

Effect of stress on carcass and meat quality of sheep, goat and pig

SWAGAT MOHAPATRA¹, SANTWANA PALAI^{1✉}, SOUBHAGYA RANJAN PRADHAN²,
SHIVANI DAS¹, AMBIKA PRASAD KHADANGA MAHAPATRA¹, LIPIKA PRIYADARSINI¹,
RITUN PATRA¹ and NIRUPAMA DALAI¹

Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751 003 India

Received: 29 July 2022; Accepted: 28 July 2023

ABSTRACT

Domestic animals like sheep, goat and pig are subjected to many chronic stressful conditions regularly. The stressors include handling, transportation, cold, heat, temperament, diseases, parasites and introduction to a new group. Irrespective of the etiology, stress decreases the normal wellbeing and productivity of the animal. Farm animals attempt to deal with these stressors through behavioural and physiological adaptations aimed at restoring homeostasis. When these responses fail, common signs of persistent stress arise. As the symptoms of stress are unidentifiable by the farmers, there can be a significant deterioration in quality and quantity of meat produced. The increasing need for food due to population growth and urbanization has to be met through proper health management of farm animals. More research is needed to alleviate stress in farm animals and improve product quality and yield. This review paper aims to emphasize on stress factors in farm animals like sheep, goat and pig, and their impact on productivity and meat quality. With a greater understanding of stressors, altered physiological mechanisms, stress adaptability, it would be possible to implement methodologies for stress mitigation in farm animals.

Keywords: Carcass quality, Goat, Meat quality, Pig, Sheep, Stressors

In animal husbandry, stress is considered as a reflex reaction when animals face adverse environmental conditions causing mere discomfort to death. Feeling of intimidation either through handling procedures or change of the environment puts the animal in agony (Villarroel *et al.* 2003, Ohl and Van der Staay 2012). Stress encountered during routine handling and restraint of meat animals declines quality in meat production (Dodzi and Muchenje 2011).

Selye's General Adaptation Syndrome (GAS) presumes three stages- firstly, the alarm reaction when the autonomic nervous system gets activated with release of glucocorticoids and epinephrine. Secondly, the long-term adaptation where body acclimatizes itself to physiological changes of first stage with reduction in cortisol. If stressful circumstance ends in the resistance stage, the body will return to normal. However, if the stressor persists, the body stays on high alert, and stress hormones continue to be generated. The last stage of GAS (tiredness) is due to continuous failing attempts to recover from initial alarm reaction stage. Unable to deal this stress, animals may experience tiredness, depression, and agitation (Lana 2017).

As per animal welfare, it is very difficult to determine

the amount of stress on farm animals. Animal welfare can be associated with meat and carcass quality. Broom (2000) elucidated the animal welfare as a state of attempting to adjust with the environment. The welfare of animal is said to be compromised when the animal is not able to cope or copes with difficulty to the environment. When exposed to various stressors, the animal response affects carcass and meat quality.

Stress can be either physical like fatigue, injury, thirst, nutrition, thermal stress and psychological like restraint, handling the animal etc. (Vogel *et al.* 2019). Stress changes pituitary hormones secretion, behaviour, immune competence, metabolism and reproduction. Thermal stress has detrimental effect on cardiac cells of goats (Parida *et al.* 2020). There is alteration in cardiac electrical activity and injury to myocardial cells during heat stress in cattle (Mohapatra *et al.* 2021). Extreme stressful conditions cause irreparable loss in productivity or even death of the animal (Uzal *et al.* 2016).

With increase in stress, there is decrease in quality of meat. Transportation, environmental conditions, season of the year, lairage time and genotype are also involved (Mantis *et al.* 2019). Meat quality is determined by confirmational qualities, which entail production in response to market demand, and functional qualities, which include desirable attributes in the product (Adzitey 2011).

The important points which are highlighted in this review are identification of different stressors experienced by meat

Present address: ¹College of Veterinary Science and Animal Husbandry, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha. ²West Bengal University of Animal and Fishery Sciences, Kolkata, West Bengal. ✉Corresponding author email: palaisantwana@gmail.com

