Sheep welfare during transport and slaughter in Bulgaria – Impact of welfare on slaughter carcass and meat quality: a review

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1. Introduction
The issues of animal welfare and humane attitudes to animals have gained increasing popularity in recent years, both in European countries in general and in Bulgaria.

Animal welfare is a concern for the animals' suffering and satisfaction [1]. Stress is a physiological response of animals to threats or harmful situations. An example of stress is the uncontrollable shaking of some animals exposed to loud sounds and situations in a slaughterhouse. The most practical definition of good welfare states that the animal is healthy and has all it wants [2]. The emphasis placed on animal health underlines the importance of factors related to health (food, water, and lack of injuries), although the issue of what an animal wants means that good welfare goes beyond physical health [3].

It becomes clear that the above-mentioned animal welfare definitions differ, although key words in them all are “physical and mental state”, “needs”, “animal suffering”, and “health”. In this regard, it is said that animal welfare is difficult to be determined [4], because it is multidimensional. It includes health, comfort, behavior expression, etc. Therefore, its evaluation requires multicriteria analysis [5].

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Abstract: The present work aimed to review the state of sheep welfare in Bulgaria during transportation and slaughter and to evaluate its relationship with slaughter carcass and meat quality. Over the last few years, animal welfare has become increasingly important. Normative documents related to welfare during rearing, transport, and slaughter of animals have been developed and promulgated. A major percentage of these animals are reared for meat production, but attempts to minimize stress and pain during transport and slaughter should be made. Stress reduction and pain control improve animal welfare and also impact carcass and meat quality. This overview demonstrates that improper preslaughter handling deteriorates meat quality and increases stress levels in animals. Consumers are increasingly concerned about meat quality and are even ready to pay more to purchase products of higher quality. One of the main ways for improvement of meat quality is to comply with animal welfare standards. This review focuses on some EU countries such as Bulgaria, taking interest in proper preslaughter handling of sheep due to its beneficial effects on meat and carcass qualities. In addition, this review highlights the factors to consider in sheep handling and their effect on meat and carcass quality.

Key words: Animal welfare, animal handling, carcass and meat quality, transportation

In relation to animal welfare, the so-called “five freedoms concept” has gained popularity [1]. According to this concept, animals are entitled to:

- Freedom from hunger and thirst - the animals should have permanent access to fresh water and feed to maintain their health.
- Freedom from a discomfort - the animal should be provided with an appropriate environment including shelter and a lairage area.
- Freedom from pain, injury, or disease - animals should receive disease prevention and rapid and appropriate treatment.
- Freedom to express normal behavior - animals should be provided with sufficient space, proper facilities, and interaction with individuals from their species/breeds.
- Freedom from fear and distress - when handling animals, it should be done in a way to avoid stress and suffering.

The compromised welfare of animals during their handling for slaughter is related to 5 main factors [6]:

1. The equipment of the vehicles and the means of transport;
2. Poor and inadequate training of the staff involved in loading/unloading of the animals;
3. The extreme physical load of the animals during their transportation;
4. Inappropriate devices and equipment of premises for preslaughter handling and for stunning;
5. Poor general condition of the animals arriving at the slaughterhouse.

During the last few years, a number of normative documents have been developed, including laws and regulations governing the welfare of animals during husbandry, transport, and slaughter. The most important legal acts regulating the welfare of animals in Bulgaria are:

1.1 Animal Protection Act, effective from 31.01.2008 (Prom. State Gazette Issue 13 of 8 February 2008) [7];
1.2 Ordinance No. 22 of 14 December 2005 to minimize animal suffering during slaughter or killing (Prom. State Gazette No. 42 of 25 May 2006) [8];
1.3 Ordinance No 16 of 3 February 2006 on the Protection and Welfare of Farm Animals during Production and Improvement. (Prom. State Gazette Issue 18 of 28 February 2006) [9];
1.4 Ordinance No. 26 of 28 February 2006 on Conditions for the Protection and Welfare of Animals During Transport (Publ. State Gazette No. 23 of 17 May 2006) [10];
1.5 Council Regulation (EC) No. 1/2005 of 22 December 2004 on the Protection of Animals During Transport and Related Operations and Amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97 [11].

