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Pre-slaughter stress, animal welfare, and its implication on meat quality

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Abstract

Meat quality includes technological quality attributes, consumer acceptance, and credence characteristics. In terms of credence characteristics, animal welfare is one of the most interesting topics to both consumers and the livestock industry. Consumers prefer meat produced from livestock that has been raised in low stress and ecofriendly environments. The livestock industry cares about animal welfare to meet the requirements of consumers. Animal welfare is closely associated with the stress and physiological response of livestock to stress. Moreover, stress just before slaughter (i.e., pre-slaughter stress) has negative effects on not only animal welfare but also ultimately on meat quality. It is well-documented that pre-slaughter stress can influence ante- and post-mortem biological changes of the muscles, especially their metabolic properties and metabolites. The metabolic properties and metabolites contents also can modulate the postmortem changes of the muscles. Conversion of muscles to meat during postmortem is a very important process because it determines ultimately the meat quality. Thus, understanding pre-slaughter stress and physiological responses to stress in farm animals is important for animal welfare and meat quality. The purpose of this paper was to examine the concept of stress, physiological responses to stress, measurement of stress, and the relationships between stress indices and meat quality traits.

Keywords: animal welfare, meat quality, pre-slaughter stress, stress measurement

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Introduction

Meat quality is a very complex and difficult term defining those traits that the consumer perceives as desirable (Warner et al., 2010). Those traits include both technological quality attributes, consumer acceptance, and credence characteristics (e.g. ethical quality) (van der Wal et al., 1997; Warner et al., 2010; Warriss, 2010; Lee et al., 2012; Kim et al., 2016). Technological quality includes color, water holding capacity (WHC), and texture, and are affected by biological processes during postmortem conversion of muscle to meat (van der Wal et al., 1997; Lee et al., 2012). Consumer acceptance results from a complex combination of visual appeal and eating satisfaction, which is closely associated with tenderness, juiciness, and flavor of the meat (Glitsch, 2000; Warner et al., 2010; Lee et al., 2012). Ethical quality is composed of two main elements; one is a meat producing systems that are sustainable and environmentally friendly, and the other is meat producing ways sympathetic to animal welfare (Warriss, 2010). Consumers are increasingly concerned with animal welfare during rearing and at slaughter while they continue to consider technological and sensory quality of meat as important issues (Terlouw, 2005; Koknaroglu and Akunal, 2013).

Definition of animal welfare is too difficult but it is obvious that welfare is associated with physical and mental well-being of animals (Hewson, 2003; Terlouw, 2005; Warriss, 2010). Physical well-being implies that an animal is fit and healthy but mental well-being is harder to define compared with physical well-being because it is difficult to understand whether an animal is satisfied or not with its environment (Warriss, 2010). Animals may face welfare problems even though they are in good environmental conditions. For example, broiler chickens, which reaching market weight at 42-day feeding in good environmental conditions, develop leg deformations that have the negative aspects of the welfare of the animals (Koknaroglu and Akunal, 2013). In this sense, Koknaroglu and Akunal (2013) define animal welfare as providing environmental conditions in which animals can display all their natural behaviors in nature. However, most of meat producing animals face numerous conditions before slaughter and these conditions have negative effects on the psychological and physical state of animals. Thus, various procedures and handling before slaughter, such as transportation, loading, unloading, and lairage, worsen animal welfare and attribute to alterations in the rate and extent of postmortem glycolysis, which may influence meat quality (D'Souza et al., 1998a, b; Hambrecht et al., 2005b). Especially, pigs and chickens are susceptible to pre-slaughter stress and poor quality of meat such as pale, soft, and exudative are produced consequently. Therefore, this review paper will look over the concept of stress, physiological responses to stress, and measurement of stress and their relationships with meat quality traits.

Concept of stress and pre-slaughter stress in livestock

Concept of stress

The one most often cited definition of stress is "an animal is in a state if it is required to make abnormal or extreme adjustments in its physiology or behavior in order to cope with adverse aspects of its environment and management" (Fraser et al., 1975; Terlouw, 2005). However, this definition does not include the mental or psychological state of the animal. Recently, researchers have considered the psychological aspects of animal when defining stress. Thus, stress can be defined as behavioral, physiological, and emotional status of the animal confronted with a situation that it perceives as threatening to the homeostasis (Chrousos, 2009; Kyrou and Tsigos, 2009; Ranabir and Reetu, 2011). All organisms must maintain a complex dynamic equilibrium, homeostasis, which is the correct functioning of organisms' bodily or mental state. Homeostasis are continuously challenged by internal or external adverse forces, called stressors (Chrousos, 2009; Kyrou and Tsigos, 2009; Ranabir and Reetu, 2011). In general, stressor refers to the environmental pressure or stimulus which can cause stress and stress is reserved for the animal's response to a stressor (Warriss, 2010).