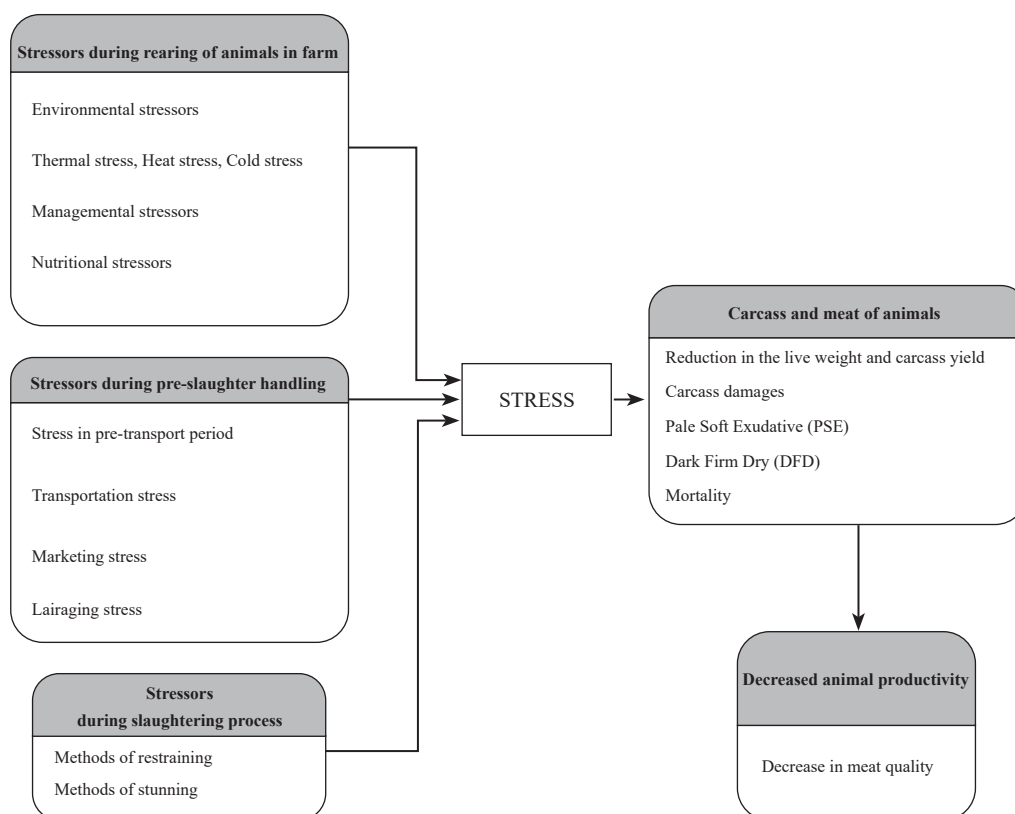


Fig. 1. Effect of different stressors on sheep, goat and pig.

animals from birth to slaughter (Fig. 1); understanding of the biology of stress response components and learning outcomes or implications of stress on carcass quality and meat of the animal.

Stressors experienced by sheep, goat and pig in farm

Environmental stressors

The cumulative effects of continued or chronic environmental stressors affect the quality of meat (Alarcon *et al.* 2005).

Thermal stress: Thermal stress is defined as conditions of extreme environmental temperature leading to disruption in homeostasis of animals (Parida *et al.* 2020). Stull (1997) stated that young or sick animals are more severely affected by heat or cold stress. The thermoneutral zone quantifies the thermal comfort. Most favourable thermal environment encourages maximum performance by giving least stress to the animals. The animal can maintain body temperature, i.e., homeothermy in the thermoneutral zone without expending any extra energy. The normal health status of the animals is affected by either rise or fall of the environment temperature leading to stress (Mitchell *et al.* 2018).

Heat stress: Solar radiation, humidity and elevated ambient temperature are key factors to cause strain on animals. The increased body temperature leads to adaptive depression in metabolic rate resulting in decreased appetite marking the change over from aversive to miasmatic stage. Nutritional imbalance, deficiency and water deprivation aggravate the heat stress effects (Gupta and Mondal 2019).

High temperature as well as high humidity level leads to decreased body weight gain of animals ultimately reducing weight of the carcass. Increased respiration rate and body temperature indicate heat stress in goat. Also, it causes degradation of meat quality (Kadima *et al.* 2004), imbalances in electrolyte concentration (West *et al.* 1991) and severe fiscal losses through surge in mortalities and drop in overall animal performance (Hahn and Mader 1997).

Cold stress: The rate of absorption of nutrition is decreased due to cold stress in the animals. The food intake is lowered leading to lesser thermal production by digestion and absorption of nutrients. Thus, there is declined growth rate of calves. The factors like wind, moisture due to rain or mud and humidity affects the lower and upper temperature of the environment (Stull 1997).

Managemental stressors

Managemental stress involves improper handling of animals by caretakers in the farm which has potential to cause behavioural and physiological stress. It is the sole stressor that can be easily curbed as it is due to human error. Animals are reared almost entirely in farms. Animals are handled in farm right after birth till time of loading into vehicles for their transportation to slaughter houses. Bruising and other serious injuries can occur in animals that are not habituated to enclosed space and thus reacting adversely (Gregory 2008). These situations are more worsened if the stock person or animal handler doesn't know animal behaviour principles, social instincts, flight zones and visual fields (Grandin 2000). These principles

Table 1. Behavioural indicators of stress in sheep, goat and pig

Species	Pre slaughter stress	Behaviour	Positive/ negative	References
Sheep	Housing and transportation	Show their distress by increase in bleating and locomotor activity.	Negative	Kumar <i>et al.</i> 2012
Goat	Heat stress and transportation	Increase in respiration rate, rectal temperature and heart rate, and feed intake affecting growth rate, production, and even death in severe case.	Negative	Gupta and Mondal 2019
Pig	Lairages and transportation	Bar biting, tongue rolling, head-weaving of sows confined in narrow sow stalls	Negative	Kumar <i>et al.</i> 2012, Murphy <i>et al.</i> 2014, Chulayo and Muchenje 2015

help the animals to cope with physical disturbances arising due to powerful communication like rough handling or hitting for re-grouping during confinement (Grandin 2000) which leads to deterioration in meat quality. The decline in quality of carcass results in huge loss to farmers and meat industry.

In cases, where strange animals are mixed, there is fight to establish a new hierarchy socially causing dark cutters and losses due to death in stressed animals. Excitement and fighting are some psychological stressors which are more stressful than physical stressors like lack of feed, excessive physical exertion or inclement weather (Yau and Potenza 2013). Anxious bleating sounds and isolation stresses the sheep too much. Slaps, fast movements, hits, shouting and noise are negative handling behaviour that increases fear, causing stress, handling difficulties and avoidance in the animal (Gebregeziabhear and Ameha 2015). Strong correlation exists between stress and negative handling proving that negative handling produces stress affecting animal production and welfare (Hemsworth 2011, Etim and Oguike 2014). Reproductive efficiency is sometimes adversely affected by psychological disturbance encountered by animals during improper animal handling techniques (Al-Dawood 2017).