2. Transportation of animals
The transportation and handling of animals are important issues of meat production systems. Animals intended for slaughter are subjected to stress by factors such as loading, transport, restraint, handling, unloading, adverse weather, hunger, thirst, and fatigue [12].

If animals are to be transported before being slaughtered, this should be performed in specially equipped vehicles under conditions guaranteeing their health and physiological needs. Transportation stress is inevitable [13,14]. During loading, transport, and unloading, the animals are in a new environment. This is something different, which is probably happening for the first time. It is something unfamiliar that causes stress during transport. Apart from the negative consequences of stress on animal welfare, it causes economic losses and poor meat quality [12,15]. Although transportation stress cannot be avoided, attempts can be made to minimize it.

Road transport in Bulgaria is mostly used for animals. Specialized vehicles and containers should be used for that purpose [8]. Every means of transport carrying live animals must meet certain basic criteria:

- Their design should provide complete safety for animals during loading, transport, and unloading;
- they should protect animals from injury and unnecessary stress, adverse climatic conditions, and prolonged exposure to noise and vibrations; and
- they should have no sharp edges, protruding objects, holes, or spaces facilitating injuries.

Vehicles intended for the carriage of animals must also be provided with a ventilation system, which:
- should be designed to operate continuously when the animals are in the vehicle, regardless of whether it is moving or not;
- should provide circulation of uncontaminated air;
- should maintain a temperature in the vehicle between 5 and 30 °C;
- should be equipped with an appropriate monitoring device; and
- can be adjusted depending on the temperature inside and outside of the vehicle.

Only identified and registered animals that are clinically healthy and prepared for traveling are transported if conditions for normatively defined care during the travel and at arrival are met. The duration of transportation of different animal species and categories is specified by an ordinance. Transport time should not exceed 8 h [10]. For short-distance transportation with a duration of up to 8 h, animals are provided only with drinking water. Duration of transportation could be longer only if the vehicle responds to some additional requirements.

The loading density for the transportation of lambs and sheep is specified in a legal act. It is stated that the loading density for road transport of shorn sheep and lambs under 55 kg is 0.2–0.3 m² per animal and 0.30–0.35 m² for those weighing more than 55 kg. Fleeced sheep weighing <55 kg require 0.30–0.40 m² and those weighing >55 kg require 0.40–0.45 m² [10].

Devices for loading and unloading, including the floor space (m²/animal), should be designed in a way such that:
- should prevent injuries or suffering of animals and minimize the excitement and exhaustion at the time of shifts as well as ensure their safety. The surfaces must not be slippery; side protection devices must be fit to avoid the escape of the animals; and
- should be cleaned and disinfected easily.

During the loading and unloading of the animals, it is prohibited to:
- hit or kick the animals;
- exert pressure on any sensitive part of the animal’s body in a way that may cause unnecessary pain or suffering; and
- lift or drag the animals by the head, ears, horns, legs, tail, or fleece or manipulate them in a way causing unnecessary pain or suffering.
After being transported to a slaughterhouse, the animals shall be unloaded as soon as possible after their arrival, and if not possible, they shall be protected from adverse weather conditions and provided with sufficient air exchange until unloading [11].

3. Stunning, slaughter, and bleeding of animals
Minimum requirements that minimize animal suffering during slaughter or killing are stipulated by a normative act [8]. These requirements are to be observed during:
- unloading, moving, preslaughter lairage and preparation, fixing and stunning, and slaughter or killing.

