Journal of Agricultural Science and Technology B 9 (2019) 305-315
doi: 10.17265/2161-6264/2019.05.001

Meat Quality Parameters and the Effects of Stress: A Review

Tatiany Carvalho dos Santos[1], Richard Stephen Gates[2], Cecília de Fátima Souza[1], Ilda de Fátima Ferreira Tinôco[1], Márcia Gabrielle Lima Cândido[1] and Letícia Cibele da Silva Ramos Freitas[1]

1. Department of Agricultural Engineering, Federal University of Viçosa, Viçosa, Minas Gerais 36570-9000, Brazil

2. Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, United States

Abstract: The objective of this review was to address the stress effects on meat quality considering the main attributes that involve meat quality. Animal protein production has been increasing with global demand for meat with meat quality a major concern, especially for more demanding consumers who are looking for quality products to meet their needs. The quality of the meat is the result of what happened to the animal throughout the production chain, that is, good rearing conditions result in a better meat quality. Different types of stress can be harmful to animals due to inadequate or improper animal handling on farms, inadequate transport conditions, poorly maintained trucks and roads, and conditions that agitate animals can lead to bruising, thermal stress. The stress in animals occurs when they are in adverse conditions and can significantly compromise meat quality loss. As an example, stress can significantly affect meat quality parameters as drip loss (DL), meat color, change ultimate pH and cause meat anomalies. Among the main parameters of evaluation used for meat quality are color, characterized by luminosity (L^*, a^*, b^*), lipid and protein oxidation, pH, water holding capacity (WHC) and softness. Producing and processing high-quality meat is a challenge since it is necessary to apply methods that promote comfort in a complete sense, in a way that minimizes inducing significant stress. Based on the results presented it is remarkable that stress alters the meat quality, compromising the main attributes that involve it, like color, pH, WHC, Warner-Bratzler shear force (WBSF), lipid oxidation, among others andis necessary to avoid or reduce stress caused during the production of the animals to ensure a high-quality meat, resulting in greater profitability for the producer.

Key words: Animal stress, drip loss, farm buildings, meat quality, tenderness.

1. Introduction

Animal protein production has been increasing with global demand for meat [1, 2] with meat quality a major concern, especially for more demanding consumers who are looking for quality products to meet their needs [3, 4]. Meat quality can be perceived by its sensory attributes (color, texture, juiciness, taste, odor, softness), nutritional composition (fat content, fatty acid profile, protein percentage, minerals and vitamins), technical parameters (pH, water holding capacity (WHC) and thawing loss), absence of chemical and microbial residues (antibiotics, hormones, dioxins, *Salmonella*, *Listeria*, or other contaminants), ethical considerations (animal husbandry, animal well-being) and, in addition, by the sustainable production aspects [4, 5].

Carcass traits and meat quality, such as tenderness and color, are critical for consumer acceptance [6]. Some aspects of meat quality such as color and amount of fat can be perceived visually, but others such as nutritional value and the absence of residues are only ensured by means adequate analysis and labeling and certification.

The level of stress experienced by the animal is one of the factors affecting the meat quality [7]. When subjected to stressful conditions, the meat of slow-growing chickens could be different from that of fast-growing [8]. Meat (and meat products) can deteriorate due to microbial growth and subsequent

Corresponding author: Tatiany Carvalho dos Santos, Ph.D. student, research fields: meat quality, thermal environment, thermal stress.

chemical deterioration, with the most common form of chemical deterioration being lipid and protein oxidation [9]. Deterioration may be caused when the animal is subjected to adverse conditions that lead to stress, directly influencing the meat quality. Karaca *et al.* [10] reported that fasting had a negative effect on some meat quality parameters, with significant increases in some physiological stress indicators after fasting periods of 24 h or longer on traits of lambs.

Some specific processes during the production cycle result in stress for the animal. In the process of transferring animals from farm to slaughter, stress is an inevitable consequence [11]. Pre-slaughter stress is both an animal welfare and a meat quality issue [12]. There is a direct association of meat quality with pre-slaughter management, whether on the property or while transporting animals to a slaughterhouse [12-16]. Incorrect pre-slaughter handling may cause carcasses to develop meat abnormalities such as pale, soft, exudative (PSE) or dark, firm, dry (DFD) [15].