Nutritional stressors

Feed plays a vital role in the quality of meat and offal. The fattening of pigs, and quality and quantity of meat is influenced by feeding. The nutritional factors revamping the quality and quantity of the meat products as well as tissue composition are primarily due to the levels of metabolizable energy and protein (Falkowski *et al.* 2001). The quantities of carbohydrates and proteins in animal diets result in the post-slaughter meat-to-fat ratio. Carbohydrates mainly furnish energy to animals. The protein requirements of exogenous amino acids should be provided to animals in diets. Through suitable balancing of the feeding ration in relation to energy and protein supplemented with crystalline amino acids, the minimal coverage of animal nutritional demands would be successful considering their genotype, developmental stage and physiological state in their post-natal life (Trottier *et al.* 2014). Any sort of disturbance in the amount of these components in diet leads to stress. Animal health and production are also affected by the quality of components applied in manufacturing feed mixtures. Nutritional procedures resulting in stress and

dehydration negatively affect live and carcass weights, and meat quality (Gregory 1998).

Stressors during pre-slaughter handling

The final two stages of the animal production system which ultimately leads to the production of high-quality meat are transportation and slaughter of the farm animals (Grigor *et al.* 2004). Stressors which affect the farm animals during the pre-slaughter period are called the precipitating factors of stress and are grouped as physical, psychological and physiological factors in addition to the state of the animal (Fig. 2). These factors include loading and unloading, noise and vibration, congregation, journey, handling by humans, unfamiliar environment, deprivation of food and water, mixing with unfamiliar animals, changes in climatic conditions etc. (Flores-Peinado *et al.* 2020). It has been reported that severe pre-slaughter stress adversely affects the quality of meat in livestock (Apple *et al.* 1995). Several efforts are needed in raising an animal up to the desired weight, quality and age. These few days of pre-slaughter period deteriorate their condition significantly by reducing their weight, affecting the meat quality and ultimately reducing the profit. In addition to that, handling procedures in the pre-slaughter management chain often intensify these effects and reduce welfare of the animal, which is indicated by alteration of behavioural or immune responses of sheep, goats and pigs (Miranda-de *et al.* 2008) (Table 1), decreasing quality of meat and reducing farmer income (María 2008). The detrimental effects of pre-slaughter handling, transport and stunning is seen on meat quality of sheep (Adzitey *et al.* 2011), lambs (Miranda-De *et al.* 2009), goat (Pophiwa *et al.* 2020), kids

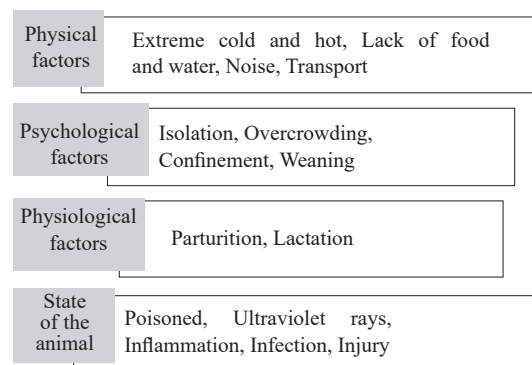


Fig. 2. Precipitating factors of stress in sheep, goat and pig.

(Zimerman *et al.* 2011) and pig (Channon *et al.* 2000, Vermeulen *et al.* 2015).

Stress in pre-transport period: Feed withdrawal is one of the preparatory steps for transfer of meat animals for slaughter. Feed withdrawal done before transportation helps in minimizing the gastrointestinal contents thus decreasing carcasses fecal contamination (Wesley *et al.* 2005, Gajana *et al.* 2011). Additional stresses can occur in cases of multiple transportation and repeated feed withdrawal, in cases where animals are not directly transferred to the slaughter house (Jarvis *et al.* 1996, Driessen *et al.* 2020). Carcass weight loss is incurred due to the loss of fluid through feces and urine, and decrease in tissue substance and muscle glycogen levels due to longer feed interval (Xing *et al.* 2019). Vehicle design for transit also affects weight loss (Bench *et al.* 2008, Dewey *et al.* 2009). Healthy animals are exposed to pathogenic organisms if transported in dirty cages or vehicles (Rajkowski *et al.* 1998). Properly cleaned vehicles should be used for animal transportation.

Catching and loading before transportation are rapid sources of stress for food animals. Also, noises and handling during loading and unloading of transportation is vital stress and injury control point (Fisher 1996, Faucitano 2018).

Transportation stress: According to Von Borell *et al.* (2001), transportation is considered as a significant stressor of farm animals causing hazardous effects on well-being, performance, product quality etc. The mode of transport, type and age of the animals should be considered while planning their transportation. Well-designed facilities and good management can reduce stress during transportation. Poor transportation facility might put the animals in harm's way. Farms are typically located far from cities in order to provide better and less expensive feed, sale, etc. This necessitates transportation of animals to markets and slaughter houses (Sionek and Przybylski 2016). As per the suggestion of Adzitey and Nurul (2010), both loading and unloading should be done in gentle and quiet environment before and after transportation, respectively. Other environmental stress factors like heat, cold, humidity, noise, overcrowding of animals, over speeding, sudden stops, long journey without any interval will affect the carcass and meat quality. The animal losses and the risk of pale, soft, exudative (PSE) condition in pork is higher in summer (Guardia *et al.* 2004) and that of bruised carcasses and dark, firm, dry (DFD) condition is higher in winter (Gosalvez *et al.* 2006) (Table 2). Stress caused by transportation decreases tenderness and acceptability of meat (Villaruel *et al.* 2003) and adversely affect welfare of animal leading to economic losses (Akinwumi *et al.* 2013). Various physical, microbial, environmental hazards during transportation negatively affect health, welfare of animals and quality end products (Sommavilla *et al.* 2017). The stress due to transportation and pre-slaughter handling also impair cellular immune responses causing physiological changes affecting the safety and quality of meat products (Harvey *et al.* 2001, Faucitano and Goumon 2018).