After unloading at the slaughterhouse, the animals enter the slaughterhouse premises only if they will be immediately slaughtered. When the slaughter is not done immediately, the animals are accommodated for rest in pens or paddocks protecting them from adverse climatic events. These premises should meet the following requirements:
- the flooring should not allow slipping and injury to the animals and should be easily cleaned and disinfected;
- provision of ventilation conditions adequate to the expected temperatures and humidity;
- appropriate facilities for tying the animals; and
- provision of space for each animal to stand upright, to lie down, and to turn around without difficulties.

According to the same normative act, the following conditions must be met during accommodation of animals on the premises for resting/relaxing:
- all animals are provided with drinking water in a suitable waterer and those that will be slaughtered after more than 24 h should receive moderate amounts of food at appropriate intervals in a way providing access to food to each animal;
- if the animals are tied, this should be done in a way allowing them to lie down without difficulties;
- animals that may injure one another by reason of species, gender, or age are accommodated in separate pens/paddocks or sheds;
- protection against adverse climatic conditions should be ensured, and in humid and very hot weather, measures should be taken to cool the animals by appropriate means; and
- the duration of preslaughter rest is up to 4 h for transportation distances up to 80 km, and for distances over 80 km it is up to 12 hours.

It was found that animals slaughtered after a 12-h stay in a slaughterhouse experienced less stress compared to lambs slaughtered immediately upon arrival [16]. This was probably because preslaughter rest permitted animals to calm down and rest before being slaughtered.

After the animals have rested from the travel, they are moved into the slaughter premises. Before slaughter, the animal must be stunned to eliminate pain, stress, and discomfort from the procedure. Animals are not stunned if exsanguination is not possible immediately after slaughter; stunning represents rendering animals unconscious until death [8]. The main goal of stunning is to render the animal immobile and unconscious in order to feel no pain [1].

There are three main stunning techniques: percussive, electrical, and gas stunning. In sheep, mainly electrical and percussive stunning are practiced (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf).

3.1. Gas stunning
This is an expensive method and therefore not frequently used.

3.2. Percussive stunning
This is done by means of a pistol with a stun bolt gun. The method works using the principle of the gun: a trigger pull pushes a short bolt to the outside. The latter penetrates the skull, causing concussion of the brain via brain damage or increased intracranial pressure. The stun bolt gun is perhaps the most universal stunning tool as it is appropriate for use in cattle, pigs, sheep, and goats; moreover, it is compact and easy for transportation. A very important prerequisite for efficient stunning is the proper positioning of the gun. In sheep it is placed at the uppermost point of the head, in the direction of the jaw joint (Figure 1) (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf).

3.3. Electric stunning
This method is very suitable for stunning pigs, sheep, and goats. Presuming that electric stunning leading to unconsciousness is a humane slaughtering method, this procedure is the most widely spread technique for the stunning of animals [17]. Electric stunning also has the advantage of low noise levels during application. On the contrary, the use of a stun bolt gun produces much noise during the shot. This may result in additional stress of other animals waiting at the slaughterhouse. Electric stunning is done by means of a stun bolt gun. The method works using the principle of the gun: a trigger pull pushes a short bolt to the outside. The latter penetrates the skull, causing concussion of the brain via brain damage or increased intracranial pressure. The stun bolt gun is perhaps the most universal stunning tool as it is appropriate for use in cattle, pigs, sheep, and goats; moreover, it is compact and easy for transportation. A very important prerequisite for efficient stunning is the proper positioning of the gun. In sheep it is placed at the uppermost point of the head, in the direction of the jaw joint (Figure 1) (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf).

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Figure 1. Site for stunner placement for sheep.
stunning uses an alternating current with low voltage applied through the electrodes of the stunning device (Table). Electric stunning causes an epileptic state of the brain in two stages: tonic seizure followed by clonic seizure (Table). If exsanguination does not follow these two stages, the animal regains consciousness. As the animal's brain is small, the electrodes should be placed accurately in a stable manner on both sides of the skull (Figures 2 and 3). During the epileptic state of the brain, the nervous system of the animals is blocked; they are unconscious and do not feel pain. The unconsciousness state should last long enough to perform exsanguination, so that the animal will die of brain anoxia (complete lack of oxygen in the brain) (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf).

