Acta Sci. Pol. Zootechnica 22(1) 2023, 3–16

www.asp.zut.edu.pl pISSN 1644-0714 eISSN 2300-6145 DOI: 10.21005/asp.2023.22.1.01

REVIEW ARTICLE

Received: 10.03.2023
Accepted: 12.04.2023

PRE-SLAUGHTER PIG WELFARE AND CARCASS AND MEAT QUALITY

Artur Rybarczyk, Izabella Tobolska

Department of Animal Nutrition and Feed Science, Wrocław University of Environmental and Life Sciences, Chełmońskiego 38c, 51-630 Wroclaw, Poland

ABSTRACT

For a large number of consumers today, primarily young ones, acceptance of a foodstuff such as meat is often linked to demands for appropriate conditions for the maintenance of productive animals, as well as proper protective treatment during transport and slaughter. The way in which commercial and slaughter animals are handled is being viewed more and more critically by the public. The increasing sensitivity of consumers to the fate of animals in recent years is also reflected in the emergence of new legislation. The quality of pork meat largely depends on how the animals are handled, and in particular on factors related to pre-slaughter marketing and the conditions of slaughter itself. During pre-slaughter marketing, the body of fattening animals and the quality of pork are particularly adversely affected by conditions during loading, transport, holding in the livestock warehouse, and slaughter. Carried out even under the best conditions, they induce a severe stress for pigs, resulting in significant reduction in the quantity and quality of meat.

Key words: pigs, welfare, stress, transport, lairage time, carcass and meat quality

Introduction

Increasing the efficiency of lean pork production manifests itself in an increase in lean meat content in the carcass while reducing fat content. However, the significant improvement in lean meat content is combined with increased incidence of meat with reduced quality parameters. This phenomenon is explained by a disturbance in the internal balance of the organism of the animal and a perpetuation of the tendency for undesirable metabolic changes both during the life of the animal and in the muscles following slaughter [Roćwin-Podsiadła et al. 2006].

Genetics play a key role in shaping the composition and quality of the animal carcass and, to a lesser extent, affect traits that characterize meat quality [Cameron 1990, De Vries et al. 1998]. Taking into account advances in pig breeding, it is assumed that genetic factors determine meat quality by 10% to 30%, while the rest can be attributed to environmental factors such as conditions in the pre-slaughter market (15–25%) and during slaughter (40%) [De Vries et al. 1994]. Consequently, a reduction in environmental stressors offers tremendous opportunities to improve the quality of raw meat. The impact of such stressors is often strong enough to produce meat defects, even in animals free of the stress-sensitivity gene (*RYR1*T). Hence, a great degree of attention is paid to environmental conditions occurring at all stages of the production process, especially in those with high meat yields [Dalla Costa et al. 2019].

The pre-slaughter handling of pigs from the farm to stunning and bleeding can have long-term and short-term effects on pre-slaughter metabolism [Tarrant 1989, Rosenvold and Andersen 2003a]. Fernandez and Tornberg [1991] indicate that variability in *ante-mortem* muscle glycogen content has implications for pork quality as glycogen metabolism plays a primary role in the conversion of muscle to meat and is expressed in various quality traits of fresh meat.

The two best-known quality deviations of fresh pork are PSE (pale, soft, exudative) and DFD (dark, firm, dry) meats, with the PSE defect being more economically significant than DFD. Pre-slaughter muscle metabolism is connected with both mental and physical stressors. The characteristics of defective PSE and DFD meat are pre-

izabella.tobolska@upwr.edu.pl

sented in Table 1 and distribution of PSE meat in pork carcasses are presented in Fig. 1. While long-term stress can lead to a decrease in muscle glycogen content and an increase in the proportion of DFD meat, severe short-term stress can produce PSE meat, depending on the amount of glycogen remaining at slaughter. For DFD meat, the main glycogen metabolism occurs before slaughter, while for PSE meat it occurs after slaughter [Tarrant 1989, Tarrant 1993]. Although muscle glycogen resources in pigs at slaughter have long been recognized as critical to meat quality, the physiological nature of the regulation of muscle glycogen is poorly understood [Graham and Adamo 1999, Rosenvold and Andersen 2003a]. According to Honkavaara [1989c], *ante-mortem* handling of animals is much easier to control than *post-mortem* biochemical responses in muscle tissue induced by stressful conditions in *ante-mortem* handling.

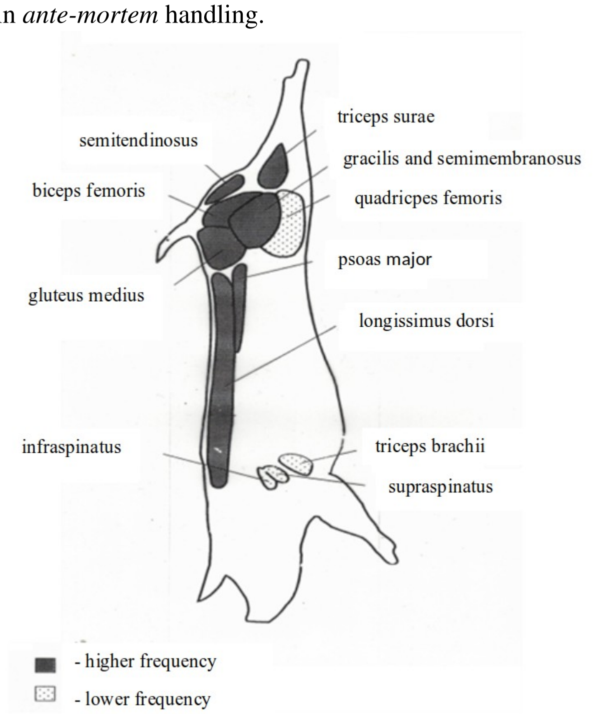

Fig. 1. Pork carcass muscles exposed to PSE meat defect [Strzelecki et al. 2006].

Welfare is closely related to such biological terms as stress, adaptation, fitness, and homeostasis, or enriched and depleted living environment. It refers to the organism as a whole and encompasses all its functions, from psychological reactions (emotions, feelings) to phenomena occurring at the cellular level. Interactions between the various levels of welfare and the biological balance of the organism arise across the entire life span and are influenced by the external and internal environment. Welfare occurs when an animal, both physiologically and ethologically, is in harmony with its surrounding environment and is able to adapt appropriately to changes in the environment [Terlouw 2005]. Welfare is diminished when the animal is unable to properly assess a situation and actively counteract adverse changes in the environment, and when the changes are unpredictable for the animal [Kołacz and Bodak 1999]. Thus, welfare means more than physical or biological comfort as it additionally takes into account the emotional balance, which is dependent on the animal's ability to fulfill its behavioral norms [Fraser 2008].

The stress experienced by animals affects not only carcass quality and fat deposition but also the physical and chemical components involved in the subsequent transformation of muscle into meat. *Post-mortem* metabolism in the pig muscle and some poultry muscles is faster than in beef or lamb. While the animals are alive, fight or flight initiates glycogenolysis and raises the heart rate, blood pressure, and lactic acid levels in the muscle – a metabolic anaerobic conversion system [Fraser 2008].