Marketing stress: The animals are kept in open pens in

groups exposed to the sun or cold in the markets. Other marketing stresses include unfamiliar environment, noise, social regrouping, starvation and dehydration due to withdrawal of feed and water longer than suggested. Multiple degrees of bruising occur on skin of animals at the market due to faulty handling during transportation. The prevalence of bruising ranges from 2 to 8 % between markets (McNally and Warriss 1996). All these add to the stress and depreciate the meat quality. Adzitey and Nurul (2010) discussed the marketing strategies for stress reduction, which ultimately led to reduction of pale, soft, exudative (PSE) and dry, firm, dark (DFD) condition of meat (Table 2).

Lairaging stress: Prior to slaughter, animals are held in the lairage for a short time. It is the collection point for various animals prior to slaughter. Any possibility of injury or infection is ruled out through animal's movement (Ćobanović *et al.* 2016). Adequate amount of proper feed and water should be provided if the stay in lairage is longer than expected. Lairaging allows rest and recovery from transportation stress but it can lead to meat quality problems (Driessen *et al.* 2020). Many degrees of injury and bruising occur due to overcrowding or fighting. Because of the fact that, lairage can be reservoirs of pathogenic bacterial infection, so longer lairaging time leads to contamination of carcass (Warriss 2003). Inappropriate handling of animals in the lairage such as using electrical rods, restricting the movement of animals through race, beating and gripping the animal's coat tightly with the hand, exposure of animals to microbial contaminations etc. decreases carcass and meat quality. The lairage should be capable of arresting infections and allow the recovery of animals from transportation stress.

Stressors during slaughtering process

During slaughtering process, stress occurs as per the method adopted for slaughter in the abattoir particularly through methods of restraining and stunning (Grandin 2010). The religious slaughter of meat animals does not allow stunning, causing stress in animal while proceeding to slaughtering platform. Stunning methods negatively affects carcass leading to downgraded meat quality. These can be seen as bruising and hemorrhages, bone fractures, pelt burn in sheep, changes in meat colour due to DFD condition and decreased eating quality like toughness (Cetin and Topcu 2009). Proper stunning with help of electrical stimulations is better for better-quality meat production (Biswas *et al.* 2007, Abdullah *et al.* 2019).

Biology of stress and its effect on carcass and meat of sheep, goat and pig

In terms of danger or threat, regarding past experience, personal expectation and opportunities for control, the central nervous system gathers information from internal and external (sensory organs) environment which initiates the adaptive responses like neuroendocrine changes and behavioural adjustments to reach the energy requirements

Table 2. Events leading to PSE and DFD in meat of sheep, goat and pig

Events	Pale, soft and exudative (PSE)	Dark, firm and dry (DFD)	References
Type of stress	Acute or short-term stress	Chronic or long-term stress	Adzitey and Nurul 2011,
pH limit	<6 at 45 minutes after slaughter	>6 at 24 hours after slaughter	Stajković <i>et al.</i> 2017,
	Meat with ultimate pH value between 5.4-5.6 or even lower value i.e. 5.3	Meat with ultimate pH value between 6.5-6.8 or more preferably 6.4	TC dos Santos <i>et al.</i> 2019,
Water holding capacity	Low	High	Poznyakovskiy <i>et al.</i> 2015,
			Wang <i>et al.</i> 2017,
Factors responsible for high/low pH	Accelerated rate of post mortem glycolysis leads to low pH even if temperature of carcass is still high	Depletion of stored glycogen leads to higher ultimate pH of meat	Chulayo and Muchenje 2015,
			Mir N A <i>et al.</i> 2017,
Extracellular space	Larger	Smaller	Gotardo <i>et al.</i> 2015,
Scattering of light	More hence higher difference in refractive index	Less hence lower difference in refractive index	Frimpong <i>et al.</i> 2014
Characteristics of meat quality	Pale, lean and soft texture	Dark, variation in tenderness and dry	
Drip loss	High	Low	
Tendency of protein denaturation	High	Low	
Effect of absorption of visible light	Reduction in absorption of green light by myoglobin	Increased absorption of light by myoglobin	
Type of muscle fibre susceptible	White muscle fibre is more susceptible to PSE	Red muscle fibre more susceptible to DFD	

for the behavioural response in order to maintain homeostasis (Schiller *et al.* 2021). The endocrine responses are activated by psychological aspects of environmental stimuli. The pituitary-adrenal axis response is dependent on amount of psychological stress experienced by an animal. The behavioural and hormonal responses are interrelated. In stressful conditions, animal respond through raised catecholamine concentrations and creatine kinase activity (Chulayo 2011) and increased hormone, enzyme levels negatively affect quality of meat due to rapid glycolysis and elevated lactate production, which in turn elevate the blood lactate level (Lewis *et al.* 2006). The physiological changes like increased body temperature, heart rate and respiratory rate lead to changes in immune system due to stress (Ekiz *et al.* 2012). Stress in pigs causes the activation of hypothalamic pituitary-adrenal axis, which leads to release of glucocorticoids into the blood (Lewis *et al.* 2006). During pre-slaughter handling, the raised physical activity or physiological stress in farm animals depletes muscle glycogen reserves resulting in higher pH of meat with increased water holding capacity and dark tough meat (Muchenje *et al.* 2009). Animals habituated with human during early life exhibit less fearful (during handling) and stressed behaviours at the abattoir.

