properties. The variation in the quality of chicken meat is caused by the initial rate of pH decline after slaughter and the ultimate pH (pH_u) of meat reached at 5-6 hours post-mortem. A strong relationship between pH_u and lightness (L* value) of the breast meat in chicken has been reported (Allen et al., 1997; Barbut, 1997; Qiao et al., 2001; Anadon, 2002; Barbut et al., 2005). Such has also been reported for turkey (Owen et al., 2000). In addition, drip loss of raw meat are strongly related and correlated with pH_u and L* (Le Bihan-Duval et al., 2001). Also pH_u and L* are strongly linked and correlated with water-holding capacity and cooking yield (Le Bihan-Duval et al., 2001; Debut et al., 2003). Solubility and water binding capacity are minimal with a drop in pH of meat to the isoelectric point (where

the positive and negative charges are equal on proteins) and this is due to the fact that there is no net charge on the proteins to bind to water molecules and also there is no enough space for water within the myofibrils due to increased affinity within myofibrils. Swatland (1994) reported a pH of 5.5 for isoelectric point of muscle myofibrillar protein. In contrast, Srihari et al. (1981) reported different isoelectric point for various components of myofibrillar protein with actin having a pI ranging from 5.5-5.8; myosin heavy chain from 6.3-7.3 and myosin light chain from 4.8-5.6.

Table 3: pH rating Scale for Chicken Meat according to Gigaud et al. (2010)

Quality Defects	pH value
PSE defect	<5.70
Normal Meat	5.70<pH<6.20
DFD defect	>6.20

An understanding of the relationship between pH_u and L* could be a marker for quality differentiation of poultry meat. High ultimate pH produces a dark, firm and dry (DFD) meat with high WHC, poor storage quality due to high moisture content and a faster rate of production of off-odours and an accelerated microbial growth (Allen et al., 1998; Le Bihan-Duval, 2004). On the other hand, a fast drop in pH post-mortem and low final pH results in Pale, soft and exudative meat (PSE defect) although with better tenderness and reduced WHC.

2.6.2 Meat Colour

Meat colour is also an important meat quality parameter that determines the overall acceptability and purchase decision by consumers. Most consumers attributes meat colour to freshness and overall quality. Poultry meat shows a remarkable difference in colour due to its muscle biochemistry and histology. Poultry are classified as either white (breast meat with pale pink colour) or dark (leg and thigh meat with red colour) meat. The noticeable difference in the colour of meat is as a result of myoglobin pigment concentration. Anadon (2002) reported that changes in breast meat colour is more pronounced which is as a result of its natural light colour and because it makes up a large percentage of the carcass. Consumers are very sensitive to colour variations and if adequate care is not taken, it can lead to downgrading of the meat and hence causing great economic loss to the industry (Fletcher, 2002).

Meat colour differs based on the myoglobin and haemoglobin concentration (major meat colour pigments), chemical state of pigments, light reflection off the meat (Froning, 1995). Haemoglobin is found in the red blood cells and its concentration in meat is dependent on the efficiency of bleeding during slaughtering process (Swatland, 1994). Myoglobin is a soluble protein formed from a single polypeptide chain, which is surrounded by an oxygen-carrying heme group composed of an atom of iron and a porphyrin ring. The myoglobin functions primarily for the transportation of oxygen within the muscle fibre (Swatland, 1994). Factors such as age, sex, species and genotype can affect the concentration of myoglobin (Barbut, 2002). Meat colour, fibre content and myoglobin content are highly correlated because the basic difference in meat colour is due to relative amounts of white and red fibres. pH and post-mortem temperature play an important role on the extent of protein denaturation and physical appearance of meat (Lawrie, 1998). The extent of protein denaturation is directly

proportional to light scattering from a muscle surface. At pH ≥ 6.0, protein denaturation is minimal and water molecules are tightly bound thereby causing more light to be absorbed by the muscle hence, the meat appears translucent in colour. In contrast, at pH ≤ 6.0, protein denaturation is higher causing an increase in light scattering and making the muscles darker. Lightness (L*) is affected by light scattering but has a minimal effect on meat redness (a*) and yellowness (b*) (Barbut, 1997; Swatland, 1994).

Evaluation of colour can be done using different systems, the most common are CIE LAB and Hunter L, a, b solids scale. In the CIE LAB system, the L* value is an expression of the lightness of the surface ranging from 0-100 (black to white), a* value indicates red ranging from negative to positive (green to red) and b* value also ranging from negative to positive which stands for blue to yellow (Barbut, 2002). It has been reported that meat lightness increases significantly over post-mortem time hence the time at which L* value is measured could affect reading values of L* (McCurdy et al., 1996).

Meat colour has been reported to relate to other meat quality parameters and functional properties of meat (Barbut, 1997; Fletcher et al., 2000; Owen et al., 2000; Van Laach, 2000; Qiao et al., 2001; Bianchi & Fletcher, 2002; Bianchi et al., 2004, 2005, 2006, 2007). L* measurement can be used as an indicator of poultry breast meat quality for further processed products as well as poultry meat defects including PSE and DFD conditions. L* values of dark broiler breast fillets are reported to have significantly lower values, higher redness values (a*) and lower yellowness values (b*) than light broiler breast fillets (Allen et al., 1997, 1998; Petracci et al., 2004; Barbut et al., 2005; Bianchi et al., 2007). A variety of lightness (L*) of breast meat has been reported by different researchers ranging from; 35.3 to 55.6 (Barbut, 1997),

42.0 to 71.0 (Woelfel et al., 2002), 45.0 to 67.0 (Wilkins et al., 2000), 47.7 to 66.5 (Anadon, 2002), 40.0 to 66.0 (Petracci et al., 2004) and 41.0 to 56.0 (Lesiow et al., 2007). This wide variation in L* values are reflective of the wide distribution of muscle pH values at 24 hours post-mortem because these traits are inversely correlated. Factors such as genetics, age, sex, flock, nutrition, season of the year affects the lightness value (L*) of meat.

2.6.3 Water Holding Capacity

Water holding capacity is a significant quality parameter for both consumers and meat processors. The ability of meat to hold water helps with tenderness, juiciness, firmness and appearance of the meat leading to an improvement in quality and economic value. WHC of meat can be classified as water binding potential (WBP), expressible moisture and free drip. WBP is defined as the ability of the muscle proteins to retain excess water under the influence of external forces. It can also be regarded as the maximum amount of water the muscle proteins can retain under external forces (Swatland, 1994). Expressible moisture represents the amount of water that can be expelled from the meat by the use of force while free drip is the amount of water lost from the meat as a result of gravity (Swatland, 1994) which is important for consumer acceptability and retail display of tray packed meat.

Most of the water (88-95%) inside the muscle is held within intracellular spaces between actin and myosin filaments and only a small portion (5-12%) is located between the myofibrils (Offer & Knight, 1988). Several factors such as pH, sarcomere length, ionic strength, osmotic pressure and development of rigor mortis influence WHC (Offer & Knight, 1988). After animal death, lactic acid production and pH decline causes the reduction in water binding ability of the meat due to protein

denaturation, loss of protein solubility and therefore reduction of reactive groups available for water binding on muscle protein (Offer & Knight, 1988).