Pre-slaughter handling is referred to as the totality of activities associated with slaughter animals from the time they finish fattening or are taken over by purchasing points and transferred to meat plants for slaughter [Wajda and Denaburski 2003]. Many authors point out that factors causing stress to animals and even death, as well as quantitative and qualitative losses in pre-slaughter handling, are temperature, humidity, density, health status, and animal handling practices [Warriss and Brown 1994, Fischer 1996, Wajda and Denaburski 2003]. Poor pre-slaughter handling of animals causes material losses, such as a reduced weight of the live animal, and also deaths. Losses in *ante-mortem* handling can also result from mechanical damage, which leaves traces after slaughtering animals in the form of congestion and bruises. Through improper *ante-mortem* handling, defective meat of PSE or DFD type can be produced following slaughter. In addition, bleeding efficiency drops, which makes the meat less resistant to autolytic and microbiological processes [Tereszkiewicz et al. 2004]. Rybarczyk et al. [2015] showed that the finishers slaughtered without a pre-slaughter rest, with the shortest fasting time and by a greater amplitude of ambient temperature during the pre-slaughter handling, were characterized by the lowest blood loss.

The following parameters of pre-slaughter animal handling have a significant impact on obtaining high carcass and meat quality: fasting time, loading and unloading equipment (e.g., ramp angle), type and equipment of transport vehicles, loading density, duration of transport, driving and handling of the animals, and the time and manner of pre-slaughter rest. On the other hand, during slaughtering, the method of stunning and the timing of subsequent bleeding, as well as the technique for cooling the half carcasses, have also a significant impact [Warriss and Brown 1983, Lambooy and Engel 1991]. Relationships between stress reactivity, slaughter conditions and meat quality are presented in Fig. 2.

Table 1. The properties of normal and faulty meat [Koćwin-Podsiadła et al. 2006].

Traits	Normal	PSE	DFD
Shelf life	normal	good	low
Water binding	normal	bad	
Weight loss of raw meat (WN_{48})	normal (2–6%)	high (>6.0%)	low (≤2.0)
Weight loss after curing and smoking (72°C)*	normal	high (2–3% higher then normal meat)	low
RTN (%)	≥91	<91 (very low)	≥91
Colour (L-meat lightness)	correct (52–58)	pale (>58)	dark (<52)
Taste	good	strong acidity	bad
Consistency	normal	soft	firm
Tenderness and juiciness	correct	correct	dry
Result of curing and smoking	correct	bad	
Technological usefulness	all products culinary meat	alternatively only durable products	alternatively only cooking products

* in the production of "Sopocka Loin", WN_{48} – drip loss at 48 h *post mortem* (%), RTN – technological yield

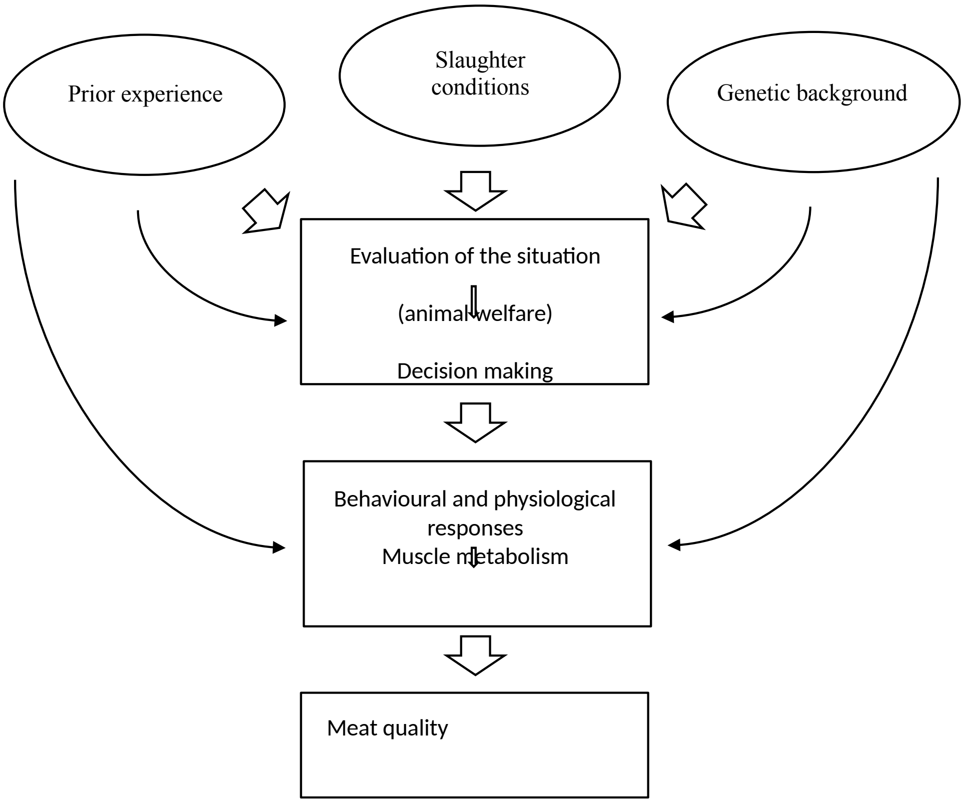

Fig. 2. Diagram representing relationships between stress reactivity, slaughter conditions and meat quality [Terlouw 2005].

Feed withdrawal

The Council of Europe Regulation 1099 [EC 2009] states in the section on the protection of livestock that animals should be offered water *ad libitum* and should be starved within reasonable limits. The main rationale for depriving pigs of feed before transport (known as pre-slaughter starvation) is to reduce the risk of death during transport, especially in hot weather [Warriss 1994, Bradshaw et al. 1996], to improve meat quality (lower PSE meat turnout), and to avoid the risk of bacterial contamination from intestinal contents during evisceration [Eikelenboom et al. 1991, Gispert et al. 1996].

The period before slaughter from the last feeding is a determinant of *ante-mortem* muscle glycogen concentration and post-slaughter PSE meat happening [Tarrant 1989, Eikelenboom et al. 1991]. It is widely believed that the pre-slaughter starvation period provides a lower muscle glycogen concentration and a lower lactic acid content *post-mortem* [De Smet et al. 1996], resulting in a higher final pH, improved water holding capacity, and darker meat color [Jones et al. 1985, Rybarczyk et al. 2007]. Some pigs expend large amounts of energy, especially if they are fighting, while others do not. Long periods of starvation contribute to muscle glycogen depletion. When pigs are starved, the glycogen reserves in the muscles are used for energy. Inadequate feeding and lack of rest may result in a glycogen deficiency before slaughter, which later may be responsible for an increase in the frequency of defective DFD meat. In addition, the incidence of DFD meat increases within the first hours of the slaughterhouse pig storage period due to fighting. It has been indicated that long periods of feed deprivation prior to slaughter may be used intentionally to lower muscle glycogen levels, which would affect less *post-mortem* muscle acidification and reduce the incidence of PSE meat [Fischer et al. 1988, Eikelenboom et al. 1991, Wittmann et al. 1994]. Consequently, in many countries, 12–18 hours of starvation before slaughter is a common practice to reduce the risk of microbial contamination during slaughter and to limit meat quality deviations [Eikelenboom et al. 1991, Driessen et al. 2020a]. Studies by Faucitano et al. [2010] indicate that a 24-hour period between the last feeding and slaughtering of the animals appears to be an acceptable compromise for obtaining carcasses with optimal performance, characterized by the meat of good quality and safe for consumption. A study by Rybarczyk et al. [2017] showed that while maintaining the same pre-slaughter rest period (14 h) in the livestock store, fatteners subjected to a longer pre-slaughter starvation (24 h vs. 18 h) were characterized by better physicochemical quality of meat.