Due to fighting or transportation, the animals are affected with muscle damage or bruises. In response to muscle damage or excess exercise, muscle and tissue damage results (Myers 2006, Schimelpfenig 2021). The increased concentration of Lactate dehydrogenase (LDH) and Creatine kinase (CK) in blood can be treated as indicator of trauma due to damages during transport and handling of animals (Knowles and Warriss 2007). However, in case of lambs transported without pre-transport supplementation, plasma

CK activity increased while LDH level remained same.

Reduction in the live weight and carcass yield of animals: Generally, prior to slaughter, animals are deprived of food and water. If the time interval is too long, live weight of animals will be decreased due to reduction in gut fill and breakdown of muscle glycogen for energy (Warriss 2020). According to Warriss (2000), these losses in live or carcass weight is considered as 'Shrinkage' leading to a significant loss of meat and carcass yield.

Carcass damages: Due to improper handling, damages to carcass like bruising, blood splash skin blemishes, hemorrhages and broken bones occur (Lessler *et al.* 2007). In such cases, excessive blood gets accumulated inside the skin and blood vessels which has to be cut off during processing. If a part of the carcass is trimmed off, then there will be reduction of meat quality and yield, and ultimately there will be increase in processing time (Schwartzkopf-Genswein *et al.* 2012). The untrimmed parts, having ugly appearance serve as potential source for microbial growth resulting in sooner spoilage of the meat. Bone splinters in meat which is caused due to broken bones can be dangerous to the consumer if undetected even after deboning (Warriss 2000).

Pale Soft Exudative (PSE) and Dark Firm Dry (DFD): The fighting among animal just before sticking, use of electric goads and overcrowding leads to acute or short-term stress causing PSE (Manalo and Gabriel 2020). Similarly, chronic or long-time stress which is mainly due to long hours of transportation, food and water deprivation and overcrowding of animals leads to DFD condition in carcasses (Ponnampalam *et al.* 2017). PSE and DFD meats are ugly-looking and unacceptable by consumers (Viljoena *et al.* 2002). PSE meat is having pale, lean and soft texture

in appearance with low water holding capacity. DFD meat looks dark, varies in tenderness and more prone to spoilage (Adzitey and Nurul 2010).

Mortality of animals: Death of animals occurs due to faulty pre-slaughter handling (Sabow *et al.* 2017). The severe stress ultimately leads to death when timely treatment of animals is not done during their sickness or transported under harsh and stressful environment. The worst effect of pre-slaughter handling on carcass and meat quality is due to death of animals leading to total loss of carcass and meat quality and the dead animal has to be disposed (Šimová *et al.* 2016).

Conclusion

Activities and processes prior to slaughter are essential factors which are ultimately responsible for carcass and meat quality defects of sheep, goat and pig. Proper attention should be given to the animals irrespective of age, sex, kind, species and breed during the stage of rearing, pre-slaughter and slaughter. The animals are exposed to precipitating factors of stress during transportation in farm, at the market and in lairage leading to carcass damages, reduction in live weight, PSE and DFD condition in meat and sometimes death of the animal. These factors also compromise animals' welfare. For reduction of stress of the animal, proper attention and care must be given by the animal handlers before the process of slaughter. Animal handlers should be calm, quiet, confident and positive during animal handling because animals are much sensitive to fear and hesitation of the handler. The veterinarian, expert or professionals should bear the sole responsibility of closely monitoring work in the abattoirs, meat processing units to nullify the carcass and meat quality defects in sheep, goat and pig.