The effects of environmental temperature on meat tenderness vary depending on temperature and duration of exposure [17]. Heat stress also decreases meat quality [6]. According to Kim *et al.* [18] cyclic heat stress had little impact on color, WHC, protein functionality and lipid/protein oxidation stability of ground chicken leg meat. Increased levels of stress hormones in the muscle could lead to *post-mortem* metabolic/structural modifications that could be reflected on meat quality [19]. The objective of this review was to address the stress effects on meat quality considering the main attributes that involve meat quality.

2. Stress Factors That Affect Meat Quality

The concept of stress was introduced by Selye [20] in 1936, but is still a controversial subject among people involved with animal production, from workers to the scientific community, perhaps because of the commonly established relationship between stress and animal welfare [21]. Cortisol is one of the most common stress indicators measured [22] and cortisol response to stress has been shown to vary between individuals as well as fluctuate during pre-slaughter handling [23].

Livestock meat and carcass quality characteristics are governed by several intrinsic and extrinsic factors [24]. The intrinsic factors that affect meat quality in ruminants include species, breed, age, weight at slaughter and gender (male, female, castrated). Similarly, extrinsic factors affecting the meat quality include stress (environmental effects, transportation and handling), diet and weaning [5]. Animals respond to the stressors faced during transport by making behavioral, immunological, hematological and metabolic changes [25], which may impair slaughter performance, and carcass and meat quality [26].

Many authors have investigated the effects of different factors, such as journey, transport and lairage duration [14, 27, 28], environmental conditions [29], welfare [30] and stocking density [31]. The results found by Toldrá [32] show that when an animal is stressed before slaughter, the resultant meat quality often suffers as a result. Pre-slaughter stress may result in the development of dark-cutting beef because of depletion of antemortem muscle glycogen stores and less *post-mortem* lactic acid accumulation [33]. Pre-slaughter stress can be roughly divided into two types: (1) long-term (chronic), from the collection, boarding and transportation stages; (2) short-term (acute), regarding management stages at the slaughterhouse (selection, waiting and driving at slaughter) [34, 35]. Pre-slaughter heat stress must be minimized to the greatest degree which is possible to minimize PSE defects in broiler breast meat, the most valuable animal cut [36]. Trocino *et al.* [28] showed increased meat pH and WHC in rabbits subjected to long journeys. Holinger *et al.* [37] point out that carcasses of stress-exposed pigs had thicker backfat, lower lean meat percentage and different fatty acid composition of the adipose tissue.

It is important to highlight that thermal stress directly affects the development of animals, since it compromises the maintenance of homeothermy. Due to this, a physiological imbalance occurs that is caused by adverse temperatures and air relative humidity, either during rearing or at the time of slaughter, affecting the muscle glycogen reserves that are responsible for the development of *post-mortem* biochemical reactions that determine the meat quality and its functional properties.

Dokmanović *et al.* [38] correlated different categories of animal stresses, meat quality, and carcass quality characteristics in pigs and found that cortisol affected the carcass quality. High cortisol values in beef cattle resulted in high pH but cooking loss values were still within the normal range [39]. After arrival at the slaughterhouse, two important factors that may affect the level of stress in pigs and consequently pork quality, are lairage time and handling procedure immediately prior to slaughter [40]. Also, long lairage time proved to be a more stressful procedure and had a detrimental effect on carcass quality of pigs [40].

Heat is one of the most important environmental stressors for the poultry industry in the world [41]. Impacts of stress induced by high temperatures lead to a series of consequences for productivity, with higher water consumption and lower feed consumption, which directly affects feed conversion, growth rate, carcass yield and meat quality for organoleptic properties [6].

According to Wang *et al.* [36] heat stress increased the production of lactate in muscle, which in turn increased the rate of pH decline and subsequently decreased the quality of breast meat and increased the proportion of PSE meat of broiler chickens. Heat stress also reduces the muscle pH which in turn affects all the physicochemical attributes such as cooking loss, WHC, meat color and shear force [42].

Due to the changes that occur during the process of transformation of the live tissue muscle in consumable meat, it should be stressed that inadequate conditions of general environment offered to the animal, which can result in its stress, may lead to the formation of low quality products and rejection by the consumer.