When pH decreases to values close to the isoelectric point of protein, water binding ability of the protein is impaired causing the myofibrils to shrink and the volume of sarcoplasm increases. As muscle fibres depletes all their ATP, the membranes no longer confine the cell water and fluid is lost from the muscle fibre that may contribute to the exudate lost from the meat (Swatland, 1994).

2.7 Factors Affecting Meat Quality

This can be broadly categorised into intrinsic and extrinsic factors.

2.8 Intrinsic factors

2.8.1 Genotype

Effects of genotype/genetic studies on meat quality characteristics of poultry are very recent. Several studies have investigated the effect of genetic line and growth rate on several quality properties of chicken meat (Berri et al., 2001; Anadon, 2002; Debut et al., 2003; Berri et al., 2005; Debut et al., 2005; Bianchi et al., 2006).

Genetic type has been reported to be associated with the rate of post-mortem pH decline (Berri et al., 2001). Some visible differences were recorded in the post-mortem biochemical development between chickens of same age but different genotypes (Berri et al., 2001; Le Bihan-Duval et al., 2001). These differences were noticed in fast growing line which was associated with lower level of activity on the shackle and a decrease in the extent of pH drop. In addition, Debut et al. (2003) reported significant differences in most of the meat quality parameters investigated between a slow-growing French Label-type line and a fast-growing standard line of chickens exposed to different pre-slaughtering stress conditions. It was reported that

the breast muscle of Label chicken has more glycogen reserves at the time of slaughter than the standard chicken types. This difference was attributed to the variability of muscle fibre structure among genetic types. So, they concluded that the extent of pH decline of slow-growing chicken lines is faster than in fast-growing chicken lines.

In contrast, Youssao et al. (2009) reported in their study on Label Rouge and indigenous chickens of North and South ecotypes that there was no significant difference among genotypes in pH recorded at 1 hour and 24 hours post mortem.

Furthermore, Lonergan et al. (2003) reported in their findings carried out on chicken from 5 genetic groups (inbred Leghorn, inbred Fayoumi, commercial broiler, F5 broiler-inbred Leghorn cross and F5 broiler-inbred Fayoumi cross) to compare chicken meat quality showed high differences in breast meat composition and quality. Their results suggested that the Leghorn inbred line breasts were more pure and has more intense red colour than the crossbred lines. Although the shear forces values (kg/g of sample) was higher in breast meat of broilers than in breast meat from the inbred lines.

Selection for fast growth and high yield has been reported to affects the sensory and functional attributes of the meat (Dransfield & Sosnicki, 1999; Le Bihan-Duval et al., 2001; Le Bihan-Duval, 2004); therefore differences in meat quality may exist between fast and slow-growing broilers.

It has been reported that different genes are responsible for the rate and extent of decrease in pH post-mortem in chickens. These results show that glycolytic potential and pHu of chicken meat have close genetic control and can be modified by selection. The slow-growing chicken meat tends to have a longer time of rigor inset with lower ultimate pH compared to broiler meat resulting in lower water holding capacity (Larzul et al., 1999; Le Bihan Duval et al., 2008). Also Fanatico et al., (2005)

indicated that percentage drip loss and cooking loss were reported to be significantly affected by genotype in slow-growing broilers. This result is in agreement with the earlier report of Debut et al. (2003) who reported a higher drip loss in breast from slow-growing broilers when compared with the fast-growing broilers. In addition, Jaturasitha et al. (2008a) indicated in their study of carcass and meat characteristics of male chickens from Thai indigenous, improved layer breeds and their crossbred that drip, thawing and cooking losses of breast and thigh muscle were significantly different among the various chicken genotypes.

Castellini et al. (2006) outlined that physico-chemical and sensory characteristics of chicken meat are greatly affected by genotype. They compared two chicken genotypes (Ross 205 and Kabir) reared using the same method. It was reported that meat from Ross chicken had a higher Thiobarbituric Acid Reactive Substances (TBARS) value when compared to their Kabir chicken counterpart. They further reported that these higher TBARS values were also negatively correlated to lightness and yellowness. Some researchers recorded that the lightness (L*), redness (a*) and yellowness (b*) of breast and thigh meat differ significantly among genotypes (Quentin et al., 2003). Other authors reported that slow-growing birds have a redder and darker meat when compared with fast-growing or high-performance birds (Le Bihan-Duval et al., 1999; Berri & Jehl, 2001; Debut et al., 2003). This dissimilarity in meat colour between genotypes may be as a result of variations in their slaughter age which significantly affected the myoglobin content in the muscle. The work of Gordon and Charles (2002) was in agreement with this statement but Lonergan et al. (2003) on the other hand attributed the distinction in redness between genotypes to a difference in the muscle fibre type.

The effect of genotype on nutritional chicken meat quality is contentious. Fanatico et al. (2005) showed that the *Pectoralis* muscle dry matter, fat and ash contents were mostly uninfluenced by genotype. This result is in agreement with earlier report by Latter-Dubois (2000) who found no significant differences in dry matter or ash in the breast meat among 5 crosses of fast-, medium-, and slow-growing chickens. In contrast, Lonergan et al. (2003) reported that lipid content were higher for breast meat obtained from fast growing broilers compared to the slow-growing ones. This statement was also supported by Havenstein et al. (2003) who observed more carcass fat for modern 2001 strain of broiler chicken than strains from 1957. In Thailand, it was also reported (Wattanachant et al., 2004; Wattanachant & Wattanachant 2007; Chuaynukool et al., 2007 Jaturasitha et al.(a), 2008) that genotype (breed and strain) of chicken plays a pivotal role in carcass fatness and meat quality. Oluwatosin et al. (2007) revealed a notable effect of genetic factors on the nutritional quality of the breast and thigh of cockerels of exotic strains (Nera, Bovan and Harco) and the local Nigerian strains. Their results suggested that the local Nigerian strains were nutritionally better than the exotic cockerels.

2.8.2 Muscle Fibre and Muscle type

The highest proportion of chicken carcass meat is located in the breast and thigh muscles and they differ in their chemical composition, technological and sensory qualities (Oluyemi & Roberts, 2000). Oluwatosin et al. (2007) reported that the thigh muscle is relatively more nutritive in terms of crude protein, crude fat, dry matter, organic matter and nitrogen free extract than the breast muscle in all cockerel strains. Many other authors have also reported the influence of the type of muscle on the quality of meat of chickens and ducks (Oluyemi & Roberts, 2000; Latter-Dubois,

2000; Baeza, 2006; Woloszyn et al., 2006; Berri et al., 2007; Jaturasitha et al. (a), 2008; Huda *et al.* 2011).

Scheuermann et al. (2003) reported that selection in chicken can induce greater muscle weight at the same age by increasing the fibre size and number. They concluded that increased muscle fibre number may also participate to improve breast yield. Berri et al. (2007) on the other hand associated increased breast weight and yield with an increased fibre cross-sectional area, reduced muscle glycolytic potential and reduced lactate content at 15 min post-mortem. It was concluded that *Pectoralis major* muscle exhibiting a larger fibre cross-sectional area has a greater pH at 15min post-mortem and at 24hours post-mortem thus producing meat with lower L*, reduced drip loss and were more potentially adapted for further processing than muscles exhibiting small fibre cross-sectional area. In addition, when post-mortem time increases during storage (between 4 and 12°C), the lightness (L*) and yellowness (b*) of chicken breast meat increases but the redness (a*) decreases (Zanusso et al., 2001; Petracci & Fletcher, 2002). This variation of colour with post-mortem aging time was attributed to the variation of concentration of pigments, the chemical state of pigments and the way light is reflected off the meat (Abdullah & Matarneh, 2010).