REFERENCES

- Abdullah F A A, Borilova G and Steinhäuserova I. 2019. Halal criteria versus conventional slaughter technology. *Animals* **9**(8): 530.
- Adzitey F and Nurul H. 2010. Pale soft exudative (PSE) and Dark firm dry (DFD) meats: Causes and measures to reduce these incidences. *International Food Research Journal* **18**(1): 11–20.
- Adzitey F and Nurul H. 2011. Pale soft exudative (PSE) and dark firm dry (DFD) meats: Causes and measures to reduce these incidences-a mini review. *International Food Research Journal* **18**(1).
- Adzitey F. 2011. Effect of pre-slaughter animal handling on carcass and meat quality. *International Food Research Journal* **18**(2).
- Akinwumi A O, Odunsi A A and Omojola A B. 2013. Effect of transportation on mortality rate of cattle at Ogbomoso central abattoir. Proceedings of the 18th and 2nd ASAN. pp. 65. NIAS Joint Annual Conference.
- Alarcón A D, Duarte O, Rodríguez F A and Janacua H. 2005. Incidence of PSE and DFD muscle in pigs slaughtered in Mexico's Bajío region. *Técnica Pecuaria en México* **43**: 335–46.
- Al-Dawood A. 2017. Towards heat stress management in small ruminants-A review. *Annals of Animal Science* **17**(1): 59.
- Apple J K, Dikeman M E, Minton J E, McMurphy R M, Fedde M R, Leith D E and Unruh J A. 1995. Effects of restraint and isolation stress and epidural blockade on endocrine and blood metabolite status, muscle glycogen metabolism, and incidence of dark-cutting longissimus muscle of sheep. *Journal of Animal Science* **73**(8): 2295–2307.
- Bench C, Schaefer A L and Faucitano L. 2008. The welfare of pigs during transport, pp. 161-195. *Welfare of Pigs from Birth to Slaughter*. (Eds.) Faucitano L and Schaefer A L. Wageningen Academic Publishers, Wageningen, the Netherlands.
- Biswas S, Das A K, Banerjee R and Sharma N. 2007. Effect of electrical stimulation on quality of tender stretched chevon sides. *Meat Science* **75**: 332–36.
- Broom D M. 2000. Welfare assessment and welfare problem areas during handling and transport, pp. 43-61. *Livestock Handling and Transport*. (Ed.) Grandin T. CABI Publishing, New York, USA.
- Cetin O and Topcu T. 2009. Effects of electrical stimulation on meat quality in goat carcasses. *Journal of Food, Agriculture and Environment* **7**(3&4): 101-105.
- Channon H A, Payne A M and Warner R D. 2000. Halothane genotype, pre-slaughter handling and stunning method all influence pork quality. *Meat Science* **56**(3): 291–99.
- Chulayo A Y and Muchenje V. 2015. A balanced perspective on animal welfare for improved meat and meat products. *South African Journal of Animal Science* **45**(5): 452–69.
- Chulayo A Y. 2011. Effects of pre-slaughter sheep handling and animal-handling factors on creatine kinase levels and physico-chemical attributes of mutton. MSc. Thesis, University of Fort Hare, South Africa.
- Čobanović N, Bošković M, Vasilev D, Dimitrijević M, Parunović N, Djordjević J and Karabasil N. 2016. Effects of various pre-slaughter conditions on pig carcasses and meat quality in a low-input slaughter facility. *South African Journal of Animal Science* **46**(4): 380–90.
- Dewey C, Haley C, Widowski T, Poljak Z and Friendship R. 2009. Factors associated with in-transit losses of fattening pigs. *Animal Welfare* **18**: 355-61.
- Dodzi M S and Muchenje V. 2011. Avoidance-related behavioural variables and their relationship to milk yield in pasture-based dairy cows. *Applied Animal Behaviour Science* **133**: 117.
- dos Santos T C, Gates R S, de Fátima Souza C, Tinôco I D F F, Cândido M G L and Freitas L C D S R. 2019. Meat quality parameters and the effects of stress: A review. *Journal of Agricultural Science and Technology* **B**(9): 305-15.
- Driessen B, Van Beirendonck S and Buyse J. 2020. Effects of housing, short distance transport and lairage on meat quality of finisher pigs. *Animals* **10**(5): 788.
- Driessen B, Van Beirendonck S and Buyse J. 2020. Effects of transport and lairage on the skin damage of pig carcasses. *Animals* **10**(4): 575.
- Ekiz B, Ekiz E E, Kocak O, Yalcintan H and Yilmaz A. 2012. Effect of pre-slaughter management regarding transportation and time in lairage on certain stress parameters, carcass and meat quality characteristics in Kivircik. *Meat Science* **90**: 967–76.
- Etim N N and Oguike M A. 2014. Environmental and management stressors: Implications for reproductive and productive performances of farm animals in the tropics. *Journal of Agriculture and Sustainability* **5**(2).
- Falkowski J, Maslanek A and Flis M. 2001. A note on naked oats as a substitute for wheat and barley for young pigs. *Journal of Animal and Feed Sciences* **10**(2): 215–18.