Stress can significantly compromise meat quality, and among the main meat quality evaluation parameters that stand out are color-luminosity (L^*, a^*, b^*) [43], pH [44], WHC [45], tenderness (shear force) [46] and lipid and protein oxidation [47]. Table 1 shows different stressor agents can affect meat quality in the species.

Table 1 Stress factors that affect meat quality of poultry, pigs, cattle, sheep, calves and lamb.

Stressor agent	Species	Effects observed on meat quality	Reference
Heat stress	Poultry	Higher incidence of pale, soft, exudative (PSE) meat and decrease in the a^* value of meat;	Tankson *et al.* [48]; Dai *et al.* [49]; Vaz *et al.* [50]
		Increased the rate of pH decline and incidence of PSE meat;	Wang *et al.* [36]
		Higher L^* value;	Zhang *et al.* [46]
		Developed PSE or dark, firm, dry (DFD) breasts;	Gotardo *et al.* [51]
		Higher lipid oxidation.	Vaz *et al.* [50]
Cold stress	Poultry	Acute demands on energy metabolism and increases glycogenolysis, which may result in meat with DFD characteristics;	Dadgar *et al.* [52, 53]
		Increase of pH and decrease of L^* value.	Napper *et al.* [43]
Acute stress	Cattle	Tougher Warner-Bratzler shear force (WBSF).	Zhao *et al.* [54]
Fighting	Pigs	Increased plasma levels of cortisol, adrenaline and metabolites, and meat ultimate pH increases proportionally to fighting levels.	Fernandez *et al.* [55]; Terlouw *et al.* [56]
Transport and lairage	Cattle	Lairage decreased ultimate pH; bulls subjected to 24 h lairage had the lowest L^*, b^* and H^* values; lairage time had no effects on water holding capacity (WHC), cooking loss and shear force values.	Teke *et al.* [57]
		Greater WBSF.	Gruber *et al.* [58]
	Pigs	A stronger increase in salivary cortisol and their meat had more drip loss (DL);	Teke *et al.* [57]; Geverink *et al.* [59]
		Transport time significantly affected DL, pH and meat color;	Chai *et al.* [60]
		Highest WBSF.	Lukić *et al.* [61]

(Table 1 continued)

Stressor agent	Species	Effects observed on meat quality	Reference
Slaughter and Pre-slaughter	Poultry	Altered ultimate pH of thigh meat;	Debut *et al*. [62]; Berri *et al*. [63]
	Pigs	Higher ultimate pH;	Terlouw *et al.* [56]
	Calves and Cattle	Higher ultimate pH;	Lensink *et al*. [64]; Mounier *et al.* [65]
	Lambs	Increased the rate of pH decline and ultimate pH, as well as the ability of muscle to hold water;	Simmons *et al*. [66]; Bond and Warner [67]
	Lambs	Increases in DL.	Bond and Warner [67]
Higher noise	Pigs	Significant negative effect on meat initial pH (pH_i)	Van de Perre *et al.* [68]
Food/water deprivation/fasting	Poultry	Increased muscle pH and increased sarcomere at *post-mortem* 0 h, while decreased at *post-mortem* 10 h;	Wang *et al*. [69]
	Lambs	Tenderness scores varied significantly between the 0 h and 48 h groups.	Karaca *et al*. [10]
Stunning	Poultry	Affected breast meat color by decreasing *a*∗ and 9 d, 150 V, 60 Hz stunning reduced lipid oxidation in breast meat.	Xu *et al*. [70]

3. The Stress Influence on Meat Quality Parameters

3.1 Color

Color is one of the most important sensory attributes used to evaluate the quality of products and first criterion consumers use to judge meat quality and acceptability [71]. The main pigment responsible for meat color is myoglobin, a protein present in the sarcoplasm of the muscle fiber [35].