Electric stunning is performed in compliance with the following requirements [8]:

- the electrodes of the stunning device are placed in a manner to embrace the animal's skull and to provide efficient passing of the current through the brain;
- to improve electroconductivity, excess wool or hair coat is shaved, and the skin of the head is moistened with water;
- the animal is bled as soon as possible after being stunned in a way allowing for rapid and complete bleeding out; and
- bleeding is done before the animal regains consciousness by cutting the carotid arteries or blood vessels from which they originate.

4. Postmortem changes in meat

After slaughter, several processes with substantial significance for its quality take place in meat [18,19]. One of the main criteria for meat quality is the ultimate pH of the muscles, determined by glycogen depletion and postmortem accumulation of lactic acid [20]. The processes occurring in meat postmortem are interrelated. The most important among them are as follows:

4.1. Postmortem rigidity (rigor mortis)

This is characterized by muscle rigidity. The muscles are stiff and firm [21]. Such muscles are hardly salt cured and are not appropriate for cooking. Even the bouillon after cooking such meat is cloudy.

The cause of rigor mortis is the interruption of oxygen flow to muscles; hence, biochemical events occur in an anaerobic environment and as a result glycogen is rapidly degraded [22]. Complete rigor mortis takes different amounts of time depending on animal-specific features and environmental conditions [23]. At 4 °C stiffness of carcasses of small ruminants occurs after 12–16 h. It develops more rapidly in muscles of young animals and more slowly in muscles of fattened animals. Rigor mortis is most pronounced in skeletal muscles, and it is less perceptible or almost imperceptible in smooth muscles.

4.2. Meat ripening

Aging or ripening of meat lasts several (3–14) days [19,24,25]. During ripening, physicochemical changes are observed, resulting in the improvement of organoleptic properties. Meat assumes a pronounced flavor and taste, with higher water-holding capacity, and it becomes more tender and juicy [23,26]. Meat tenderness is facilitated by postmortem proteolysis activated by proteolytic enzymes (calpains) and is inhibited by proteolytic inhibitors (calpastatin) [19,27,28].

| Parameters | Value |
|------------|-------|
| Duration of phases electrical stunning |     |
| Tonic | 10–20 s |
| Clonic | 15–45 s |
| Recovery | 30–60 s |
| Loss of brain function bleeding methods |     |
| Chest stick | 4.5 s |
| Full cut | 14 s |
| Half cut | 70 s |
| Recommended currents for stunning and killing animals |     |
| Stun (head-only) | 1.0 A |
| Kill (applied to heart) | 1.0 A |
| Approximate electrical resistance of animals to stunning current |     |
| Electrode position | Across the head, light fleece cover |
| Resistance (ohms) | 150–1000 |
4.3. Postmortem glycolysis
The energy for muscle activity of live animals is provided by muscle glycogen. The glycogen content of muscles in healthy rested animals is high (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf). After slaughter, the blood circulation in the body is interrupted; hence, the delivery of oxygen and nutrients to muscles and muscle fibers also is. Metabolic processes already occur in an oxygen-free environment and muscle glycogen is converted into lactic acid [22]. As lactic acid is not transported along with the circulation to the liver and the heart, it remains in the muscles and this results in a reduction of pH from usual values of 7.00–7.40 in live animals to about 5.40–5.70. Lactic acid is necessary to produce tender meat with good taste and good color.

If the animal experiences stress before and during slaughter, glycogen is depleted, and the lactic acid formed in meat postmortem decreases [29]. This has a serious negative impact on meat quality. Therefore, during preslaughter handling, animals should not be subjected to stress and injuries in order to preserve unnecessary muscle glycogen depot depletions.