Brooke and Kaiser (1970), classified the muscle fibres into three groups based on their biochemical and functional properties as follows; slow-twitch oxidative (STO), fast twitch oxidative-glycolytic (FTO) and fast twitch glycolytic (FTG). Jaturasitha et al. (2008b) noticed no significant difference in the percentage of each breast muscle fibre type among Thai native chickens, Thai native X Bar Plymouth Rock, Bar Plymouth and Shanghai chickens. Dark muscles contain predominantly STO while light muscles contain primarily FTG. The FTG content of *Pectoralis* muscle of broiler and turkey

was reported as 99.5 and 99.8% respectively by Lengerken Von et al. (2002). In conclusion, STO, FTO and FTG diameters varies among genotype.

2.8.3 Sex

The gender of an animal may influence post-mortem metabolism due to different responses of sex to pre-slaughter stress. Findings on the effect of sex on breast meat quality are conflicting; Ngoka et al. (1982) reported no effect of sex on breast muscle pH, WHC, cooking loss and colour L*, a* and b* of turkeys. In another research by Anadon (2002) on broiler chickens, it was discovered that *Pectoralis major* muscle of female birds exhibited lower pH values at all times post-mortem, higher L*, a* and b* values and lower WHC compared to males. Muscles of female birds showed a greater rate and extent of pH decline (pHu=5.69), lighter, redder and yellower breast meat colour and lower WHC (15.8%) compared to males (pHu=5.84; WHC=18.8%). Higher rate of protein denaturation may likely be responsible for this result in muscles from female birds that exhibited lower pH values at all-time post-mortem.

In addition, Lopez et al. (2011) reported that female broiler have a lower pH of 5.87 at 24 hours post-mortem. They related the glycogen content in the muscle as a factor responsible. The research of Gigaud et al. (2007) was in agreement with previous work that sex had an observable effect on glycogen use rate and this rate in glycogen is important in female birds with lower pH. Abdullahi and Matarneh (2010) in their study on the influence of carcass weight, birds sex and carcass aging time on meat quality traits of *Pectoralis major* muscles in broiler birds reported that cooking loss was affected by bird sex with the highest value recorded in females (27.8%) than in male (26.7%). Also it was observed that the carcass of the male birds exhibited higher thawing loss values than those from female birds. The highest thawing loss found in

male carcasses may have been as a result of excess amount of moisture picked up by carcasses from male birds because of the thickness of breast or the space between muscle fibres. In contrast, these authors found no significant effect of sex on WHC, colour and chemical composition of meat.

Similarly, Lopez et al. (2011) reported no difference existed for sex and for mean shear force. All shear force values were lower than 30N which is suggesting that meats were sufficiently tender and will therefore be highly acceptable by consumers. It has also be documented that male birds are usually less fatty (at equivalent age) than their female counterparts. Sunday et al. (2010) found that lipid content of chicken meat was significantly higher in females than male whereas crude protein content was higher in males than in female birds. It was also reported by these authors that the interaction between genotype and sex significantly affected the crude protein and lipid contents. In a similar study by Bogosavljevic-Boskovic et al. (2010), they reported that male broiler had higher protein content in leg muscles than females provided age and rearing conditions are held constant. It was further reported that fat content and dry matter was significantly higher in females than in male birds. However, Konrád and Gaál (2009) found that sex has a significant impact only on ash content of thigh meat of Yellow Hungarian cockerel and Pullet kept in free range for 84 days with the highest ash content recorded in pullet (0.98% vs 0.89%). It was further revealed that the sex of the chicken influences the fatty acid profile of chicken muscles (Brunel et al. 2006). De Marchi et al. (2005) found that female Padovana breed of chicken had higher content of C16:0, C18:3w3 fatty acid than male, while male had the highest content in C18:1w7t and C20:4w6 fatty acids than female.

2.8.4 Slaughter Age

Several studies have studied the effect of slaughter age on the overall meat quality of broiler chicken (Sandercock et al., 2001; Anadon, 2002; Smith et al., 2002; Bianchi et al., 2006, 2007). They all reported that the composition of chicken muscle and quality changes as the animal gets older. Fletcher et al. (2000) and Gigaud et al. (2008) reported that as slaughter age decreases, the flavour of meat decreases whereas tenderness and juiciness increases. Sandercock et al. (2001) reported a lower pH immediately post-slaughter; lower shear force values, higher ultimate pH and drip loss for 35 day old birds compared to 63d old birds which was reported to be as a result of higher rate of post-mortem glycolytic metabolism in the more matured muscles. Anadon (2002) further reported higher WHC for breast fillets from 53d old birds than 42d old birds despite the lack of any significant differences in pH, L* and a* values at 24h post-mortem. It was however observed that the pH and a* values at 15mins and 4h post-mortem were significantly higher in birds processed at 53d thus, resulting in improved protein functionality and higher water holding properties of breast meat for these birds. The study from Anadon et al. (2002) suggested that rigor mortis and post-mortem glycolysis occurred faster in younger birds than in old birds. This fact was disputed by Sandercock et al. (2001). Also Anadon (2002) reported an age related change in colour of *Pectoralis major* muscle where L* values tended to increase linearly with increasing age at slaughter which did not agree with their earlier study.

In addition, the age of chicken influences strongly nutritional quality of its meat through the profile in fatty acids of the muscle (Brunel et al., 2006). In Thailand, Wattanachant & Wattanachant (2007) studied the changes in composition and structural properties of muscle protein and meat quality of Thai indigenous chickens during growth from 6 to 24 week old and confirmed that moisture content in muscle

decreased from 77.8 to 71.6% whereas fat and protein contents increased from 1.35 to 3.90% and 21.5 to 24.0% respectively. This result was similar to the research by Suchy et al. (2002) on chemical composition of muscles of hybrid broiler chickens during prolonged feeding. In addition, De Marchi et al. (2005) also found significant difference for protein content of Padorana breed of chicken slaughtered at 150 and 180 days of age with the highest protein concentration recorded at 180 days old.

In conclusion, older chickens present a lower ultimate pH, redder breast meat, higher drip loss and protein content, lower yield and intramuscular fat.

2.8.5 Live Weight

At the same age, the live weight can affect the chicken carcass composition and the meat quality properties (INRA, 2008). The weight variability of the chickens can be very important within a batch (Gigaud & Berri, 2007). This variability can be tied to individual variability but also to the sexual dimorphism. Thus, some differences in post-mortem metabolism of chicken muscle could be explained by difference in growth rate. According to INRA (2008), it was reported that heavier chickens present a lower pHu, redder breast meat, higher drip loss, lower muscle percentage yield and more importantly intramuscular fat. Furthermore, Bianchi et al. (2006) reveals that heavier birds (>3.3kg) live weight produced a darker breast meat (L*= 51.67) than the lighter birds (<3.0 and 3.0-3.3kg; L*=52.63 and 52.84 respectively) ($P<0.001$). In addition, Abdullah and Matarneh (2010) reported that lighter carcasses had a higher thawing loss percentage in breast muscle while higher shear force values were recorded in breast muscles from heavier carcasses. This could be due to a greater denaturation of muscle protein in the lighter carcasses compared with heavier ones.