According to Mir *et al.* [72], light scattering affects meat lightness (*L**) in a fashion inverse to that caused by heme pigment concentration, having a minimal effect on meat redness (*a**) and yellowness (*b**). It could be argued that appearance is the most important quality attribute of cooked or raw poultry meat because consumers associate it with the product's freshness, and they may decide whether or not to buy the product based solely on their opinion of its attractiveness [72]. In general, meat with a higher proportion of red fibers has a higher concentration of myoglobin, which is related to the predominance of aerobic (oxidative) metabolism, and a red color (greater than *L**) and darker (lower *L**) [35]. According to Zhang *et al.* [46], high ambient temperature had a significant influence on broiler meat quality. The meat color data showed that the meat of the breast and thigh of broilers subjected to constant high temperature presented higher *L**. A significant increase in the red content (*a**) was observed by Vaz *et al.* [50] in the chests of birds that remained in the warm environment for 48 h and 72 h, compared with birds that were not exposed to such stress. These authors suggest that a lower incidence of pale breast meat was found in birds raised under the heat stress conditions.

Extreme anomalous conditions include PSE and DFD meat, which are responsible for considerable economic losses in the industry [35]. The DFD meat, of dark color (dark), firm texture (firm) and extremely non-exudative (dry), is observed with some frequency in cattle, and can also be found in swine and birds. On the other hand, PSE is reported as the main anomalies in swine and birds [35]. The difference between "PSE" and "DFD" is that the former is associated with stress during a short time, just before slaughter, while DFD is closely linked to long-term stress before slaughter without the occurrence of adequate carbohydrate replacement in the body [73].

In a study conducted by Gotardo *et al.* [51], these inequalities indicate that, under a heat stress period of 1 h/d, broiler chickens at different stages of management will develop PSE or DFD breasts. Soares *et al.* [74] have proposed the following criteria for the classification of breast meat into quality categories: $L^* \geq 53$ means a PSE meat, $L^* \leq 44$ means a DFD and $44 < L^* < 53$ means a normal meat.

PSE meat is the result of accelerated *post-mortem* glycolysis, which results in a rapid *post-mortem* decline in pH while carcass temperatures are still high. Among the environmental factors to induce occurrence of PSE meat, *ante-mortem* stress, heat stress at the end of the growth or pre-slaughter phase and methods of stunning in the slaughterhouse seem to play the main role [72, 73]. Van de Perre *et al*. [68] reported that in the summer, the risk of PSE in pigs is almost double the risk in winter, as these animals are sensitive to high temperatures. The apparent pale color in poultry meat is associated with lower pH [36]. PSE can be detected by combining pH values (below 5.8) and color (*L** value above 52) measured 24 h post-slaughter [75, 76].

It is known that DFD meat is a problem caused by chronic stress before slaughter, which depletes glycogen levels. The incidence of DFD meat is observed when the pH remains above normal, since the water retention capacity of the muscle proteins is very high, neither fibers are swollen by filling with sarcoplasmic fluids and their dispersed surface is less light [73]. Poor handling of cattle prior to slaughter might lead to a high incidence of DFD meat (6.22 ± 0.10) and a low mean value of percent cooking loss (22.5 ± 3.25) [16]. This type of change in meat is also observed in swine [77], broiler [76], sheep [78] and especially in cattle [79].

3.2 The pH

Stress has a direct effect on the quality and physical-chemical characteristics of the meat as it changes the pH drop pattern due to the rapid use of glucose when the animal is subjected to conditions that modify its well-being. The main critical points that contribute to this are events related to pre-slaughter handlings, such as transport [80].

According to Boudjellal *et al*. [81], the rate of pH drops, as well as the final pH of the meat after 24-48 h, is quite variable. The pH drop is faster in pigs, intermediate in sheep and slower in cattle [82]. For cattle, glycolysis usually develops slowly; the initial pH at one-hour post-slaughter is around 7.0, drops to 6.4-6.8 after 5 h, and to 5.5-5.9 after 24 h. In pigs, the rate of dropping is higher, reaching values of 5.6-5.7 after 6-8 *post-mortem* hours and 5.3-5.7 after 24 h [82]. For DFD meat, pH drops gradually by only a few tenths during the first hour after slaughter, the meat with final pH value (after 24 h) remains between 6.5 and 6.8. For reddish pink, firm and non-exudative (RFN) meat, pH drops approximately 7.0 in live muscle to ~5.6 after 6-8 h *post-mortem*, reaching a final pH between 5.5 and 5.7 (normal). For PSE meat, pH drops rapidly in the first *post-mortem* hour, for values lower than 5.8 in 45 min, presenting a final pH between 5.4 and 5.6, or even lower values. For acidic meat, pH drops gradually, but with very low final value, close to 5.0. Dotted curves illustrate intermediate quality categories such as slightly dark meat and PSE (Fig. 1) [35].