Pre-slaughter stress

Livestock are exposed to a lot of potential stressors in the period from leaving the production unit to slaughter at the slaughter house (D'Souza et al., 1998b). These stressors include removal from the familiar fattening pen, loading, transportation, unloading, fasting, mixing with unfamiliar animals, overcrowding, and exposure to novel environments

(D'Souza et al., 1998b; Salajpal et al., 2005; Terlouw et al., 2008). Handling, such as the use of electric prods and physical violence by human, and stress immediately before stunning/slaughter also causes extreme stress to animals. Especially, stress just prior to stunning/slaughter has more negative effects on psychological and physiological state of animals compared to pre-slaughter stress experienced before lairage at the slaughter plant (van der Wal et al., 1999; Hambrecht et al., 2005a). In addition, Edwards et al. (2010a) have shown that the blood lactate level is variable and had predictive of the rate of early postmortem metabolism though experimental pigs were under low-stress pre-slaughter handling and standard marketing conditions. According to Terlouw (2005), it is important to note that the stress levels of the animal depend indirectly on the situation, and directly on the animal's evaluation of the situation. Each individual is unique, depending on its genetic background and its prior experience. Thus, its assessment of the situation, and its possibly resulting stress levels are subjective, that is, individual-dependent.

Physiological responses to stress

Physiological response to stress in livestock have been reviewed by Johnson et al. (1992), Minton (1994), and Warriss (2010). This section is the summary of the literatures of Johnson et al. (1992), Minton (1994), and Warriss (2010). Animals physiologically respond to stress in a characteristic way that has two components (Minton, 1994; Warriss, 2010). The first is a rapid short-term 'alarm' response, that is referred as the emergency syndrome by W. B. Cannon, the American physiologist. For instance, when animal faces a threat, such as a sudden arrival of a predator, they prepare their body for 'flight or fight' (Warriss, 2010). These preparations largely involve the activity of the sympatho-adrenal system and the secretion of the catecholamine hormones, adrenaline and noradrenaline (also known as epinephrine and norepinephrine) (Johnson et al., 1992; Minton, 1994; Warriss, 2010). The second component of the stress response occurs after the first 'alarm' response and last over a longer time period (Minton, 1994; Warriss, 2010). The role of the second component is to allow the animal to recover from the alarm response or to 'adapt' to the new situation, so Hans Selye referred this as the general adaptation syndrome when considered along with the alarm response (Minton, 1994; Warriss, 2010). This component involves the hypothalamo-adrenal axis (Warriss, 2010).

Response to stress via the sympatho-adrenal system

When animals are under the stressful situations, the sympatho-adrenal system is stimulated (Warriss, 2010). Noradrenaline is secreted into the blood and the adrenal medulla is stimulated directly through the nerves (Minton, 1994; Warriss, 2010). The stimulated adrenal medulla release both noradrenaline and adrenaline into the blood that allow the animal to prepare for 'fight' or 'flight', including an increase in heart rate and a rise in blood glucose levels from the rapid breakdown of glycogen in the liver (Johnson et al., 1992; Minton, 1994; Warriss, 2010). Glycogen breakdown in the liver causes results that the circulation of nutrient-rich and oxygenated blood is increased in the body, blood flow is switched away from the viscera to the muscles, and the spleen, a reservoir of red blood cells, contracts (Johnson et al., 1992; Minton, 1994; Warriss, 2010). As a result of contraction of spleen, red blood cells are released into the circulatory system and oxygen-carrying capacity is increased (Minton, 1994; Warriss, 2010). Other effects of stimulation of the sympathetic nervous system include dilation of the pupils of the eyes, reduced salivation, piloerection, secretion of more sweat and constriction of the blood vessels of the skin (Minton, 1994; Warriss, 2010). Finally, especially in human experience, these physiological changes under the stress exhibit a dry mouth, the hair on the back of our neck standing up, sweaty hands and pallor of our faces (Warriss, 2010).