However, prolonged pre-slaughter starvation may pose a risk of increased hierarchical aggression and fighting in groups of pigs, especially in mixed groups from different suppliers [Murray et al. 2001]. Fernandez et al. [1995] showed no significant differences between fattening pigs that were fed or starved and their aggressive behavior, plasma catecholamine concentrations, or blood cortisol levels. In addition, it is generally found that prolonged pre-slaughter starvation affects a reduction in pre-slaughter animal weight and carcass weight at the same time [Eikelenboom et al. 1991]. Several studies have reported no significant effect of starvation for up to 48 hours on carcass weight losses [Warriss and Brown 1983], or even up to 60 hours [Murray and Jones 1994]. According to Beattie et al. [2002], pre-slaughter weight losses in pigs are related to urine and fecal excretion, and not due to carcass weight losses.

Glycolytic and energetic resources

Studies [Rosenvold et al. 2001a, Rosenvold et al. 2001b] have shown that muscle glycogen stores can be controlled prior to slaughter not just by a sufficiently long pre-slaughter starvation, but also by feeding, thereby influencing the rate of pH decline and possibly the technological quality of pork. According to Tikk [2007], in pork production, strategic feeding is a major factor in managing and controlling meat quality. In recent years, there has been increasing interest in controlling muscle glycogen stores at slaughter as glycogen plays a key role as a substrate in live muscle energy metabolism, as well as in *post-mortem* metabolism, during which muscle is converted to meat [Rosenvold et al. 2003, Andersen et al. 2005]. One reason for manipulating muscle glycogen stores for slaughter is that it plays a critical role in shaping meat quality, mainly through its effect on pH drop [Offer 1991, Offer and Cousins 1992] and thus on water holding capacity (WHC) and meat color [Rosenvold et al. 2001b, Tikk et al. 2008].

Providing animals with feed high in digestible carbohydrates aims to reduce the problem of poor meat quality associated with high pH 24 *post mortem*, known as DFD [Rosenvold and Andersen 2003b]. DFD meat is produced by reducing the formation of lactate in muscle in the *post-mortem* period with low glycogen and creatine phosphate levels [Oliver et al. 1996]. Feeding a diet high in digestible carbohydrates for one or two days prior to slaughter can increase muscle glycogen stores and thus lower final pH [Conte et al. 2021]. In contrast, feeding pigs a diet rich in fat (17–18%) and protein (22–24%) combined with low digestible carbohydrates (<5%) in the 3 weeks prior to slaughter lowers glycogen stores in the *longissimus dorsi* muscle [Rosenvold and Andersen 2003b].

Galleway et al. [1977] noted that it is possible to rebuild glycogen stores in pigs that have been improperly transported with the consumption of sugar and molasses. However, improper treatment of animals prior to slaughter is combined with their intense excitement prior to slaughter, accelerated glycogenolysis *post-mortem*, thus acidification of muscle tissue, and the increased risk of PSE watery meat [Conte et al. 2021]. While a definite improvement in meat quality by giving pigs water with molasses before slaughtering was obtained by Borzuta [1994], this was not confirmed by Bąk [1995] study, which found lighter color, slightly worse water holding capacity, and no effect on the proportion of PSE and DFD meat in pigs.

Using components in the feed ration that can directly or indirectly reduce the stress response, pork quality can be improved. The immediate response to stress triggers is the release of neurotransmitters in the brain that activate the nervous system and release stress hormones into the blood, which can stimulate muscle metabolism, negatively affecting meat quality. Magnesium is indicated to counteract the effects of catecholamines in stressful situations [D'Souza et al. 1998a], with many such studies indicating better pork quality [Schaefer et al. 1993, D'Souza et al. 1998b, D'Souza et al. 1999]. From the neurotransmitter serotonin, tryptophan concentration is lower in pigs with some degree of stress. Accordingly, increasing the dietary intake of tryptophan leads to an increase in serotonin synthesis in the brain [Adeola and Ball 1992]. A reduction in pre-slaughter aggression and the incidence of carcasses with PSE meat was found in a study on pigs by Warner et al. [1998].

Loading, unloading and mixing unfamiliar

It is generally accepted that the most stressful elements of transport are the loading at the farm and unloading at the slaughterhouse [Barton-Gade 1997]. The concentrations of the stress hormone cortisol and beta-endorphins are significantly elevated immediately after loading the pigs. Emotional excitement during loading and unloading, and fighting between unfamiliar pigs causes muscle fatigue, which can also result from long-term stress [Bradshaw et al. 1996].

Loading is an important activity that can cause stress in pigs because it is the first time in their lives that they are moved from a fattening site to an unfamiliar location off the farm. In addition, they are exposed simultaneously to several stressors associated with transport, i.e., mixing with unfamiliar pigs, forced contact with humans, and high animal density. In addition, the pigs are forced to walk from the collection point to the ramp and then into the means of transport. According to van Putten [1982], about 50% of pigs suffered from leg weakness during the pre-slaughter handling. Nanni Costa et al. [1996] reported a higher incidence of foreleg injuries and a higher percentage of carcasses with PSE meat in pigs loaded from the ground using a ramp, compared to pigs loaded using a hydraulic ram.

The use of an elevator instead of a ramp allows loading a smaller group of 8–10 pigs, thus reducing stressful loading conditions and human interaction. [D'Souza et al. [1998a] indicate that improper treatment of fattening pigs by handlers on the farm affects early *post-mortem* muscle glycogen stores, as well as lowers final pH and a higher carcass incidence of PSE meat when compared to animals that are better treated on the farm. The loading and unloading of animals could be done gently using a ramp that is as horizontal as possible. It is recommended to use ramps with a slope of no more than 15–20°. On ramps that are steeper and smoother, animals are reluctant to enter voluntarily, which can lead to an aggressive reaction of handlers and often an increase in skin injuries [van Putten and Lambooij 1982]. According to these authors, the heart rate of the pigs increased linearly as the slope of the ramp increased.