2.9 Extrinsic factors

2.9.1 Production system

The breeding mode of chicken affects the characteristic of their meat quality. The study of Fanatico et al. (2005) on the meat quality evaluation of slower-growing broiler genotypes with or without outdoor access indicated that meat quality differences exist among production systems particularly on the sensory quality. They reported that outdoor access enhanced the meat to be yellower for the slow-growing genotype ($P < 0.05$), but there was no effect of outdoor access on the commercial fast-growing genotype ($P > 0.05$). Mikulski et al. (2011) found that colour of the breast and thigh muscles of chickens bred with outdoor access was significantly darker, compared with birds raised in confinement. Changes in the colour of meat in their study were accompanied by a better water-holding capacity of breast muscles and lower juiciness of breast from free-range chickens. Moreover, Fanatico et al. (2005) reported an increase in drip loss for slow-growing genotype chickens when they had access to outdoor movement. However, when there was no outdoor access, there was little or no impact on water-holding capacity.

The shear force of the meat also varied significantly according to the production system. The study of Castellini et al. (2002) on the effect of organic production on broiler carcass and meat quality showed that the production system affected the shear force value, which was higher in either the breast or drumstick of the organic animal, presumably as a consequence of their motor activity. The same tendency was observed by Santos et al. (2005) in free range broiler chicken strains raised in confined or semi-confined systems, Husak et al. (2008) for the breast meat from chickens reared under a lower stocking density. Thus, rearing systems, such as intensive and extensive farming, promote differences in meat texture.

In term of nutritional value, fat content variation can be tied to the production system since the organic system reduces by three times the lipid content of chicken breast meat (Brunel et al., 2006). Indeed, the conventional production system and the organic production system were compared on the chickens of 56 and 81 days old by Castellini et al. (2002) and it comes out from their study that a fat content of 2.37% was observed for conventional production system *vs* 0.74% for the organic chickens at 81 days old. Thus, the organic production system is then very interesting in term of nutritional quality of meat since it allows not only obtaining less fatty meat (Konràd & Gaàl, 2009) but rich in haem iron and protein (Bogosavljevic-Boskovic et al., 2010). Furthermore, dry matter content of chicken meat can be affected by the breeding system (Brunel et al., 2006). According to the finding of Mikulski et al. (2011) when studying growth performance, carcass traits and meat quality of slower-growing and fast-growing chickens raised with and without outdoor access, the breast meat of free-range chickens contained significantly more dry matter and protein than the breast meat of chickens raised without outdoor access. Similarly, according to Fletcher (2002), differences in dry matter content and juiciness of meat, may be due to the fact that free-range birds have a greater motor activity than indoor confinement chickens without outdoor access. However, Fanatico et al. (2005) revealed that *Pectoralis* muscle dry matter (%), fat (%), and ash (%) were largely unaltered ($P > 0.05$) by outdoor access (production system).

In short, the meat of free-range chickens may be darker in colour, with higher protein content and a better water-holding capacity, but it may be less juicy than the meat of birds raised indoors. This is because free-range chickens have less percentage of fat due to the fact that the fat deposit serves as a source of energy for the birds to move

around. Hence, the more the muscle is used, the tougher and less juicy the meat cut will be.

2.9.2 Water, feed withdrawal and Pre-slaughter stress

The energy stock available at the end of fasting of chicken before slaughter influences the kinetics of pH reduction in chicken meat (Immonen et al., 2000). Feed is normally withdrawn for several hours before catching in order to reduce the danger of microbial (*Salmonella, Campylobacter*) contamination of carcass. Feed withdrawal before slaughter allows emptying of the digestive system and reduces the likelihood of faecal contamination during processing (Shawkat et al., 2008). The effects of fasting on meat quality of poultry are particularly important because feed withdrawal periods of 8 to 12 hours before slaughtering are common. This practice has been shown to accelerate *rigor mortis* and final product quality by decreasing the amount of glycogen available for energy production prior to the onset of *rigor mortis*. Feed withdrawal from broilers prior to slaughter significantly reduces muscle energy stores that could be used during *post mortem* metabolism (Sams & Mills, 1993). Moreover, Savenije et al. (2002) reported that there is no significant effect of feed withdrawal (5 hours of fasting) on the colour (L *, a * and b *) of the chicken meat at 96 hours after slaughtering.

According to Berri and Jehl (2001), stresses before slaughter in chicken like fasting, manipulations, transportation, crating and extreme temperatures accelerates the fall of the pH while increasing the ATP activity of the muscle. The same impact of stress on the meat quality was reported in turkey by McKee and Sams (1998) who recorded a low initial and ultimate post-mortem and higher rates of post mortem pH decline for breast meat from heat stressed turkeys compared to non- stressed birds.

2.9.3 Post mortem aging time

The pH and cooking loss increase with the aging time while colour (L*, a*, b*, C*, and H*) and Warner-Bratzler shear force decrease (Northcutt et al., 2001; Bianchi et al., 2006). Qiao et al. (2001) and Petracci & Fletcher (2002) reported that aging time had a significant effect on broiler breast meat colour. However, the influence of aging time on meat quality traits of *Pectoralis major* muscles was studied in broiler birds by Abdullah and Matarneh (2010) and it appears that water-holding capacity, colour, and chemical composition were not affected by this factor, whereas thawing loss percentage decreased significantly with an increase in aging time. Moreover, shear force values were significantly higher for breast fillets aged for 0 and 2 h. However, a major improvement in tenderness resulted after 4 h of aging, with tenderness being comparable among carcasses of all weights. It is undeniable that post chilling carcass aging duration is critical to chicken meat quality characteristics (Abdullah & Matarneh, 2010).

2.10 Meat Quality Defects

2.10.1 Pale, soft, exudative defect

Pale, soft and exudative (PSE) meat is a quality defect in the meat industry, which accounts for huge losses particularly in the pork and poultry sectors. PSE meat development was earlier related to increased rate of early post-mortem glycolysis, indicated by elevated muscle temperature and rapid pH decline, which results in sarcoplasmic and myofibrillar protein denaturation and meat with pale colour, soft texture and high water loss (Briskey, 1964). More recently, it has been shown that extended glycolysis and low ultimate pH could also result in PSE meat (Sellier & Monin, 1994). PSE pork occurs in 5-20% of pig carcasses, with reported 15.5% PSE

in pork produced in the USA (Stetzer & McKeith, 2003). The tendency to produce PSE pork might have a genetic basis (porcine stress syndrome; PSS) (Eikelenboom & Minkema, 1974) or might be a result of excess glycogen content at time of slaughter (Monin & Sellier, 1985). Pigs with a single point mutation, Rendement Napole (RN), that was first found in the hampshire breed (LeRoy et al., 2000) are very prone to develop PSE meat. PSE pork is undesirable and costly for both fresh and further processed products, by having 10-12% more drip than normal pork after 2-5 d of storage (Honikel, 2002), and showing as high as 40% cook loss (Briskey, 1964). PSE meat costs the pork industry around $30 million each year as reported by USDA (Smith & Northcutt, 2009).