Response to stress via the hypothalamo-adrenal axis

During stressful events the hypothalamus secretes corticotrophin-releasing factor (CRF) (Minton, 1994; Warriss, 2010). This stimulates the pituitary gland to secrete adrenocorticotropic hormone (ACTH) into the blood (Minton, 1994; Warriss, 2010). ACTH in the blood stimulates the cortex of the adrenal gland to secrete corticosteroid hormones, cortisol (hydrocortisone) and corticosterone (Minton, 1994; Warriss, 2010). The release of the corticosteroid hormones is a distinctive response of an animal to stressors (Minton, 1994; Warriss, 2010). Most animals produce both hormones but cortisol predominates in primates such as man, pigs, cattle, sheep, dogs, and cats, while corticosterone predominates in rodents and chickens (Minton, 1994; Warriss, 2010). When cortisol is administered to animals, blood glucose level is increased and deposition of glycogen in the liver is promoted (Johnson et al., 1992; Minton, 1994; Warriss, 2010). The increase in blood glucose comes partly both from 1) a decrease in the rate of its breakdown and 2) an increased synthesis from protein (gluconeogenesis) (Warriss, 2010) (Fig. 1).

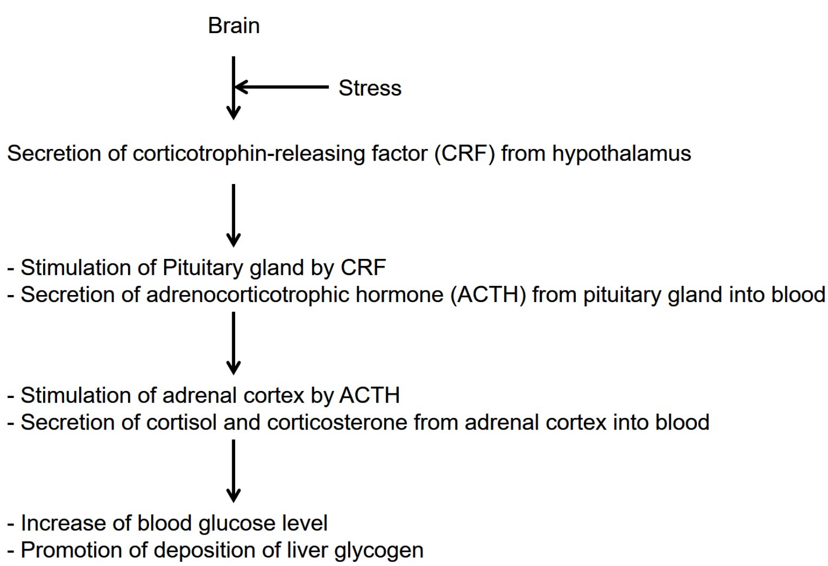

Fig. 1. Cascade reaction of the hypothalamo-adrenal system under the stressful episode. Cited from Warriss (2010) with slight modifications.

Physiological changes via the effects of the corticosteroids are complex and extensive, but it is apparent that the corticosteroids tend to counteract many of the effects of the catecholamines (Minton, 1994; Warriss, 2010). Catecholamines promote the breakdown of glycogen in the liver to increase the amounts of glucose available to the muscles at a time when they are under the situations that require energy, such as escape or defense (Johnson et al., 1992; Minton, 1994; Warriss, 2010). During the recovery or adaptive phase of the stress response (i.e., the second component of the stress response), the corticosteroids promote resynthesis of glycogen in the liver from circulatory glucose while the level of blood glucose is maintained by gluconeogenesis (Johnson et al., 1992; Minton, 1994; Warriss, 2010).

Measurements of stress and meat quality traits

Cortisol is the most reliable indicator of stress, especially psychological stress (Warriss, 2010). Cortisol is secreted by the adrenal cortex under the control of ACTH, which is secreted by the pituitary gland stimulated by CRF (Terlouw, 2005; Warriss, 2010). In this sense, cortisol is called as the stress hormone. In addition, circulating cortisol level can reflect the quality of pre-slaughter handling process, because it responds less rapidly against stressors and recovers more slowly compared with other indices (Warriss et al., 1994). Most of the studies about stress of animals used cortisol level in blood, muscle, hair, saliva, and urine (Shaw et al., 1995; Foury et al., 2005; Faucitano et al., 2006; Kalra et al., 2007; Choi et al., 2012; Russell et al., 2012). However, though cortisol level provides reliable information of stress, the relationship between cortisol level and meat quality have not been still clear because cortisol level could be influenced by genetic and environmental factors, such as breed, sex, susceptibility to stress, and repeatability to the same stressor (Warriss et al., 1994; Brown et al., 1998; Kanitz et al., 2005; Terlouw, 2005; Li et al., 2009; Choi et al., 2012). Furthermore, assessing cortisol level requires an invasive blood sampling. Blood sampling for assessing cortisol also requires capture, handling, and bleeding of animal but these blood sampling causes a rapid increase in blood glucocorticoid concentrations within 3 min (Scheriff et al., 2010). However, blood sampling of free-ranging animals is not possible within 3 min (Romero and Romero, 2002).