The effect of mixing unfamiliar pigs on the incidence of skin damage was clearly demonstrated by Karlsson and Lundström [1992], who found a beneficial effect of keeping pigs together in the same group from weaning to slaughter. The struggle for hierarchy in the group is associated with activity, which leads to an increase in cortisol and creatine kinase (CPK) enzyme levels, as well as depletion of glycogen stores in the muscles, resulting in a higher pH of the final meat. This metabolic condition leads to the formation of DFD meat [Oliver et al. 1996]. One possible method of counteracting this is the use of containerized transport, which allows the pigs to be moved in groups of 10–15 individuals from the rearing site through transport to the slaughter of the animals [Driessen et al. 2020b].

Transport

Transportation plays a coordinating role in the various links in the production chain and the provision of nutritionally adequate food. The days when a feature of agricultural transportation was the high versatility of the means of transportation are passing into history. There can be no situation where a product that meets all quality requirements is destroyed or its quality is reduced as a result of inappropriate means of loading or transportation. Modern agriculture and high-quality products must rely on modern specialized means of transportation [Marczuk 2005].

The movement of agricultural products and livestock is subject to a number of regulations, both in Poland and across the entire EU. Particular attention is paid to sanitary and veterinary requirements in the transportation of slaughter animals, as they concern the transportation of living organisms, sensitive to pain and stress. The problem of the legal protection of animals is included in six conventions and five directives of the Council of Europe [Nielsen et al. 2022]. Humanitarian and economic considerations have led to the elimination of rail transport in the transportation of live animals for slaughter. Since 1992, rail transport of slaughter animals, common in the past, has disappeared within Europe in favor of road transport. The convenience of road transport stems from the fact that it reduces transport time as much as possible and reduces the most stressful handling, and above all, it is in line with the assumptions of the Council of Europe's Conventions on animal rights [Maciołek 1996].

Means of transport and containers should be designed to protect animals from cold or overheating and provide opportunities for control and care. If tethers cannot be avoided, they should be strong and long enough to allow them to lie down and eat and drink freely. If animals of different species are transported in the same room, they must be separated by species and sex. Transportation should be carried out as quickly as possible, and information about animal shipments should be brought to the attention of checkpoints as early as possible to ensure that entry and transit formalities are handled as quickly as possible.

The Directive Regulation 2017/625 of the European Union [EC 2017] says that the duration of animal transportation in principle must not exceed 8 hours. This time can be extended if the means of transport meet such requirements as the possibility of supplying animals with bedding, with feed, if it has drinkers, portable partitions, and the possibility of ventilation. If pigs are transported in adapted vehicles, feeding and rest breaks are mandatory. Pigs can be transported for a maximum of 24 hours, provided they have constant access to water. This time can be extended by a further 2 hours if the destination can be reached within this time. However, if the transport route is longer, then after the 24-hour transport, when the animals cannot be fed inside the vehicle during transport, then they must be unloaded at a suitable place for watering and feeding (the so-called stopping point), and they must rest for a minimum of 24 hours [Nielsen et al. 2022].

Of all the livestock species, pigs are the most susceptible to adverse environmental factors, which manifests itself in a propensity for sudden death and injury, especially during transport [Lister et al. 1981]. Prior to slaughter, pigs are removed from their family enclosure, chased down a walkway to a ramp, and from there onto a carriage where they may be together in a single compartment with unfamiliar individuals. These sudden changes to adjust in a short period of time to new environmental conditions can result in physical and psychological stress for pigs [van Putten and Lambooij 1982].

Studies indicate that transportation stress can seriously compromise the physiological state of pigs and affect meat quality [Lambooij 2000]. Martoccia et al. [1995] found that transport is the most significant pre-slaughter factor for pigs because it affects both meat quantity and quality. Studies on transportation stress are difficult to analyze due to the combined contribution of many transportation-related factors [Stephens and Perry 1990]. Transport conditions such as density, ventilation, humidity, noise, driving quality, distance, extreme ambient temperatures during transport, and even the driver's driving technique, all can affect muscle metabolism in vivo [Lambooy and Engel 1991, Barton-Gade 1997, Warriss 1998, Faucitano 2001]. In general, transport conditions affect the quality of *post-mortem* meat by provoking stress or fatigue in the animals [Lambooij and van Putten 1993].

The duration of transport has various effects on pork quality. Warriss et al. [1990] found that pig transit time of 1 to 4 hours had no significant effect on the final pH of the meat. Shorter transit times may be more detrimental than longer ones if driving conditions, animal density, and ventilation are not adequate [Tarrant 1989]. Stephens and Perry [1990] suggest that pigs may become accustomed to the stress of transport. The aforementioned authors found that the greatest increase in heart rate occurred immediately after starting the engine, and then gradually decreased during transport. Grandin [1994] noted that pigs transported over very short distances (time up to 30 minutes), especially under adverse conditions, are more stubborn and difficult to manage in slaughter plants, and have a higher incidence of PSE meat than pigs exposed to longer transport, which is associated with a higher incidence of DFD meat as a result of prolonged stress and depletion of muscle glycogen stores.

Many difficult-to-control environmental factors can interact with genetic predispositions in shaping meat quality [Warriss et al. 1990]. It is generally accepted that stress in the pre-slaughter period should be minimized to reduce the risk of meat quality deviations, especially in animals with the stress-sensitivity gene (*RYR1*T). Studies indicate a significant deterioration of meat quality characteristics under various stressors in pigs with the stress sensitivity gene (*RYR1*T) compared to pigs lacking this allele [De Smet et al. 1996, Nanni Costa et al. 1999, Hammermeister et al. 2004].

According to the Directive 91/628 EEC [EC 1991], the internal transport temperature may vary from 5–30°C with a tolerance of ±5°C depending on the animal species and climatic conditions. The effect of climatic conditions on stress in animals during transport is difficult to assess. Weather conditions are dependent on location, time of day, and season. The optimal conditions in terms of temperature during pig transport are 16–20°C and a relative humidity of 50–80% [Lambooy 1988], as higher temperatures and humidity are very dangerous for pigs due to the inefficient way of removing excess heat from their bodies [Grandin 1998]. For pigs, air temperatures above 30°C are already stressful. Spraying animals with water immediately before or after transport to increase body cooling should be used [Nielsen et al. 2022]. Logtestijn et al. [1982] noted that the number of transport falls increased during the summer months during hot weather and/or high relative humidity.

Both very high (>24°C) and very low (<2°C) ambient temperatures can also be a source of stress for pigs [Honkavaara 1991]. High ambient temperatures during transport and during the pre-slaughter period will lead to an increase in body temperature, and this suggests that the pigs are often at the upper level of thermal tolerance

[Lambooy et al. 1987, Warriss 1991]. Studies indicate that the temperature during transporting of the pigs affects the quality of their meat [Lambooy 1988]. Excessive pig density and poor ventilation during hot weather, poor transportation equipment, road conditions, and driving technique can reduce the quality of pig meat [Grandin 1997].