The PSE defect has also been reported in turkey (Barbut, 1997) and chicken (Van Laack et al., 2000; Woelfel et al., 2002), respectively. PSE incidences of 5-40% and 0-47% were reported respectively for commercial flocks of turkeys (Owens et al., 2000) and chickens (Barbut, 1997; Woelfel et al., 2002). While the origin for development of PSE meat is already established in pork, details on characteristics and causes of PSE in broiler breast meat remain unclear. However, growing evidence suggests that it is very likely that thermal stress conditions immediately prior to slaughter is one of the causes of PSE meat in poultry (McKee & Sams, 1998; Sams, 1999; Owens et al., 2000). Several authors have studied poultry stress syndrome (PtSS) to evaluate if PSE development in poultry is related to a stress syndrome similar to PSS related to PSE pork. Owens et al. (2000) reported that PtSS could lead to PSE meat; however, the 3.5% turkeys identified as Hal+ did not end up with a significantly higher incidence of PSE at slaughter. On the other hand, Soares et al. (2007) reported 47% incidence of PSE breast meat from the Hal+ population. Therefore, the genetic basis of PSE development in broilers is not established as strongly as it is known in pork. However,

Hal+ broilers are prone to produce PSE breast meat, but PSE development in broilers needs further investigation. It is assumed that PSE in broiler breast meat is comparable to PSE pork meat (Barbut, 1998), but it is not established if PSE breast meat happens to the same extent as PSE pork meat. PSE turkey has pale colour and poor processing characteristics (Pietrzak et al., 1997) similar to PSE pork, but the fresh meat drip loss was not comparable (Dransfield & Sosnicki, 1999). In addition, a number of studies have reported broiler breast meat to exhibit PSE symptoms similar to pork PSE (Barbut, 1997; VanLaack et al., 2000; Zhang & Barbut, 2005). However, in a review by Smith and Northcutt (2009) it was concluded that broiler breast meat selected as PSE are mainly based on the pale colour, and might not truly be exhibiting PSE properties as seen for pigs. Furthermore, these authors mentioned that it might not be appropriate to use the term PSE for pale broiler breast meat, since it does not meet the criteria for PSE as originally derived from the pork industry due to very pale colour, soft texture and excess drip. Currently, researchers are trying to better explain the PSE-like condition in poultry and find the possible origin or causes of this quality defect in the poultry meat industry, and some work has already been published on the causes behind the PSE-like condition in poultry (McKee & Sams, 1997, 1998; Owens et al., 2000; Woelfel et al., 2000; Soares et al., 2007; Smith & Northcutt, 2009).

Pre-slaughter stress and struggling have been reported to accelerate metabolism in chicken and turkey breast meat, resulting in accumulation of lactic acid in the muscle right after slaughter to a level comparable to or even greater than that reported for PSE pork muscle (Smith & Northcutt, 2009). A severe depletion in glycogen stores and increase in the level of lactic acid early post-mortem was reported for PSE breast meat (Berri et al., 2001). Slow chilling of turkey meat after slaughter was reported as an important factor in development of PSE-like meat characteristics (McKee & Sams,

1998; Rathgeber et al., 1999; Alvarado & Sams, 2004). From a morphological point of view, PSE meat is shown to have gaps of variable width between fibre bundles but no structural irregularities (Barbut et al., 2005). These intracellular open spaces between the muscle bundles, along with more extensive protein denaturation for PSE meat compared to DFD meat resulted in higher drip loss and unbound brine in the raw state of fresh and further processed products, respectively (Barbut et al., 2005).

Several studies have shown that early post-mortem pH might be an effective method of detecting low quality (PSE-like) turkey (Froning et al., 1978; Ngoka et al., 1982) breast meat. Turkey carcasses with low initial pH (< 5.7; fast glycolyzing) are reported to have higher drip loss and L* value and lower protein extractability compared to the medium pH (5.7 to 6.18) and high pH (> 6.18; slow glycolyzing) carcasses (Wynveen et al., 1999). In addition, cooked meat from the fast glycolyzing group was tougher than the normal glycolyzing group (Rathgeber et al., 1999; Wynveen et al., 1999; Molette et al., 2005). Consistent with these studies, Sandercock et al. (2001) also found that higher drip loss in the muscle of heat-stressed broilers was closely associated with the rate of muscle pH immediately post-slaughter. However, Owens et al. (2000) did not show the same relationship between pH at either 1.5 or 24 h post-mortem and drip loss in turkey meat, and reported that drip loss was significantly affected by L* value rather than the pH.

Different boundary points have been suggested by various researchers to classify poultry breast meat as PSE. McCurdy et al. (1996) suggested a cut off value of L* >50 for PSE turkey that was based on lower WHC above this range, whereas, Owens et al. (2000) proposed a cut-off point of L*> 53 for PSE turkey meat based on the relationship between pH, colour and expressible moisture. However, Woelfel et al. (2002) established a cut-off point of L*=54 based on poor WHC of meat with

lightness of 54 and above. Barbut (1997, 1998) recommended a truncation value of L*> 49/50 and L*> 52/53 for broiler chickens and turkey hens respectively, whereas, Petracci et al., (2004) suggested a boundary value of L*=56 to identify PSE-like broiler breast meat. However, it was recommended that each processing plant needs to determine its own lightness values for sorting PSE meat depending on type of birds, processing factors, and final product specifications (Barbut, 1997; Woelfel et al., 2002; Petracci et al., 2004).

From a consumer point of view, sensory aspects and nutritional values are the most important factors for quality evaluation. Komiyama et al., (2008) did not find any difference based on consumers' general acceptability, flavour, and tenderness of cooked pale chicken breast meat and normal breast meat. Zhuang and Savage (2010) also did not find any effect of raw fillet colour on flavour intensity of the cooked fillet. However, it was shown that the average intensity scores for textural attributes, the light fillets were significantly ($P<0.05$) higher than either the dark or the medium fillets (Zhuang & Savage, 2010). Therefore, low pH of PSE meat can influence the sensory and textural properties of cooked poultry fillet.

2.10.2 Dark, firm, dry defect

Meat with DFD condition is dark in colour, has a firm texture and dry appearance, which are mainly related to its high pH and higher protein functionality resulting in higher water holding ability and in return a firm texture and dry surface characteristic for this meat (Owens & Sams, 2000; Barbut et al., 2005). The high WHC of DFD meat might increase its susceptibility to microbial contamination and therefore result in a shorter shelf life for this meat (Allen et al., 1998). In addition, higher WHC of DFD meat results in lower light scattering from the surface and therefore a

substantially darker colour for DFD meat (Swatland, 1994; Barbut et al., 2005). Breast meat with DFD characteristics was investigated for both broiler chickens (Barbut, 1997; Qiao et al., 2001; Woelfel et al., 2002; Barbut, 2005) and turkeys (Zhang & Barbut, 2005). From a morphological point of view the muscle fibres in DFD meat are arranged in a much denser and more compact manner compared to normal meat, which had a fairly loose microstructure with no abnormalities (Barbut et al., 2005). The cut off point for pHu of poultry breast meat with DFD defect has been established at 6.1 or higher by the majority of researchers (Barbut, 1997, 1998; Berri et al., 2001; Qiao et al., 2001; Woelfel et al., 2002; Petracci et al., 2004; Barbut *et al.*, 2005). However the cut off point for colour lightness (L*) used for DFD classification has been set at different points among the aforementioned studies. Petracci et al. (2004) suggested L* < 50, whereas, L* < 46 has been recommended by Barbut (1997), Woelfel et al. (2002), Qiao et al. 2001; and Barbut et al. (2005). However, as previously mentioned it is suggested by Petracci et al. (2004) that cut off points should be determined for each processing plant based on flock and final product specifications.