The blood lactate level is also a widely used indicator of stress (Hambrecht et al., 2004, 2005a, 2005b; Edwards et al., 2010a, 2010b). In particular, the blood lactate level is elevated rapidly to physical stress (Warriss, 2010). When animals are exposed to stress situations, muscles become prepared to meet the demand for contractions that an emergency might require. In this event, the anaerobic pathway for glycogen breakdown, leading to the formation of lactate, is favored by the action of adrenaline, one of the catecholamine hormone. Consequently, a shift type of metabolism occurs spontaneously in the living animal in the same way for rapidly contracting muscle and postmortem muscle (Aberle et al., 2001). Compared to cortisol level, the blood lactate level is a reliable indicator of meat quality as well as stress (Hambrecht et al., 2004, 2005a, 2005b; Edwards et al., 2010a, 2010b). According to Edwards et al. (2010a, 2010b), the blood lactate level at exsanguination was related to specific pre-slaughter animal-handling, and predictive of the rate of early postmortem metabolism. Hambrecht et al. (2004, 2005a) have reported that pigs exposed to aggressive handling just prior to stunning increased blood lactate level at exsanguination and exhibited higher drip loss. Thus, Hambrecht et al. (2004) proposed that blood lactate level had a potential indicator of physical and psychological stress associated with the handling of pigs immediately before slaughter. In addition, measurement of blood lactate is easy and quick due to hand-held analyzer (Edwards et al., 2010a).

Recent studies have reported that pre-slaughter stress could cause imbalance of electrolytes, including calcium, magnesium, potassium, sodium, and chloride (Schaefer et al., 1997; Salajpal et al., 2005; Becerril-Herrera et al., 2010; Mota-Rojas et al., 2012). In particular, transport and handling may cause significant changes in electrolyte balance (Schaefer et al., 1997). Becerril-Herrera et al. (2010) and Mota-Rojas et al. (2012) have reported that prolonged transport or stunning methods cause physiological disorders and metabolic disturbance in pork. However, the relationship between the concentration of individual electrolytes and meat quality has not been previously reported.

The blood glucose level is regarded as an indirect indicator of stress (Mota-Rojas et al., 2012). It is obvious that the stress elevates blood glucose level via rapid breakdown of glycogen in the liver due to the action of catecholamine, which is secreted by stress. In addition, cortisol increases blood glucose level because elevated cortisol level decreases the rate of breakdown and increases synthesis from protein (gluconeogenesis) (Johnson et al., 1992; Aberle et al., 2001; Warriss, 2010). Blood glucose level is the main source for anaerobic pathway, which is the main metabolic pathway when animals are under stress condition (Karlsson et al., 1999; Aberle et al., 2001). It means that blood glucose level may be related to the blood lactate level in stress animals. However, blood glucose is not a main concern when discussing animal stress because it is under control of various hormones and influenced by various factors (Becerril-Herrera et al., 2010; Mota-Rojas et al., 2012), even though the blood glucose level is closely associated to pork quality traits (Choe et al., 2009; Choe and Kim, 2014; Choe et al., 2015) (Table 1). Measurement of blood glucose is also easy and quick like blood lactate measurement because hand-held analyzer can be used (Choe et al., 2009; Edwards et al., 2010a, 2010b; Choe and Kim, 2014).

Table 1. Correlation coefficients between blood parameters at exsanguination and pork quality traits (cited from Choe et al., 2015).

	$pH_{45\ min}$[y]	$pH_{24\ h}$[y]	L^{*z}	a^{*z}	b^{*z}	FFU	Drip loss	WBS
Cortisol	-0.26**	-0.22*	0.18	0.00	0.05	0.38***	0.37***	-0.13
Lactate	-0.46***	-0.26**	0.30***	0.17	0.19	0.40***	0.46***	-0.28***
Glucose	-0.29***	-0.38***	0.31***	0.07	0.29***	0.38***	0.46***	-0.27***
Ca^{2+}	-0.35***	-0.11	0.09	0.20*	0.03	0.28**	0.18	-0.05
K^{+}	-0.26**	-0.03	0.16	0.34***	0.26**	0.23*	0.09	-0.22*
Na^{+}	-0.38***	-0.15	0.00	0.14	0.11	0.43***	0.30***	-0.05
Cl^{-}	-0.07	0.16	0.12	0.11	0.07	0.11	0.04	-0.07

[y]Muscle pH measured at 45 min and 24 h postmortem, respectively.
[z]Commission Internationale de l'Eclairage lightness (L^*), redness (a^*), and yellowness (b^*).
Abbreviations: FFU, filter paper fluid uptake; WBS, Warner-Bratzler shear force.
Level of significance: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

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