During transport, animals must be able to stand in a natural position and all must be allowed to lie down at the same time [Lambooij 2000]. Failure to provide pigs with adequate space during transport exposes the pigs to heat stress and an increase in body temperature, fatigue, reduced meat quality, and to an increase in skin damage, and higher mortality. Too much space is also not beneficial, as it affects possible damage to pigs thrown at sudden stops and during cornering [Guise and Warriss 1989, Tarrant 1989]. Honkavaara [1989a] found that the highest maximum mortality occurred on warm days (14–24°C), while the fewest deaths were recorded in cooler weather (about 8°C). Consequently, loading levels need to be reduced by 10% during hot weather and in high-traffic or urban areas, as ventilation may be reduced as a result of slowing or stopping the movement of the means of transport. Therefore, Grandin [1998] recommends that pig transport be scheduled to slaughter facilities at night or early in the morning.

According to Eilert [1997], low temperatures in the carriage do not affect pork quality. However, if pigs experience cold during transport, this will require adequate pre-slaughter rest at higher temperatures, which is detrimental to meat quality. Lambooy [1988] showed that the temperature in the middle and rear sections of the carriage during pig transport was higher and that pigs from these compartments of the carriage after the slaughter had a lower temperature and higher pH of the *semimembranosus* muscle.

The season of the year is associated with the temperature of transport, which affects the amount of weight loss and meat quality in pigs. Wajda and Denaburski [1983] found greater weight losses in porkers in summer than in winter, which, in line with the results of Bąk [1995], indicates the absolute necessity of watering porkers prior to slaughter at this time of year. Meller [1992] showed that the season in which pigs were slaughtered influenced the final quality of meat. Koćwin-Podsiadła et al. [1990] noted a higher proportion of PSE meat in porkers slaughtered in the spring compared to those slaughtered in the fall. Kaczorek et al. [1998] and Strzelecki et al. [2006] showed that meat from pigs slaughtered in winter showed significantly better physicochemical indices compared to meat from pigs slaughtered in summer. The proportion of individuals with PSE meat was several percent higher in summer than in winter, with the same pre-slaughter marketing conditions. Krzęcio et al. [2002] noted a higher incidence of PSE meat in spring-summer than in autumn-winter, and this was closely related to the stress sensitivity gene (RYR1); pigs with the TT genotype relative to RYR1 showed higher dynamics of glycolytic metabolism than pigs free of the stress sensitivity gene (CC/RYR1).

Lairage time

Once delivered to slaughterhouses, pigs are held in pens and remain there for a period of time depending on the plant's slaughter capacity. Each slaughterhouse strives to hold live pigs for as short as possible due to the issues of feeding and watering and the possibility of animal deaths. According to Directive 93/119/EEC [EC 1993], animals that have not been slaughtered within 12 hours after arriving at the slaughterhouse must be fed. Many meat plants, therefore, plan slaughters within 12 hours to avoid feeding the animals.

The main purpose of plants holding animals in livestock pens is to maintain the speed and continuity of slaughtering regardless of differences in the timing of deliveries. The second function of keeping animals in pens is to allow the animals to recover physiologically after being transported, known as the pre-slaughter rest. The duration of pre-slaughter rest can vary depending on the severity of the stress, for example, the greater the transport stress, the longer the time spent in the livestock pens [Trevisan and Brum 2020]. Martoccia et al. [1995] found that it is not possible to determine the level of stress in pigs based just on transport distance and that the benefit of proper handling of animals during the preceding stages of farming may be lost if animals are subjected to high levels of stress immediately prior to slaughter. During pre-slaughter rest, additional stress and physical pain can be induced, leading to further deterioration of meat quality and an increase in the degree of skin damage. Therefore, the optimum time for pre-slaughter rest will closely depend on the conditions of the livestock pens, i.e. mixing of unfamiliar animals, density, and temperature together with the intensity of stress experienced by the pigs during transport [Rosenvold and Andersen 2003a].

Varying environmental conditions (temperature and humidity) during rest can have additional effects on pig homeostasis and meat quality [Warriss 1991, Roseiro et al. 1996]. Honkavaara [1989b] indicates that the optimal temperature, humidity, and duration of pre-slaughter rest are, respectively: 15–18°C, 59–65%, and 3–5 h, and indicates that such conditions in the livestock pens contributed to a lower lactic acid content in the muscles and a lower incidence of pig carcasses with PSE meat. In addition, pigs in live storage should have access to potable water ad libitum and possibly be sprayed with water on hot days [Weeding et al. 1993, Grandin 1994]. Such a practice limits the temperature rise in the muscles before bleeding and during the early *post-mortem* metabolic period [Klont and Lambooy 1995]. Offer [1991] found that lowering the body temperature by 2°C before exsanguination reduced the initial rate of myosin denaturation by 37%, resulting in reduced meat drip loss.

It is important that conditions in the livestock pens keep the pigs calm, observe a stocking density of 0.55–0.67 $m^{-2} \cdot 100$ kg, and do not mix pigs from different suppliers. The data shows that the average aggression rate was 2 incidents per pig per hour in a group of several pigs known to each other, with pigs in an unfamiliar group showing as high as 12 incidents per pig per hour [Faucitano 2001]. During the first hour of pre-slaughter rest, pigs experience stress as a result of aggressive behavior [Grandin 1997], causing increased metabolic activity which in turn lowers muscle pH and increases body temperature [Enfält et al. 1993]. The average cessation of fighting during post-transport pre-slaughter rest is 2 hours, and pigs actually begin to rest [van der Wal et al. 1997, van der Wal et al. 1999]. In contrast, after 4 hours of rest in the livestock warehouse, pigs begin to "wake up" and resume aggressive behavior, which can ultimately affect meat quality [Grandin 1997].

Studies by many authors indicate that longer pre-slaughter rest in pigs reduces stress hormone levels and at the same time reduces the incidence of PSE meat; however, there is a risk of an increase in the incidence of skin lesions and DFD meat and is associated with a chronic release of corticosteroids into the blood [Warriss 1998a]. The increase in the proportion of DFD meat is mainly due to physical exertion (fighting) and the associated depletion of glycogen stores in muscle [Warriss et al. 1998, Nanni Costa et al. 2002]. If stress occurs immediately before slaughter, PSE meat can also occur [Trevisan and Brum 2020]. Studies have shown that pigs rested for 24 hours had only 1.9% of carcasses with PSE meat, while pigs rested from 0 to 2 hours with high energy reserves had 13.1% of carcasses with PSE meat [Faucitano 2001].

Glycogen depletion may not be sufficient to raise the final pH of meat, especially in some pigs that have higher glycogen concentrations (up to 70% in white muscle), which usually leads to very low final pH values in these pigs. Even under conditions of long confinement, meat with a high final pH did not appear in these pigs [Wassmuth and Glodek 1992].