- Faucitano L and Goumon S. 2018. Transport of pigs to slaughter and associated handling, pp. 261–293. *Advances in Pig Welfare*. Woodhead Publishing.
- Faucitano L. 2018. Preslaughter handling practices and their effects on animal welfare and pork quality. *Journal of Animal Sciences* **96**(2): 728–38.
- Fischer K. 1996. Transport of slaughter animals: Effects, weaknesses, measures. *Fleischwirtschaft* **76**(5): 521–26.
- Flores-Peinado S, Mota-Rojas D, Guerrero-Legarreta I, Mora-Medina P, Cruz-Monterrosa R, Gómez-Prado J and Martínez-Burnes J. 2020. Physiological responses of pigs to preslaughter handling: Infrared and thermal imaging applications. *International Journal of Veterinary Science and Medicine* **8**(1): 71–84.
- Frimpong S, Gebresenbet G, Bobobee E, Aklaku E and Hamdu I. 2014. Effect of transportation and pre-slaughter handling on welfare and meat quality of cattle: Case Study of Kumasi Abattoir, Ghana. *Veterinary Sciences* **1**: 174–91.
- Gajana C S. 2011. 'Effects of pre-slaughter handling on pork quality from a small holder abattoir.' Doctoral dissertation, MSc. thesis, University of Fort Hare, South Africa.
- Gebregeziabhear E and Ameha N. 2015. The effect of stress on productivity of animals: A review. *Journal of Biology, Agriculture and Healthcare* **5**(15): 14–22.
- Gosalvez L F, Averos X, Valdevira J J and Herranz A. 2006. Influence of season, distance and mixed loads on the physical and carcass integrity of pigs transported to slaughter. *Meat Science* **73**: 553–58.
- Gotardo L R M, Vieira P B, Marchini C F P, Nascimento M R B M, Antunes R C, Guimarães E C, Bueno J P and Santos D B. 2015. Cyclic heat stress in broilers and their effects on quality of chicken breast meat. *Acta Scientiae Veterinariae* **55**: 1–5.
- Grandin T. 2000a. Animal handling troubleshooting guide. *Meat Poultry March* 64–69.
- Grandin T. 2010. Auditing animal welfare at slaughter plants. *Meat Science* **86**(1): 56–65.
- Gregory N G and Grandin T. 1998. Animal welfare and meat science (No. 636.08947 G7). CABI Publishing.
- Gregory N G. 2008. Animal welfare at markets and during transport and slaughter. *Meat Science* **80**(1): 2–11.
- Grigor P N, Cockram M S, Steele W B, McIntyre J, Williams C L, Leushuis I E and Van Reenen C G. 2004. A comparison of the welfare and meat quality of veal calves slaughtered on the farm with those subjected to transportation and lairage. *Livestock Production Science* **91**: 219–28.
- Guardia M D, Estany J, Balasch S, Oliver M A, Gispert M and Diestre A. 2004. A risk assessment of PSE condition due to pre-slaughter conditions and RYR1 gene in pigs. *Meat Science* **67**: 471–78.
- Gupta M and Mondal T. 2019. Heat stress and thermoregulatory responses of goats: A review. *Biological Rhythm Research* **52**(3): 407–33.
- Hahn G L and Mader T L. 1997. Heat waves and their relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Proceedings of the Fifth International Livestock and Environment Symposium. pp. 563–567. Minneapolis, ASAE, St. Joseph, MO.
- Harvey R B, Anderson R C, Young C R, Swindle M M, Genovese K J, Hume M E, Droleskey R E, Farrington L A, Ziprin R L and Nisbet D J. 2001. Effects of feed withdrawal and transport on cecal environment and *Campylobacter* concentrations in a swine surgical model. *Journal of Food Protection* **64**(5): 730–33.
- Hemsworth P H, Rice M, Karlen M G, Calleja L, Barnett J L, Nash J and Coleman G J. 2011. Human–animal interactions at abattoirs: Relationships between handling and animal stress in sheep and cattle. *Applied Animal Behaviour Science* **135**(1–2): 24–33.
- Jarvis A M, Messer C D A and Cockram M S. 1996. Handling, bruising and dehydration of cattle at the time of slaughter. *Animal Welfare* **5**: 259–70.
- Kadima I T, Mahgoub O, Al-Ajmia D S, Al-Maqbalya R S, Al-Mugheiryb S M and Bartolomeb D Y. 2004. The influence of season on quality characteristics of hot-boned beef m. longissimus thoracis. *Meat Science* **66**: 831–36.
- Knowles T G and Warriss P D. 2007. Stress physiology of animals during transport, pp. 312–328. *Livestock Handling and Transport*. 3rd edn. (Ed.) Grandin T. CABI Publishing, UK.
- Kumar B, Manuja A and Aich P. 2012. Stress and its impact on farm animals. *Frontiers in Bioscience* **E**(4): 1759–67.
- Lana B. 2017. What to know about general adaptation syndrome.
- Lessler J, Ranells N and Choice G. 2007. Grower guidelines for poultry and fowl processing. North Carolina State University Cooperative Extension, Raleigh, NC, USA.
- Lewis C R G, Hulbert L E, Lund V, Coleman G, Gunnarsson S, Appleby M C and Karkinen K. 2006. Animal welfare science - Working at the interface between the natural and social sciences. *Applied Animal Behaviour Science* **97**: 37–49.
- Manalo M R and Gabriel A A. 2020. Influence of antemortem and slaughtering practices on the pH of pork and chicken meats. *Philippine Journal of Science* **149**(1): 1–19.
- Mantis F, Bizelis I, Symeon G K and Rogdakis E. 2019. Effects of pre-slaughter short-term factors on pork quality. *Animal Production Science* **59**(12): 2273–79.
- María G A. 2008. Meat quality, pp. 77–113. *Long Distance Transport and Welfare of Farm Animals*. (Eds) Appleby M C, Cussen V and Garces L.
- McNally P W and Warriss P D. 1996. A study of recent bruising in cattle at abattoirs. *Veterinary Record* **138**: 126–28.
- Mir N A, Rafiq A, Kumar F, Singh V and Shukla V. 2017. Determinants of broiler chicken meat quality and factors affecting them: A review. *Journal of Food Science and Technology* **54**: 2997–3009.
- Miranda-de la Lama G C, María G A and Villarroel M. 2008. Behavioural effects of social mixing in feed-lot light lambs. Proceedings of the 42nd Congress of the International Society For Applied Ethology. ISAE, Dublin, Ireland.
- Miranda-De La Lama G C, Villarroel M, Olleta J L, Alierta S, Sañudo C and Maria G A. 2009. Effect of the pre-slaughter logistic chain on meat quality of lambs. *Meat Science* **83**(4): 604–609.
- Mitchell D, Snelling E P, Hetem R S, Maloney S K, Strauss W M and Fuller A. 2018. Revisiting concepts of thermal physiology: predicting responses of mammals to climate change. *Journal of Animal Ecology* **87**(4): 956–73.
- Mohapatra S, Kundu A K, Mishra S R, Senapati S, Jyotiranjan T and Panda G. 2021. HSF1 and GM-CSF expression, its association with cardiac health, and assessment of organ function during heat stress in crossbred Jersey cattle. *Research in Veterinary Science* **139**: 200–210.
- Muchenje V, Dzama K, Chimonyo M, Strydom P E and Raats J G. 2009. Relationship between pre-slaughter stress responsiveness and beef quality in three cattle breeds. *Meat Science* **81**: 653–57.
- Murphy E, Nordquist R E and van der Staay F J. 2014. A review of behavioural methods to study emotion and mood in pigs,