It is believed that DFD meat is related to long-term stress before slaughter that causes depletion in muscle glycogen resulting in higher post-mortem muscle pH because of the prevention of glycolysis by elimination of its substrate (Owens & Sams, 2000). Many factors including transport exhaustion (Warris et al., 1999; Lesiow et al., 2007), feed withdrawal (Kotula & Wang, 1994), climatic stress, in particular cold stress (Webster et al., 1993), resting prior to slaughter (Warris et al., 1999), and aggressive behaviour could contribute to the depletion of muscle glycogen and in return limit the amount of lactate formed post-mortem. The occurrence of DFD breast meat in poultry has been studied by Lesiow et al. (2007) and Petracci et al. (2004). Petracci et al.

(2004) reported that breast meat colour was significantly darker in winter compared to summer. Lesiow et al. (2007) further confirmed that transportation during winter season caused a significant increase in the incidence of DFD broiler breast meat. In a study by Zhuang and Savage (2010), no difference in average flavour intensity scores of breast meat was reported between different groups categorized based on raw meat colour (light, L*>60; medium, 55<L*<59; dark, L*< 55). However, these authors reported no significance difference between cooked medium and the dark fillets in term of textural profile.

The characteristics of DFD breast meat are already established, however, the causes for this defect in the poultry industry are not clear. It has been shown that cold winters could increase the incidence of DFD breast meat in broiler chickens. However, more studies are required to establish the exact causes of this defect and the biochemistry behind DFD development in poultry breast meat. It is important to understand the challenges to lower the incidence of DFD in the poultry industry especially in the winter season and find solutions to use this meat properly in further processed products, i.e. by manipulating the pH.

2.11 Meat Spoilage Mechanism

Substantial amounts of meat are lost to spoilage annually. Kantor et al. (1997) stated that approximately 3.5 billion kg of poultry meat are wasted yearly during processing, distribution, storage and final consumption. This wastage has a considerable economic and environmental influence. A large amount of this loss is mostly due to microbial spoilage.

The process of animal conversion into meat involves series of inter-related steps such as transporting the animals to abattoir, loading and unloading and slaughtering of the

animals (Chambers & Grandin, 2001). Poor handling and inadequate facilities in any of these processes will lead to animals inhumane treatment causes injuries and sufferings. This may result to loss of meat, poor quality meat and meat deterioration (Chambers & Grandin, 2001). Prevention of contamination after slaughtering, during processing and storage is therefore important (FAO, 1991). Storage time can be extended through hygienic slaughtering and clean carcass handling (FAO, 1991).

Slaughtering involves different procedural processes such as stunning, bleeding, skinning and evisceration. All these operations are dependent hence shortfall at one stage may have severe negative impact on the product (FAO, 1991). Meat spoilage tends to be affected by meat acidity and muscular tissue structure. For instance, liver will tend to spoil rapidly than striated muscle of beef (Berkel et al., 2004). The animal comes to rigor mortis few hours after slaughtering and the development of stiffness after death is dependent on the pre-slaughter stress before or during the course of slaughtering (Miller et al., 2002). Pre-slaughter stress during slaughtering and method of slaughter has been implicated to affect fresh meat quality (Chambers & Grandin, 2001; Miller et al., 2002).

Meat nutritional components include fat, protein, minerals, carbohydrate and water (Heinz & Hautzinger, 2007). Digestive enzyme, microbial spoilage and fat oxidation are responsible for meat quality degradation during post mortem storage (Berkel et al., 2004). Lipid oxidation, protein breakdown and loss of other valuable molecules are some of the factors that aid meat spoilage mechanism. The breakdown of protein and lipid results in the formation of new compounds initiating changes in the flavour, tenderness, juiciness, odour and texture of meat.

2.11.1 Causes of Meat Spoilage

Pre-slaughter handling of livestock and post-slaughter handling of meat play a significant role in meat spoilage. Glycogen content in animal muscles is lowered by subjecting the animal to pre-slaughter stress which either raises or lowers the pH of the meat subject to levels of lactic acid production (Rahman, 1999; Chambers & Grandin, 2001; Miller, 2002). Lactic acid is produced as a result of the breakdown of glycogen content in animal muscles through an anaerobic glycolytic pathway (Rahman, 1999). Higher levels of pH (6.4-6.8) cause Dark, Firm and Dry (DFD) meat defect. Extended stress level in animals can cause DFD meat defect which can result in shorter shelf life (Chambers & Gradin, 2001; Miller, 2002). Severe temporary stress leads to a Pale, Soft and Exudative (PSE) meat defect. PSE meat has a pH less than the standard final value of 6.2 which is liable for protein degradation hence providing a favourable medium for bacteria growth (Rahman, 1999; Miller, 2002). The meat spoilage process after slaughtering and during storage involves microbial spoilage, lipid oxidation and autolytic enzymatic spoilage.

2.11.1.1 Microbial Spoilage

Meat and meat products serve as an excellent media for growth of varieties of bacteria, yeast and moulds some of which are pathogenic (Jay et al., 2005). These microorganisms are highly populated in the intestines and on the animal skin. The microflora composition in meat is dependent on various factors such as production practices, animal slaughter age, management of animals during slaughter, processing and distribution, preservation methods, type of packaging, handling and storage by consumer (Cervery et al., 2009).

Hayes et al. (2003) discovered *Enterococcus* spp. as the most prevalent bacteria in meat (Chicken, turkey, pork and beef). Cervery et al. (2009) reported that storage condition influenced the nature of microorganisms detected in meat product. It was also stated that *Pseudomonas* spp., *Moraxella* spp., *Psychrobacter* spp., *Acinetobacter* spp., and Gram-negative psychrotropic members of the family Enterobacteriaceae are often found in refrigerated meat product. It was similarly reported that psychrotropic lactic acid bacteria, Enterococci, micrococci and yeasts are predominantly found in raw, salted-cured products because of their resistance to curing salts.

Jouki and Khazaei (2011) observed that storage time significantly influenced the microbiological quality of packaged camel meat. They reported that total viable count (TVC), *Pseudomonas* count, LAB count and yeast and mould counts all increase during 18 d of storage at 4°C. The effect of slaughtering methods on microbiological quality during refrigerated storage is well documented (Alli et al., 2011; Addeen et al., 2014; Nakyinsige et al., 2014 Sabow et al., 2015). All these authors reported that slaughtering methods influenced the microbiological quality of meat as storage time increased.