As already mentioned, the duration of confinement in the livestock warehouse has various effects on physiology in pigs. A number of authors have shown that increasing pre-slaughter rest time to 2 hours or longer has an effect on lowering plasma cortisol levels in pigs [Dokmanović et al. 2015, Rey-Salgueiro et al. 2018]. In contrast, Warriss et al. [1998] found that pigs kept in a slaughter plant pen for three hours had similar cortisol and lactate concentrations and higher serum creatine kinase (CPK) activity compared to pigs kept in a livestock pen for one hour. In addition, the aforementioned authors noted that keeping pigs in a live storage facility all night lowered cortisol, lactate, and CPK levels compared to pigs kept for 1 and 3 hours in a live storage facility. They conclude that the optimal pre-slaughter rest time should be longer than 3 hours.

There are no conclusive results in studies on the optimal pre-slaughter rest time in pigs. This may be due to the fact that determining the optimal time of pre-slaughter rest is very difficult in practice since the return of the animal's body to a state of physiological equilibrium is possible only if the correct conditions in the livestock store are ensured. Some studies indicate that increasing the time pigs are kept in the slaughter plant pen to 24 hours improves pork quality [Milligan et al. 1998, Dokmanović et al. 2014]. Others indicate that pre-slaughter rest in the livestock warehouse for 2 to 6 hours compared to immediate slaughter after transport improves meat quality by reducing PSE formation in pigs [Grandin 1994, De Smet et al. 1996, van der Wal et al. 1997]. In contrast, Warriss [1987] analyzed the effects of the timing and conditions of both transport and pre-slaughter rest on pork quality and found that under modern conditions, the duration of pigs in live storage can have little or no effect on meat quality.

Aaslyng and Barton-Gade [2001] showed that pork quality in pigs free of the stress sensitivity gene (*RYR1*T) does not depend on the duration of pre-slaughter rest when pigs are exposed to weak stress factors. However, because of the benefits of a short *ante-mortem* rest in reducing the incidence of carcasses with PSE meat, a 2- to 4-hour holding period for pigs in live storage is standard practice in most slaughterhouses [Grandin 1994, Milligan et al. 1998, Warriss et al. 1998b]. According to Geverink and Lambooij [1994] and Roseiro et al. [1996] slaughtering pigs immediately upon arrival at the slaughterhouse will reduce the degree of skin damage to mixed porkers in the pre-slaughter pen and should reduce the formation of PSE meat as a result of being under stressful environmental conditions (>35°C, >80% humidity). In the guaranteed food quality (QAFP) system, pigs should rest for 4 hours after the end of the transport, and 6 hours if the animals are transported more than 100 km and under temperature exceeding 30°C. In that system, it is unacceptable to bypass the pre-slaughter rest and slaughter animals immediately after transport [Obiedziński et al. 2009]. Holding pigs in the meat plant livestock stores can cause stress to the animals and prevent glycogen resynthesis, but this will depend on the duration of emotional activity in the animals [Warriss 1987, Tarrant 1989]. After they have undergone the pre-slaughter rest, they are again exposed to intense muscular exertion, which, in combination with improper animal handling, can lead to low pH values in the muscles before bleeding [Enfält et al. 1993]. Honkavaara [1989a] found that the high incidence of carcasses with PSE meat arises largely due to stressful handling after the pre-slaughter rest as they are chased from the feed store to the stunning area. This indicates that this stage is a very important source of stress for the pigs headed for slaughter. It is well-known that pigs driven in a single line without visual contact with each other with more frequent handling have high blood concentrations of catecholamines and elevated body temperature [Troeger 1989]. In addition, due to fear and nervousness, the degree of muscle acidification occurs faster than normal [Troeger 1989, Enfält et al. 1993, Hunter et al. 1994]. At this stage of the procedure, the principles of animal movement and the technical solutions of the transit corridors are of fundamental importance, due to the need to move the pigs quickly, to maintain smoothness on the industrial slaughter lines of meat plants. Unfortunately, electric pig herders are often used in practice to increase the speed of herding, which results in more frequent stress, skin damage, and increased incidence of PSE meat [Geverink and Lambooij 1994, Faucitano et al. 2006]. Faucitano et al. [2006] reported a 50% decrease in carcass damage by avoiding the use of herders when guiding pigs toward the stunning chamber. This problem has been successfully solved in some slaughter plants using a system of automatic gates that guide pigs in small groups to slaughter [Barton-Gade et al. 1992].

Conclusions

The quality of pork meat largely depends on how the animals are handled, and in particular on factors related to pre-slaughter marketing and the conditions of slaughter itself. During pre-slaughter marketing, the body of fattening animals and the quality of pork are particularly adversely affected by conditions during loading, transport, holding in the livestock warehouse, and slaughter. Carried out even under the best conditions, they induce a severe stress for pigs, resulting in significant reduction in the quantity and quality of meat.

Pre-slaughter stress can be long-term related to handling animals on the farm, mixing animals from different suppliers, loading and transporting animals, and short-term stress related to conditions during unloading, pre-slaughter rest, and directing animals for stunning. These two types of stress should not be considered as two separate phenomena. Long-term stress leads to meat quality deterioration in the form of the occurrence of DFD meat, mainly due to the depletion of glycogen and ATP reserves, while short-term stress is mainly responsible for PSE meat.

REFERENCES

Aaslyng, M.D., Barton-Gade, P. (2001). Low stress pre-slaughter handling: effect of lairage time on the meat quality of pork. Meat Sci., 57, 87–92. DOI: 10.1016/S0309-1740(00)00081-4.

Adeola, O., Ball, R.O. (1992). Hypothalamic neurotransmitter concentrations and meat quality in stressed pigs offered excess dietary tryptophan and tyrosine. J. Anim. Sci., 70, 1888–1894. DOI: 10.2527/1992.7061888x.

Andersen, H.J., Oksbjerg, N., Young, J.F., Therkildsen, M. (2005). Feeding and meat quality – a future approach. Meat Sci., 70, 543–554. DOI: 10.1016/j.meatsci.2004.07.015.

Barton-Gade, P. (1997). The effect of pre-slaughter handling on meat quality of pigs. [In] Manipulating pig production VI. S.R. Frankland, Melbourne, Australia, 100–123.

Barton-Gade, P., Blaabjerg, L., Christensen, L. (1992). New lairage system for slaughter pigs: effect on behaviour and quality characteristics. [In] Proc. 38th ICoMST. Clermont-Ferrand, France, 161–164.

Bąk, T. (1995). Wartość rzeźna tuczników pojonych roztworem melasy w zakładach mięsnych oraz w zagrodzie producenta przed odstawą na rzeź [Slaughter value of fattening pigs fed with molasses solution in meat plants and in the producer's pen before shipment to slaughter]. ART Olsztyn (doctoral thesis). [in Polish]

Beattie, V.E., Burrows, M.S., Moss, B.W., Weatherup, R.N. (2002). The effect of food deprivation prior to slaughter on performance, behavior and meat quality. Meat Sci., 62, 413–418. DOI: 10.1016/S0309-1740(02)00031-1.