Karunanayaka *et al.* [83] found a correlation between pH and *L** values, the *L** value increased as muscle pH decreased. Desai *et al.* [84] subjected broilers to short-term heat stress (38 °C for 2 h) and found lower values of pH for breast meat at 15 min after death (for PSE meat than normal meat).

3.3 WHC

WHC is one of the important sensory qualities of meat [6]. It is defined as the ability of meat to hold its own or added water during the application of external forces such as cutting, heating, grinding and pressing, and is implicated in numerous technological processes in which water retention plays a major role [60, 61]. WHC is directly related to muscle fiber density and according to Huff-Lonergan and Lonergan [85], the muscular structure is composed of several “compartments” from which drip could originate. These could include the space within the myofibril, the intracellular space outside the myofibril and the extracellular space, including the space between the muscle bundles.

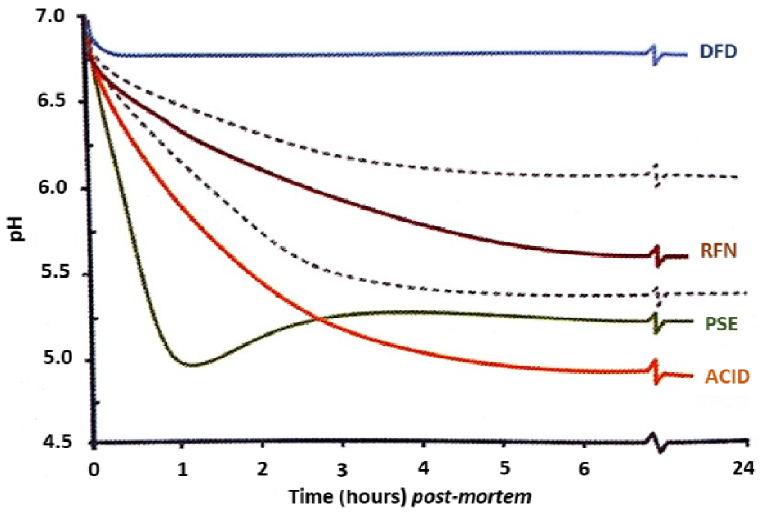

Fig. 1 Typical curves of *post-mortem* pH drops in pigs.
DFD: dark, firm, dry; PSE: pale, soft, exudative; RFN: reddish pink, firm and non-exudative.
Source: Briskey [86]. Adapted by Ramos and Gomide [35].

Drip loss (DL) can be used to determine WHC under no applied external force. To evaluate DL each sample is weighed then placed and suspended in an inflated plastic pot for 48 h at 4 °C, after which they are reweighed [87]. DL is calculated as the percentage of weight loss: [(initial weight – final weight)/initial weight] × 100% [87]. WHC is 100% – DL (%).

According to Mir *et al.* [72], WHC has a direct bearing on the color and tenderness of meat, and is among the most important functional properties of raw meat. A study showed that cyclic heat stress (32.0, 21.0 and 32 °C, for 10 h/d) had little impact on WHC of ground chicken leg meat [18]. Zhang *et al.* [45] evaluated the relationship of heat shock protein levels in swine muscles and meat quality and they observed a correlation between heat shock proteins and the WHC of the meat. DFD meat has a high WHC due to the pH being far from the isoelectric point of muscle proteins; in addition, with higher pH, there is more incidence of deteriorating microorganisms [77].

Evaluating the effect of different periods (0, 24, 48 and 72 h) of thermal stress on the physical and chemical quality of the meat of broilers, Vaz *et al.* [50] concluded that thermal stress affected the qualitative properties of the meat, especially lipid oxidation, WHC and shear force. Confirming the findings of some authors, Woelfel *et al.* [88] showed a tendency in reduction of WHC in meat from animals stressed prior to slaughter.