Another important issue is the good rest of animals during the 24-h preslaughter period. This creates conditions for the restoration of the muscle glycogen of slaughtered carcasses to the highest extent. Maximum high muscle glycogen levels are important to obtain a maximum lactic acid level in meat. This acid gives meat the ideal pH value, which is lower than 6.20. If the measured pH is higher than 6.20, this indicates that the animal was stressed or ill before being slaughtered. The lactic acid in muscles delays the replication of bacteria contaminating the carcass during slaughter and washing. These are the bacteria responsible for meat spoilage during storage. Therefore, the meat produced from animals under transport or slaughter stress has a shorter shelf life due to spoilage (http://www.agrowebcee.net/fileadmin/subnetwork/awsee/fawbg/Narachnik-FAO-redactir-1.pdf).

4.4. Cold shortening of meat
This is a problem of veal and lamb during the cooling of carcasses [30] with great impact on meat tenderness [31–33]. During the cooling of carcasses, the sarcoplasmic reticulum surrounding the myofibrils is stimulated by low temperatures (temperatures of <10–15 °C) and releases Ca²⁺ near the myofibrils [34,35]. In the presence of sufficient adenosine triphosphate amounts, Ca²⁺ provokes muscle contractions by forming permanent transverse bridges between actin and myosin. Because of these contractions, the length of the muscle sarcomeres is reduced. Muscles containing large amounts of red oxidative muscle fibers are more prone to cold shortening.

Intensively reared animals produce carcasses with thicker layers of subcutaneous fat due to the high-energy rations and restricted locomotion. The thick subcutaneous fat isolates the carcass and delays its postmortem cooling. This results in the prevention of cold shortening of muscles [36] and increases the postmortem activity of proteolytic enzymes, leading to better meat tenderness.

5. Effect of preslaughter handling on meat quality
Preslaughter handling of animals includes loading, transport, and unloading; preslaughter rest; and stunning and bleeding. Because of these manipulations, animals probably experience fear, hunger, thirst, physical injuries, and fatigue, which ultimately has a negative impact on health, welfare, and meat quality [14,37,38]. All animals are under certain stress before slaughter, which could be detrimental for meat quality [39,40].

Stunning methods could have an adverse effect on carcass quality and on meat. That could be manifested...
References

1. Gregory N, Grandin T. Animal Welfare and Meat Science. New York, NY, USA: CABI Publishing; 1998.

2. Dawkins MS. The science of animal suffering. Ethology 2008; 114: 937-945. doi: 10.1111/j.1439-0310.2008.01557.x

Another study compared the effects of different stunning techniques in lambs [49]. The animals were divided into 3 groups: those from the first group were submitted to electric stunning and those from the second group to carbon dioxide stunning, while the rest were slaughtered without stunning. Meat quality was assessed through pH, meat color (L*, a*, b*), cooking losses, and cutting force. At postslaughter hour 24, the highest meat pH was established in lambs that were not stunned before slaughter, while the lowest pH values were observed in lambs stunned with CO₂. The latter group also had more tender meat than those either stunned with an electric current or not stunned at all. In general, preslaughter stunning did not exert any effect on meat color or cooking losses. A similar conclusion was expressed by other authors as well [50], having found that at postslaughter hour 24, there were no considerable differences in meat quality due to stunning methods.

6. Conclusion

Preslaughter handling of animals is associated with their transportation to the slaughterhouse, their stay, and preslaughter preparation. Stress and injuries of animals induced by improper preslaughter handling are probably the two most essential criteria determining animal welfare.