Garcia-Lopez et al. (1998) found that at 5°C storage temperature, the growth of Enterobacteriaceae and *Pseudomonas* dominate the microflora of modified atmosphere packed meat than on vacuum packed meat. Sentence (1991) however reported that the extent of growth of *Pseudomonas* spp. was significantly retarded at 0°C, but gradually improved at 2°C and this influenced the meat keeping quality. He similarly observed a slow Salmonella growth at temperature lower than 7°C, the growth increased at temperature exceeding 7°C and this influenced the shelf life of meat. Borch et al. (1996) noticed a decrease of 2 and 4 times in the growth lactic acid bacteria on bologna-type sausage when storage temperature declined from 7-2°C and

from 7-0.6°C, respectively. Russell et al. (1996) indicated that a pH range of 5.5-7.0 is favourable for the growth of spoilage bacteria in meat. Microbial growth within this pH range results in slime formation, degradation of structural constituents, off odours and changes in physical appearance in meat. Volatile compounds such as methylamine, dimethylamine and trimethylamine are generally discovered in meat products during bacterial spoilage (Garcia-Lopez et al., 1998). Dainty (1996) indicated that microbial digestion produces fatty acids, ketones and alcohols, which display a range of pleasant odours. However, the production of hydrogen sulphide, methylsulphide and dimethylsulphide can result in rancid and sulphury odours in meat. Jay et al. (2005) reported that the formation of diamines, cadaverine and putrescine in meat products during storage is an indicator of spoilage.

2.11.1.2 Lipid Oxidation

Lipids oxidation is a natural process that involves the oxidative degradation of lipids and the production of free radicals in the cell membrane which affect fatty acids and results in oxidative deterioration of meat and off-flavours development (Gray, 1978; Pearson et al., 1983; Simitzis & Deligeorgis, 2010). After an animal has been slaughtered, the fatty acids in tissues experience oxidation after blood movement has ceased and metabolic processes blocked (Gray & Pearson, 1994; Linares et al., 2007). Lipid oxidation occurs in the presence of oxygen with double bonds of fatty acids (Hultin, 1994). It is a three phase mechanism of free radicals that involves initiation, propagation and termination (Frankel, 1985; Khayat & Schwall, 1983; Fernindez et al., 1997).

Initiation: during this stage, lipid free radicals are formed as a result of heat, metal

ions and irradiation which act as catalyst. These free radicals react with oxygen to form peroxyl radicals as follows:

$$R. + O_2 \longrightarrow R. + .OOH$$

Propagation: During this stage, hydroperoxides and new free radicals are formed from the reaction of peroxyl radicals and other lipid molecules as follows (Hultin, 1994; Fraser & Sumar, 1998):

$$R. + O_2 \longrightarrow ROO.$$

$$RH + ROO. \longrightarrow ROOH + R.$$

Termination: Termination ensues when these free radicals relate to form non-radical products as follows (Hultin, 1994):

$$R. + R \longrightarrow R - R$$

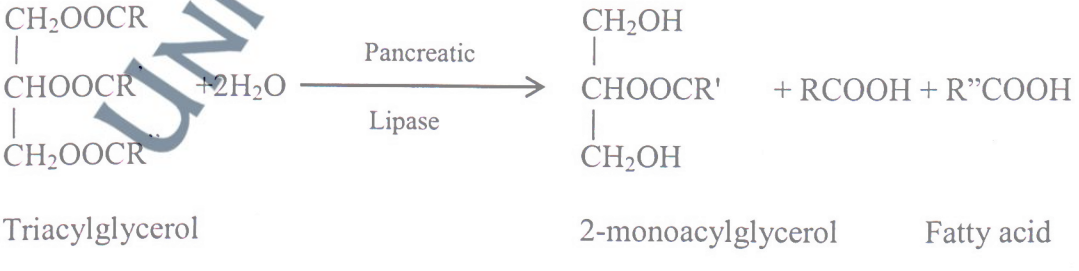
$$R. + ROO. \longrightarrow ROOR.$$

$$ROO. + ROO. \longrightarrow ROOR + O_2$$

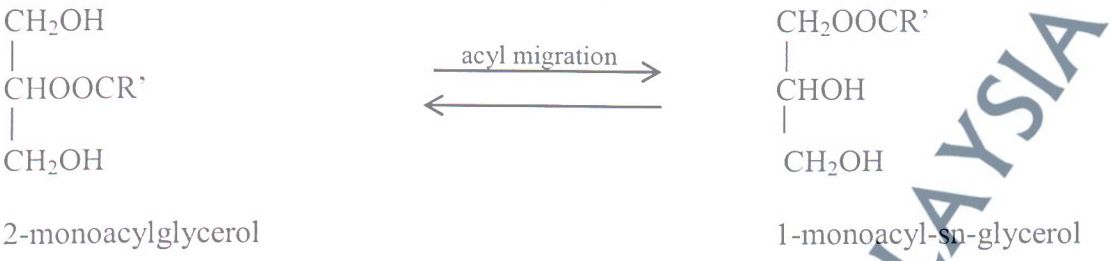
Lipid oxidation in meat is dependent on numerous factors which include: fatty acid composition, the extent of antioxidant vitamin E (α tocopherol) and prooxidants (presence of free iron in the muscles). Polysaturated fatty acids are more vulnerable to lipid oxidation. Hydroperoxides are formed as a result of lipid oxidation of highly unsaturated fatty acid fractions of membrane phospholipids, which are prone to further oxidation (Enser, 2001; Simitzis & Deligeorgis, 2010). Their breakage results in the development of secondary reaction products such as pentanal, hexanal, 4-hydroxynonenal and malondialdehyde (MDA) in addition to other oxygenated compounds such as aldehydes, acids and ketones (Shahidi, 1994; Fernindez et al.,

1997). These secondary products can result in colour loss and loss of nutritive value caused by severe effects on lipids, pigments, proteins, carbohydrates and vitamins (Simitzis & Deligeorgis, 2010) and are directly associated with carcinogenic and mutagenic processes (Raharjo & Sofos, 1993; Liu et al., 1995). In meat, lipid hydrolysis can occur enzymatically or non-enzymatically. Lipolysis is the enzymatic hydrolysis of fats or deterioration of fat. It usually occurs in the presence of specific enzymes such as lipases, estarases and phospholipase. Lipolytic enzymes could either be endogenous of the food product (such as milk) or produced from psychrotrophic microorganisms (Ghaly et al., 2010). Lipases enzymes are naturally occurring in the skin, blood and tissue of animals. During lipolysis, lipases split the glycerides forming free fatty acids which are responsible for the usual off-flavour, commonly referred to as rancidity (FAO, 1986; Huis, 1996). The main enzymes involved in meat lipid hydrolysis are phospholipase A1 and phospholipase A2 (Toldra, 2006). Lipid hydrolysis process involves three steps of biosynthetic pathway: cleavage of triacylglycerol, acyl migration and cleavage of 1-monoacyl-sn-glycerol (Belitz et al., 2009; Christie, 2010).

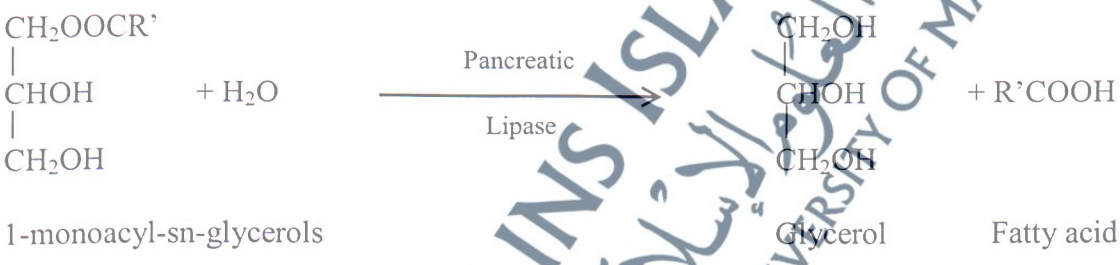
(a) Cleavage of triacylglycerol: In this step, pancreatic lipase hydrolyses the 1st and 3rd positions of the triacylglycerols to form 2-monoacylglycerols and fatty acids.