Borzuta, K. (1994). Wpływ czynników przedubojowych na jakość mięsa wieprzowego [Effect of pre-slaughter factors on pork quality]. [In] Dni przemysłu mięsnego. Inst. Przem. Mięs. Tłuszcz. w Warszawie, IPMiT Warszawa, 7–12. [in Polish]

Bradshaw, R.H., Parroti, R.F., Goode, J.A., Lloyd, D.M., Rodway, R.G., Broom, D.M. (1996). Behavioral and hormonal responses of pigs during transport: effect of mixing and duration of journey. Anim. Sci., 62, 547–554. DOI: 10.1017/S1357729800015095.

Cameron, N.D. (1990). Genetic and phenotypic parameters for carcass traits, meat and eating quality in pigs. Livest. Prod. Sci., 26, 119–135. DOI: 10.1016/0301-6226(90)90061-A.

Conte, S., Pomar, C., Paiano, D., Duan, Y., Zhang, P., L'evesque, J., Guay, F., Devillers, N., Faucitano, L. (2021). The effects of feeding finishing pigs of two genders with a high fiber and high fat diet on muscle glycolytic potential at slaughter and meat quality. Meat Sci. DOI: 10.1016/j.meatsci.2021.108484.

D'Souza, D.N., Warner, R.D., Dunshea, F.R., Leury, B.J. (1998a). Effect of on-farm and pre-slaughter handling of pigs on meat quality. Aust. J. Agr. Res., 49, 1021–1025. DOI: 10.1071/A98010.

D'Souza, D.N., Warner, R.D., Dunshea, F.R., Leury, B.J. (1999). Comparison of different dietary magnesium supplements on pork quality. Meat Sci., 51, 221–225. DOI: 10.1016/S0309-1740(98)00110-7.

D'Souza, D.N., Warner, R.D., Leury, B.J., Dunshea, F.R. (1998b). The effect of dietary magnesium aspartate supplementation on pork quality. Meat Sci., 76, 104–109. DOI: 10.2527/1998.761104x.

Dalla Costa, O.A.D., Dalla Costa, F.A., Feddern, V., dos Santos Lopes, L., Coldebella, A., Gregory, N.G., Mello Monteiro de Lima, G.J. (2019). Risk factors associated with pig pre-slaughtering losses. Meat Sci., 155, 61–68. DOI: 10.1016/j.meatsci.2019.04.020.

De Smet, S.M., Pauwels, H., De Bie, S., Deymeyer, D.I., Callewier, J., Eeckhout, W. (1996). Effect of halothane genotype, breed, feed withdrawal, and lairage on pork quality of Belgian slaughter pigs. J. Anim. Sci., 74, 1854–1863. DOI: 10.2527/1996.7481854x.

De Vries, A.G., Sośnicki, A., Garnier, J.P., Plastow, G.S. (1998). The role of major genes and DNA technology in selection for meat quality in pigs. Meat Sci., 49, 245–255. DOI: 10.1016/S0309-1740(98)90052-3.

De Vries, A.G., van der Wal, P.G., Long, T., Eikelenboom, G., Merks, J.W.M. (1994). Genetic parameters of pork quality and production traits in Yorkshire populations. Livest. Prod. Sci., 40, 277–289. DOI: 10.1016/0301-6226(94)90095-7.

Dokmanović, M., Baltić, M.Z., Durić, J., Ivanović, J., Popović, L., Todorović M., Marković, R., Pantić S. (2015). Correlations among stress parameters, meat and carcass quality parameters in pigs. Asian Australas. J. Anim. Sci., 28, 435–441. DOI: 10.5713/ajas.14.0322.

Dokmanović, M., Velarde, A., Tomović, V., Glamočlija, N., Marković, R., Janjić J., Baltić, M.Ž. (2014). The effects of lairage time and handling procedure prior to slaughter on stress and meat quality parameters in pigs. Meat Sci., 98, 220–226. DOI: 10.1016/j.meatsci.2014.06.003.

Driessen, B., Freson, L., Buyse, J. (2020a). Fasting finisher pigs before slaughter influences pork safety, pork quality and animal welfare. Animals, 10, 2206. DOI: 10.3390/ani10122206.

Driessen, B., Van Beirendonck, S., Buyse, J. (2020b). The impact of grouping on skin lesions and meat quality of pig carcasses. Animals, 10, 4544. DOI: 10.3390/ani10040544.

EC (1991). Council Directive of 19 November 1991 on the protection of animals during transport and amending Directives 90/425/EEC and 91/496/EEC.

EC (1993). Council Directive 93/119/EC of 22 December 1993 on the protection of animals at the time of slaughter or killing.

EC (2009). Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing.

EC (2017). Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products.

Eikelenboom, G., Bolink, A.H., Sybesma, W. (1991). Effects of feed withdrawal before delivery on pork quality and carcass yield. Meat Sci., 29, 25–30. DOI: 10.1016/0309-1740(91)90020-Q.

Eilert, S.J. (1997). What quality controls are working in the plant? [In] Proc. Pork Quality Summit. Des Moines, July 8–9. National Pork Producers Council, Des Moines, IA, USA. 59–63.

Enfält, A.C., Lundström, K., Engstrand, U. (1993). Early post mortem pH decrease in porcine m. longissimus dorsi of PSE, normal and DFD quality. Meat Sci., 34, 131–143. DOI: 10.1016/0309-1740(93)90023-B.

Faucitano, L. (2001). Causes of skin damage to pig carcasses. Can. J. Anim. Sci., 81, 39–45. DOI: 10.4141/A00-031.

Faucitano, L., Saucier, L., Correa, J.A., Méthot, S., Giguère. A., Foury, A., Mormède, P., Bergeron, R. (2006). Effects of feed texture, meal frequency and pre-slaughter fasting on carcass and meat quality, and urinary cortisol in pigs. Meat Sci., 74, 697–703. DOI: 10.1016/j.meatsci.2006.05.023.

Fernandez, X., Meunier-Salaun, M.C., Ecolan, P., Mormede, P. (1995). Interactive effect of food deprivation and agonistic behavior on blood parameters and muscle glycogen in pigs. Physiol. Behav., 58, 337–345. DOI: 10.1016/0031-9384(94)00364-B.

Fernandez, X., Tornberg, E. (1991). A review of the causes of variation in muscle glycogen content and ultimate pH in pigs. J. Muscle Foods, 2, 209–235. DOI: 10.1111/j.1745-4573.1991.tb00454.x.

Fischer, K. (1996). Transport of slaughter animals. Effects, weaknesses, measures. Fleischwirtschaft. 76, 521–576.

Fischer, K., Augustini, C., McCormick, R. (1988). Effect of fasting time before slaughter on the quality of pig meat. Fleischwirtschaft, 68, 485–488.

Fraser, D. (2008). Understanding animal welfare. Acta Vet. Scand., 50 (Suppl 1), S1. DOI: 10.1186/1751-0147-50-S1-S1.

Galleway, W.J., Tarrant, P.V., MacMahon, P. (1977). Pig meat quality and yield in relation to preslaughter sugar feeding. Irish J. Food Sci. Technol., 1, 71–77.

Geverink, N., Lambooij, E. (1994). Treatment of slaughter pigs during lairage in relation to behaviour and skin damage. [In] Proc. 40th ICoMST, August 28 – September 2. The Hague, The Netherlands, 1–4.