- Sus scrofa*. *Applied Animal Behaviour Science* **159**: 9–28.
- Myers D A. 2006. Common procedures and concerns with wildlife. *Veterinary Clinics: Exotic Animal Practice* **9**(2): 437–60.
- Ohl F and van der Staay F J. 2012. Animal welfare: At the interface between science and society. *Veterinary Journal* **192**: 13–19.
- Parida S, Mishra S R, Mishra C, Dalai N, Mohapatra S, Mahapatra A P K and Kundu A K. 2020. Impact of heat stress on expression kinetics of HSP27 in cardiac cells of goats. *Biological Rhythm Research* **51**(6): 925–33.
- Parida S, Mishra S R, Mishra C, Mohapatra S, Dalai N, Mahapatra A P K and Kundu A K. 2020. Impact of heat stress on transcriptional abundance of HSP70 in cardiac cells of goat. *Animal Biotechnology* **31**(3): 223–28.
- Ponnampalam E N, Hopkins D L, Bruce H, Li D, Baldi G and Bekhit A E D. 2017. Causes and contributing factors to “dark cutting” meat: Current trends and future directions: A review. *Comprehensive Reviews in Food Science and Food Safety* **16**(3): 400–30.
- Pophiwa P, Webb E C and Frylinck L. 2020. A review of factors affecting goat meat quality and mitigating strategies. *Small Ruminant Research* **183**: 106035.
- Poznyakovskiy V M, Gorlov I F, Tikhonov S L and Shelepov V G. 2015. About the quality of meat with PSE and DFD properties. *Foods and Raw Materials* **3**(1): 104–110.
- Rajkowski K T, Eblen S and Laubach C. 1998. Efficacy of washing and sanitizing trailers used for swine transport in reduction of *Salmonella* and *Escherichia coli*. *Journal of Food Protection* **61**(1): 31–35.
- Sabow A B, Nakyinsige K, Adeyemi K D, Sazili A Q, Johnson C B, Webster J and Farouk M M. 2017. High frequency pre-slaughter electrical stunning in ruminants and poultry for halal meat production: A review. *Livestock Science* **202**: 124–34.
- Schiller M, Ben-Shaanan T L and Rolls A. 2021. Neuronal regulation of immunity: why, how and where? *Nature Reviews Immunology* **21**(1): 20–36.
- Schimelpfenig T. 2021. NOLS wilderness medicine. Rowman & Littlefield.
- Schwartzkopf-Genswein K S, Faucitano L, Dadgar S, Shand P, González L A and Crowe T G. 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: A review. *Meat Science* **92**(3): 227–43.
- Šimová V, Večerek V, Passantino A and Voslášková E. 2016. Pre-transport factors affecting the welfare of cattle during road transport for slaughter—A review. *Acta Veterinaria Brno* **85**(3): 303–18.
- Sionek B and Przybylski W. 2016. The impact of ante- and post-mortem factors on the incidence of pork defective meat—A review. *Annals of Animal Science* **16**(2): 333–45.
- Sommavilla R, Faucitano L, Gonyou H, Seddon Y, Bergeron R, Widowski T and Brown J. 2017. Season, transport duration and trailer compartment effects on blood stress indicators in pigs: Relationship to environmental, behavioral and other physiological factors, and pork quality traits. *Animals* **7**(2): 8.
- Stajković S, Teodorović V, Baltić M and Karabasil N. 2017. Pre-slaughter stress and pork quality. *IOP Conference Series: Earth and Environmental Science*. **85**(1): 012034. IOP Publishing.
- Stull C L. 1997. Stress and dairy calves. University of California, Davis.
- Trottier N L, Johnston L, de Lange C and Farmer C. 2014. Applied amino acid and energy feeding of sows, pp. 117–146. *The Gestating and Lactating Sow*. Wageningen Academic Publishers, Wageningen (the Netherlands).
- Uzal F A, Plattner B L and Hostetter J M. 2016. Alimentary system. *Jubb, Kennedy & Palmer's Pathology of Domestic Animals* **2**: 1.
- Vermeulen L, Van de Perre V, Permentier L, De Bie S, Verbeke G and Geers R. 2015. Pre-slaughter handling and pork quality. *Meat Science* **100**: 118–23.
- Viljoena H F, de Kocka H L and Webb E C. 2002. Consumer acceptability of dark, firm and dry (DFD) and normal pH beef steaks. *Meat Science* **61**: 181–85.
- Villarreal M, Maria G A, Sanudo C, Oletta J L and Gebresenbet G. 2003. Effect of transport time on sensorial aspects of beef meat quality. *Meat Science* **63**: 353–57.
- Vogel K D, Fabrega Rromans E, Llonch Obiols P and Velarde V. 2019. Stress physiology of animals during transport. *Chapter* **3**: 30–57.
- Von Borell E H. 2001. The biology of stress and its application to livestock housing and transportation assessment. *Journal of Animal Science* **79**(E): E260–67.
- Wang R H, Liang R R, Lin H, Zhu L X, Zhang Y M, Mao Y W, Dong P C, Niu L B, Zhang M H and Luo X. 2017. Effect of acute heat stress and slaughter processing on poultry meat quality and postmortem carbohydrate metabolism. *Poultry Science* **96**(3): 738–46.
- Warriss P D. 2000. Meat science: An introductory text. CAB-International, Wallingford, England.
- Warriss P D. 2003. Optimal lairage times and conditions for slaughter pigs: A review. *Veterinary Record* **153**(6): 170–76.
- Warriss P D. 2020. Antemortem factors influencing the yield and quality of meat from farm animals, pp. 1–15. *Quality and Grading of Carcasses of Meat Animals*. CRC Press.
- Wesley I V, Muraoka W T, Trampel D W and Hurd H S. 2005. Effect of preslaughter events on prevalence of *Campylobacter jejuni* and *Campylobacter coli* in market-weight turkeys. *Applied and Environmental Microbiology* **71**(6): 2824–31.
- West J W, Yullinix B O and Sandifer G. 1991. Changing dietary electrolyte balance for dairy cows in cool and hot environments. *Journal of Dairy Science* **74**: 1662–74.
- Xing T, Gao F, Tume R K, Zhou G and Xu X. 2019. Stress effects on meat quality: A mechanistic perspective. *Comprehensive Reviews in Food Science and Food Safety* **18**(2): 380–401.
- Yau Y H and Potenza M N. 2013. Stress and eating behaviors. *Minerva Endocrinologica* **38**(3): 255.
- Zimmerman M, Grigioni G, Taddeo H and Domingo E. 2011. Physiological stress responses and meat quality traits of kids subjected to different pre-slaughter stressors. *Small Ruminant Research* **100**(2-3): 137–42.