(b) Acyl migration: in this step, 2- monoacylglycerol isomerizes to 1-monoacyl-sn-glycerol by acyl migration as follows;



(c) *Cleavage of 1-monoacyl-sn-glycerol*: the 1-monoacyl-sn-glycerols in this stage is hydrolysed completely to glycerol and free acid in the presence of pancreatic lipase as follows;



The non-enzymatic hydrolysis is initiated by haem proteins such as haemoglobin, myoglobin and cytochrome which are prone to oxidation and produce hydroperoxides (Love & Pearson, 1971; Kanner, 1994). During haem catalysis, a Fe^{2+} protoporphyrin complex ($P–Fe^{2+}$), like myoglobin, will be oxidized to $P–Fe^{3+}$. The produced superoxide radical anion O_2 reacts with H^+ and will produce H_2O_2. Hydrogen peroxide will then oxidize $P–Fe^{3+}$ to the oxene species P–Fe = O (Belitz et al., 2009). The free iron redox cycle contributed by ascorbic acid is the main initiator of lipid peroxidation in fresh muscle foods and it considerably upsets the oxidation of oxymyoglobin (Cascone, 2005):

$$P\text{-}Fe^{+2} + O_2 \longrightarrow P\text{-}Fe^{+3} + O^{-}_2$$

$$2O_2^- + 2H^+ \longrightarrow H_2O_2 + O_2$$

$$P\text{-}Fe^{+3} + H_2O_2 \longrightarrow P^+ \begin{cases} H \\ Fe^{+3}\ldots O^- - O\text{-}H \end{cases} \longrightarrow \begin{matrix} P\text{-}Fe^{+3} = O \\ \Updownarrow \\ P\text{-}Fe^{+3} \end{matrix} + H_2O$$

$$P\text{-}Fe^{+4}\text{-}O + ROOH \longrightarrow P\text{-}Fe^{+4}\ldots OH^- + ROO$$

$$P\text{-}Fe^{+4}\ldots O - H + ROOH \longrightarrow P - Fe^{+3} + ROO. + H_2O$$

2.11.1.3 Autolytic enzymatic spoilage

Enzymatic activities are naturally occurring process in the muscle cells of animals after slaughtering and are one of the leading causes of meat spoilage during post mortem storage. The enzymes are capable of chemically combining with other organic compounds which help to speed up chemical reaction leading to meat deterioration (Tauro et al., 1986). The autolysis process involves the breakdown of complex compounds (carbohydrates, fats and protein) of the tissues into simpler ones causing softening and greenish discoloration of the meat. These enzymatic autolytic changes involve proteolysis and fat hydrolysis which are requirement for microbial breakdown.

Tissue proteases are responsible for post-mortem breakdown of polypeptides causing flavour and textural changes in meat (Toldra & Flores, 2000). Aging of red meat post-mortem particularly beef is recommended to enhance the tenderization process (Huss, 1995). Post-mortem autolysis occurs in all animal tissues but at varying rates in different organs. It is faster in glandular tissue such as the liver and slower in muscle (Fearon & Foster, 1922). The enzymes calpains, cathepsins and amino peptidases have been reported to be responsible for the post mortem autolysis of meat by digestion of the z- line proteins of the myofibril (O'Halloran et al., 1997; Huss, 1995). Among

these enzymes, calpains has been termed as a primary contributor to the proteolytic tenderization process of meat. Similarly, cathepsins also aid tenderization of meat but at low pH. Proteolytic enzymes has been described to be active at low temperatures (5°C) leading to deterioration of meat caused by growth of microbes and production of biogenic amines (Kuwahara & Osako, 2003).

2.12 Proteomics in Meat Science

Proteomics is a branch of biotechnology concerned with the application of the techniques of molecular biology, biochemistry and genetics to analyse the structure, functions and interactions of the proteins produced by the genes of a particular cell, tissue or organisms. Since more than 20% of muscle (meat) mass is composed of proteins, therefore a link between muscle proteins and meat quality must be established. Most work on proteomics of meat focused on meat quality especially meat tenderness properties in beef and to some extent in pork.

Post-mortem changes in muscles have been investigated with proteomics (Lametsch & Bendixen, 2001; Hwang, 2004; Morsel et al., 2004) and it was reported that a large part of the proteome changes post-mortem. This may probably be due to protein degradation because many of the identified changes are protein fragments that increase in spot intensity post-mortem (Lametsch et al., 2002). Other factors that may likely contribute to post-mortem protein changes are changes in protein modification such as phosphorylation or oxidation and protein expression. It was reported that protein expression is unlikely to cause a major post-mortem protein change after muscle has entered the state of rigor mortis because protein expression is an energy requiring

process and energy is almost depleted after muscle has entered the state of rigor mortis (Henckel et al., 2002).

Several reports have claimed that neither actin nor myosin heavy chain proteins are degraded post-mortem (Koohmaraie, 1994; Huff-lonergan et al., 2005). However, Lametsch et al., (2003) and Hwang et al., (2005) reported otherwise that both proteins can be degraded post-mortem. Some of these actin and myosin heavy chain proteins fragments were reported to correlate significantly to meat tenderness.

In addition, several other structural proteins such as myosin light chain, troponin T, desmin, cofilin 2, capZ and titin were also found to degrade post-mortem. Many of them have not been previously reported to degrade post-mortem (Bendixen, 2005).

2.12.1 Proteomics and Poultry Meat Quality

Some studies were reported on poultry meat quality. Doherty et al., (2004) reported that characterisation of the proteome of layer chicken *pectoralis* muscles showed dramatic changes in relative expression levels of several proteins during growth. This study shows the complexity of this analysis because isoenzyme shifts, associations with structural elements and post-translational modifications all characterise growth in muscle system.

Molette et al., (2003, 2005) reported in their research of PSE syndrome in turkeys that turkeys exhibiting fast post-mortem glycolysis in breast muscle (-0.5 pH unit at 20 min post mortem compared to normal glycolysing birds) presented meat quality alterations such as lower water holding capacity, lower processing yield and lower tenderness. They also reported that meat from fast glycolysing animals (FG) had a lower buffering capacity and a lower sarcoplasmic protein extractability suggesting modifications of

protein functionality when the rate of pH decline was accelerated. With the use of SDS-PAGE electrophoresis of different protein fractions, differences in banding patterns were undetected but with the use of 2DE (whole muscle protein extracts, IEF between 5 and 8), the differences between the 2DE gels were shown on the basis of presence or absence of spots in the FG or NG samples. 3 spots were identified from the NG muscles and were identified to be myosin heavy chain and actin fragments, glyceraldehyde 3-phosphate dehydrogenase (GAPDH) enzyme. Samples for this analysis were collected 24 hr post-mortem when meat aging is not completely achieved. This may be due to the fact that meat aging seemed active earlier in NG than in FG muscles. This result is in agreement with the work of Monin et al., (1999) on PSE of pork meats where meat aging was reported to be lowered.