In Bulgaria there are adopted laws and regulations governing animal husbandry (in particular sheep breeding) and the requirements for carrying out preslaughtering procedures. Compliance with these requirements greatly reduces stress. The exposure of animals to stress and injuries before slaughter should be avoided as they lead to deterioration of the quality of the produced meat. If the animals suffer from stress before and at the time of slaughtering, glycogen is depleted and lactic acid formed in meat after slaughter decreases. If lactic acid levels in meat are low, this influences the ultimate meat pH. It was found that stress and injuries of lambs before slaughter resulted in higher meat pH and hence shorter shelf life. Furthermore, the produced lactic acid delays the proliferation of bacteria that contaminate the carcass; therefore, its lower concentration results in faster spoilage of meat.

Stunning is important for the welfare of lambs. Its main goal is to render the animal unconscious before slaughter, a state in which it feels no pain. It was also shown that meat quality was influenced by both stunning and nonstunning applications and the technique used (percussive, electric, or gas stunning).
3. Dawkins MS. Animal welfare and efficient farming: is conflict inevitable? Animal Production Science 2017; 57: 201-208.

4. Ohl F, van der Staay FJ. Animal welfare: At the interface between science and society. The Veterinary Journal 2012; 192: 13-19. doi: 10.1016/j.tvjl.2011.05.019

5. Botreau R, Veissier I, Butterworth A, Bracke MBM, Keeling LJ. Definition of criteria for overall assessment of animal welfare. Animal Welfare 2007; 16: 225-228.

6. Grand T. Animal welfare in slaughter plants. In: 29th Annual Conference of American Association of Bovine Practitioners; 1996. pp. 22-26.

7. Animal Protection Act, Effective from 31.01.2008; Prom. State Gazette Issue 13 of February 8, 2008, Amend. State Gazette Issue 80 of 9 October 2009, Amend. State Gazette Issue 8 of 25 January 2011, Amend. State Gazette No. 92 of November 22, 2011, Amend. State Gazette Issue 53 of June 27, 2014, Amend. State Gazette Issue 34 of 3 May 2016, Amend. State Gazette Issue 58 of July 18, 2017, Amend. State Gazette Issue 17 of 23 February 2018 (in Bulgarian).

8. Ordinance No. 22 of 14 December 2005 to Minimize Animal Suffering During Slaughter or Killing (Prom. State Gazette No. 42 of May 25, 2006) (in Bulgarian).

9. Ordinance No. 16 of 3 February 2006 on the Protection and Welfare of Farm Animals during Breeding and Use (Prom. State Gazette, Issue 18 of 28 February 2006) (in Bulgarian).

10. Ordinance No. 26 of 28 February 2006 on Conditions for the Protection and Welfare of Animals During Transport (Publ. State Gazette No. 23 of 17 May 2006) (in Bulgarian).

11. Council Regulation (EC) No. 1/2005 of 22 December 2004 on the Protection of Animals During Transport and Related Operations and Amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97 (in Bulgarian).

12. Chulayo AY, Tada O, Muchenje V. Research on pre-slaughter stress and meat quality: a review of challenges faced under practical conditions. Applied Animal Husbandry & Rural Development 2013; 43 (Suppl. 1): 64-68.

13. Costa LN. Short-term stress: the case of transport and slaughter. Italian Journal of Animal Science 2009; 8 (Suppl. 1): 241-252. doi: 10.4081/ijas.2009.s1.241

14. Adenkola AY, Ayo JO. Physiological and behavioural responses of livestock to road transportation stress: a review. African Journal of Biotechnology 2010; 9 (31): 4845-4856.

15. Hemsowth PH, Rice M, Karlen MG, Calleja L, Barnett JL et al. Human–animal interactions at abattoirs: relationships between handling and animal stress in sheep and cattle. Applied Animal Behaviour Science 2011; 135 (1-2): 24-33.

16. Liste G, Miranda-de la Lama GC, Campo MM, Villarroel M, Muela E et al. Effect of lairage on lamb welfare and meat quality. Animal Production Science 2011; 51: 952-958.