3.4 Tenderness (Shear Force)

Tenderness is probably the most important quality factor associated with consumer satisfaction of eating quality of poultry [72]. Tenderness is regarded as the most important sensory attribute affecting the meat acceptability [71].

Warner-Bratzler shear force (WBSF) is a direct indicator of the meat tenderness and eating meat quality [13]. According to Gomide [34], the shear force or softness is an attribute of the texture and the coarser the texture, the lower the softness. It is closely related to the amount of intramuscular water, and hence, WHC of the meat, so that the higher the water content in muscle, the greater the meat tenderness [89].

Previous research in beef has indicated that stress prior to slaughter is linked with a reduction in tenderness. Some studies have established a relationship between heat shock proteins and meat quality, including small heat shock proteins and their role in meat tenderness [90]. In a study with Angus cattle, Zhao *et al.* [54] subjected the animals to acute stress and the WBSF results showed that the stress group was much tougher than the control (nonstress) group. They also identified 137 differently expressed genes related to variations on stress status and beef quality. Physiological reactions of animals to transportation stress resulted in greater WBSF [58]. On the other hand, Vaz *et al*. [50] studying different conditions of thermal stress in broiler chickens at 42 d showed that the different temperatures (thermoneutral and stress conditions) and duration of stress influenced the meat tenderness, and that the meat of the birds that remained in thermal stress was more rigid; however, there was a lower *post-mortem* proteolytic potential, leading to a decrease in softness. Also, Lukić *et al.* [61] reported that pigs were affected by different durations of lairage time and WBSF was the highest in the group with 24 h lairage time.

3.5 Lipid and Protein Oxidation

Lipid oxidation is described as a deterioration of the oxygen-dependent meat quality of saturated and unsaturated fatty acids, contributing to flavor degradation and reduced product shelf life due to initiation of peroxidation [91]. Another characteristic of the lipid oxidation is to be an important quality indicator of fats, meat and meat products. Oxidized lipids not only change the color, aroma, flavor and texture of meat [92], they also result in rancid odor, unpleasant taste, loss of nutritional value, shortened shelf life and accumulation of toxic compounds which may be detrimental to the health of consumers [90, 91].

According to Reitznerová *et al.* [92], lipid oxidation in meat can be monitored through the value of thiobarbituric acid reactive substances (TBARS). Many studies have reported that broilers raised at high temperatures increased TBARS in plasma, organs and carcass [71, 72]. For this reason, these authors can conclude that the presented modified TBARS spectrophotometric method is suitable for monitoring the lipid oxidation processes in meat samples [92]. Higher lipid oxidation was observed in the meat of broilers that underwent thermal stress during periods of 24, 48 and 72 h compared to those without thermal stress [50]. In this way the quality of this meat will be inferior, since the lipid oxidation is one of the major causes of deterioration, contributing to the reduction of the useful life of the products [91].

Protein oxidation is described as the covalent modification of a protein, induced by reactive oxygen species or reaction with secondary byproducts of oxidative stress, which occurs through a free radical chain reaction, as well as oxidation of lipids in the muscles [47]. Oxidation of oxymyoglobin to metmyoglobin results in meat discoloration, while lipid oxidation leads to the production of off-flavor and decreases nutritional values of meat and meat products [47].

4. Conclusions

It is necessary to consider animal welfare in the *ante-mortem* period and during slaughter, in order to obtain a higher yield and use of carcass, and *post-mortem* processes to guarantee better quality of the produced meat.

Producing and processing high-quality meat is a challenge since it is necessary to apply methods that promote comfort in a complete sense, in a way that minimizes inducing significant stress. Based on the results presented it is remarkable that stress alters the meat quality, compromising the main attributes that involve it, like color, pH, WHC, WBSF, lipid oxidation, among others. It is necessary to avoid or reduce stress caused during the production of the animals to ensure a high-quality meat, resulting in greater profitability for the producer.

Acknowledgments

The authors are thankful to Center for Research in Environment and Agroindustry Systems Engineering (AMBIAGRO) and Department of Agricultural Engineering at the Federal University of Viçosa

(UFV). The authors also thank the Brazilian Government to provide support and funds to carry out this research. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) Finance Code 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG).

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