17. Zivotofsky AZ, Strous RD. A perspective on the electrical stunning of animals: are there lessons to be learned from human electro-convulsive therapy (ECT)? Meat Science 2012; 90 (4): 956-961. doi: 10.1016/j.meatsci.2011.11.039

18. Ouali A. Proteolytic and physicochemical mechanisms involved in meat texture development. Biochimie 1992; 74 (3): 251-265.

19. Koohmaraie M. Biochemical factors regulating the toughening and tenderization processes of meat. Meat Science 1996; 43 (Suppl. 1) 193-201. doi: 10.1016/0309-1740(96)00065-4

20. Santos A, Giráldez F, Mateo J, Frutos J, Andrés S. Programming Merino lambs by early feed restriction reduces growth rates and increases fat accretion during the fattening period with no effect on meat quality traits. Meat Science 2018; 135: 20-26. doi: 10.1016/j.meatsci.2017.08.007

21. Botha SSC, Hoffman LG, Britz TJ. Effects of post mortem temperature on rigor tension, shortening and pH in ostrich muscle. South African Journal of Animal Science 2008; 38 (3): 184-192.

22. Ouali A, Herrera-Mendez CN, Coulis G, Becila S, Boudjellal A et al. Revisiting the conversion of muscle into meat and the underlying mechanisms. Meat Science 2006; 74: 44-58. doi: 10.1016/j.meatsci.2006.05.010

23. Vasilev K. Technology of Meat Products. Sofia, Bulgaria: Matkom Publishing House; 2003 (in Bulgarian).

24. Feiner G. Meat Products Handbook. Practical Science and Technology. Boca Raton, FL, USA: CRC Press; 2006.

25. Kaü A, Żgur S. The effect of structural and biochemical changes of muscles during post-mortem process on meat tenderness. Journal of Central European Agriculture 2017; 18 (4): 929-941. doi: 10.5513/JCEA01/18.4.1987

26. Kosowska M, Majcher MA, Fortuna T. Volatile compounds in meat and meat products. Food Science and Technology 2017; 37 (1): 1-7. doi: 10.1590/1678-457X.08416

27. Koohmaraie M, Babiker AS, Schroeder AL, Merkel RA, Dutson TR. Acceleration of postmortem tenderization in ovine carcases through activation of Ca$^{2+}$ dependent proteases. Journal of Food Science 1998; 53 (6): 1638-1641.

28. Koohmaraie M. The role of Ca$^{2+}$-dependent proteases (calpains) in post mortem proteolysis and meat tenderness. Biochimie 1992; 74 (3): 239-245. doi: 10.1016/0300-9084(92)90122-U

29. Immonen K, Puolanne E. Variation of residual glycogen-glucose concentration at ultimate pH values below 5.75. Meat Science 2000; 55 (3): 279-283. doi: 10.1016/S0309-1740(99)00152-7

30. Adedgeo GO, Falade KO. Quality of meat. Journal of Food, Agriculture & Environment 2005; 3 (1): 87-90.

31. Marsh BR, Leet NG. Studies in meat tenderness. III. The effects of cold shortening on tenderness. Journal of Food Science 1966; 31 (3): 450-459. doi: 10.1111/j.1365-2621.1966.tb00520.x

32. Tornberg E. Biophysical aspects of meat tenderness. Meat Science 2000; 55 (3): 279-283. doi: 10.1016/S0309-1740(99)00152-7

33. Toohey ES, Hopkins DL, McLeod BM, Nielsen SG. Quantifying the rate of pH and temperature decline in lamb carcases at three abattoirs in New South Wales. Australian Journal of Experimental Agriculture 2006; 46: 875-878.
34. Jaime I, Beltrán JA, Ceña P, López-Lorenzo P, Roncalés P. Tenderness of lamb meat: effect of rapid postmortem temperature drop on muscle conditioning and aging. Meat Science 1992; 32 (4): 357-366.

35. Bellés M, Alonso V, Roncalés P, Beltrán JA. A review of fresh lamb chilling and preservation. Small Ruminant Research 2017; 146: 41-47. doi: 10.1016/j.smallrumres.2016.12.003

36. Brewer P, Calkins C. Quality Traits of Grain- and Grass-Fed Beef: a Review. Nebraska Beef Cattle Reports. Lincoln, NE, USA: Animal Science Department, University of Nebraska; 2003.

37. Eriksen MS, Rodbotten R, Grøndahl AM, Friestad M, Andersen IL et al. Mobile abattoir versus conventional slaughterhouse - Impact on stress parameters and meat quality characteristics in Norwegian lambs. Applied Animal Behaviour Science 2013; 149 (1-4): 21-29. doi: 10.1016/j.applanim.2013.09.007

38. Ferguson DM, Warner RD. Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? Meat Science 2008; 80 (1): 12-19. doi: 10.1016/j.meatsci.2008.05.004

39. Dokmanović M, Velarde A, Tomović V, Glamočlija N, Marković R et al. The effects of lairage time and handling procedure prior to slaughter on stress and meat quality parameters in pigs. Meat Science 2014; 98 (2): 220-226. doi: 10.1016/j.meatsci.2014.06.003

40. Ferguson DM, Bruce HL, Thompson JM, Egan AF, Perry D et al. Factors affecting beef palatability – farm gate to chilled carcass. Australian Journal of Experimental Agriculture 2001; 41 (7): 879-891. doi: 10.1071/EA00022

41. Ribarski S, Ivanov N, Miteva D. Effects of transportation and pre-slaughter rest pig welfare and carcass quality. Journal of Animal Science (BG) 2015; 6: 65-71 (in Bulgarian with an abstract in English).

42. Kadim IT, Mahgoub O, Al-Kindi A, Al-Marzooqi W, Al-Saqri NM. Effect of transportation at high ambient temperatures on physiological responses, carcass and meat quality characteristics of three breeds of Omani goats. Meat Science 2006; 73 (4): 626-634. doi: 10.1016/j.meatsci.2006.03.003

43. Ekiz B, Ekiz EE, Kocak O, Yalcintan H, Yilmaz A. Effect of pre-slaughter management regarding transportation and time in lairage on certain stress parameters, carcass and meat quality characteristics in Kivircik lambs. Meat Science 2012; 90 (4): 967-976. doi: 10.1016/j.meatsci.2011.11.042

44. De la Fuente J, Sanchez M, Perez C, Lauzurica S, Vieira C et al. Physiological response and carcass and meat quality of suckling lambs in relation to transport time and stocking density during transit by road. Animal 2010; 4 (3): 250-258. doi: 10.1017/S1751731109991108

45. Miranda-de la Lama GC, Monge P, Villarroel M, Olleta JL, García-Belenguer S et al. Effects of road type during transport on lamb welfare and meat quality in dry hot climates. Tropical Animal Health and Production 2011; 43 (5): 915-922. doi: 10.1007/s11250-011-9783-7

46. Díaz MT, Vieira C, Pérez C, Lauzurica S, Chávarri EG et al. Effect of vehicle movements during transport on the stress responses and meat quality of sheep. Veterinary Record 2001; 148 (8): 227-229. doi: 10.1136/vr.148.8.227

47. Ruiz-De-La-Torre JL, Velarde A, Diestre A, Gispert M, Hall S et al. Effects of road type during transport on the stress responses and meat quality of sheep. Veterinary Record 2001; 148 (8): 227-229. doi: 10.1136/vr.148.8.227

48. Vergara H, Linares MB, Berruga MI, Gallego L. Meat quality in sucking lambs: effect of pre-slaughter handling. Meat Science 2005; 69 (3): 473-478. doi: 10.1016/j.meatsci.2004.09.002

49. Linares MB, Bórnez R, Vergara H. Effect of different stunning systems on meat quality of light lamb. Meat Science 2007; 76 (4): 675-681. doi: 10.1016/j.meatsci.2007.02.007