Gispert, M., Guardia, M.D., Oliver, M.A., Diestre, A. (1996). Mortality rates during transport and lairage in pigs for slaughter. Meat Focus Int., 10, 362–365.

Graham, T.E., Adamo, K.B. (1999). Dietary carbohydrate and its effects on metabolism and substrate stores in sedentary and active individuals. Can. J. Appl. Physiol., 24, 393–415. DOI: 10.1139/h99-030.

Grandin, T. (1994). Farm animal welfare during handling, transport and slaughter. J. Am. Vet. Med. Assoc., 204, 372–377.

Grandin, T. (1997). Assessment of stress during handling and transport. J. Anim. Sci., 75, 249–257. DOI: 10.2527/1997.751249x.

Grandin, T. (1998). Objective scoring of animal handling and stunning practices at slaughter plants. J. Am. Vet. Med. Assoc., 212, 36–39.

Guise, H.J., Warriss, P.D. (1989). A note on the stocking density and temperature on meat quality in pigs. Anim. Prod., 48, 480–482. DOI: 10.1017/S0003356100040502.

Hammermeister, A., Kapelańska, J., Kapelański, W., Grajewska, S. (2004). Meat quality in pigs as related to RYR1 genotype and pre-slaughter rest. Anim. Sci. Pap. Rep., 22 (Suppl. 3), 31–37.

Honkavaara, M. (1989a). Influence of lairage on blood composition of pig and on the development of PSE pork. Agr. Food Sci. Finland., 61, 425–432. DOI: 10.23986/afsci.72373.

Honkavaara, M. (1989b). Influence of selection phase, fasting and transport on porcine stress and on the development of PSE pork. Agr. Food Sci. Finland., 61, 415–423. DOI: 10.23986/afsci.72372.

Honkavaara, M. (1989c). Influence of carcass temperature, glycogenolysis and glycolysis 45 min postmortem on the development o PSE pork. Agr. Food Sci., 61, 433–440. DOI: 10.23986/afsci.72374.

Honkavaara, M. (1991). Effect of transport on porcine stress. [In] Proc. 37th ICoMST. Kulmbach, Germany, September 1–6, 257–260.

Hunter, E.J., Weeding, C.M., Guise, H.J., Abboit, R.H., Penny, R.H.C. (1994). Pig welfare and carcass quality – a comparison of the influence of slaughter handling systems at two abattoirs. Vet. Rec., 29, 423–425. DOI: 10.1136/vr.135.18.423.

Jones, S.D.M., Rompala, R.E., Haworth, C.R. (1985). Effects of fasting and water restriction on carcass shrink and pork quality. Can. J. Anim. Sci., 65, 613–618. DOI: 10.4141/cjas85-072.

Kaczorek, S., Zybert, A., Krzęcio, S., Przybylski, W., Koćwin-Podsiadła, M. (1998). The influence of season of the year on frequency of faulty meat of fatteners. Pol. J. Food Nutr. Sci., 7/48, 251–256.

Karlsson, A., Lundström, K. (1992). Meat quality in pigs reared in groups kept as a unit during the fattening period and slaughter. Anim. Prod., 54, 421–426. DOI: 10.1017/S0003356100020882.

Klont, R.E., Lambooy, E. (1995). Influence of preslaughter muscle temperature on muscle metabolism and meat quality in anesthetized pigs of different halothane genotypes. J. Anim. Sci., 73, 96–107. DOI: 10.2527/1995.73196x.

Koćwin-Podsiadła, M., Kaczorek, S., Przybylski, W., Ignaciuk, A. (1990). Wpływ transportu na jakość mięsa tuczników. Rocz. Inst. Przem. Mięs. Tłuszcz., 27, 19–27. [in Polish]

Koćwin-Podsiadła, M., Krzęcio, E., Przybylski, W. (2006). Pork quality and methods of its evaluation – a review. Pol. J. Food Nutr. Sci., 15/56, 241–248.

Kołacz, R., Bodak, E. (1999). Dobrostan zwierząt i kryteria jego oceny. Med. Wet., 3, 147–154. [in Polish]

Krzęcio, E., Zybert, A., Koćwin-Podsiadła, M. (2002). Effect of slaughter season on some pork quality parameters for fatteners of various HAL genotypes. Electron. J. Pol. Agric. Univ., Ser. Anim. Husb., 5: #01.

Lambooy, E. (1988). Road transport of pigs over a long distance: some aspects of behaviour, temperature and humidity during transport and some effects of the last two factors. Anim. Prod., 46, 257–263. DOI: 10.1017/S000335610004232X.

Lambooij, E. (2000). Transport of pigs. [In] Livestock Handling and Transport. CABI Publishing, New York, NY, USA, 275–296. DOI: 10.1079/9780851994093.0275.

Lambooy, E., Engel, B. (1991). Transport of slaughter pigs by truck over a long distance: some aspects of loading density and ventilation. Livest. Prod. Sci., 28, 163–174. DOI: 10.1016/0301-6226(91)90006-C.

Lambooy, E., Hel, W., van der Hulsegge, B., Brandsma, H.A. (1987). Effect of environmental temperature and air velocity two days preslaughtering on heat production, weight loss and meat quality in non-fed pigs. [In] Energy metabolism in farm animals. Effects of housing, stress and disease. Martinus Nijhoff Publ. Dordrecht, 164–179. DOI: 10.1007/978-94-009-3363-7_11.

Lambooij, E., van Putten, G. (1993). Transport of pigs. [In] Livestock Handling and Transport. CAB International, Wallingford, UK, 213–231.

Lister, D., Gregory, N.G., Warriss, P.D. (1981). Stress in meat animals. [In] Developments in Meat Science – 2. Applied Science Publishers Ltd., Barking England, 61–92.

Logtestijn, J.G., Romme, A.M.T.C., Eikelenboom, G. (1982). Losses caused by transport of slaughter pigs in the Netherlands. [In] Transport of animals intended for breeding, production and slaughter. Marinus Nijhof Publ., The Hague, 105–114. DOI: 10.1007/978-94-009-7582-8_10.

Maciołek, H. (1996). Wymagania sanitarno-weterynaryjne w międzynarodowych przewozach zwierząt rzeźnych z uwzględnieniem Konwencji Europejskiej oraz dyrektyw Rady Europy w sprawie ochrony zwierząt [Sanitary and veterinary requirements in international transport of animals for slaughter taking into account the European Convention and the directives of the Council of Europe on the protection of animals]. Życie Wet., 5, 129–135. [in Polish]

Marczuk, A. (2005). Transport of the animals against a background of the EU legal regulations. Inż. Rol., 8, 219–227.

Martoccia, L., Brambilla, G., Macri, A., Moccia, G., Cosentino, E. (1995). The effect of transport on some metabolic parameters and meat quality in pigs. Meat Sci., 40, 271–277. DOI: 10.1016/0309-1740(94)00015-Y.

Meller, Z. (1992). Wpływ stresu wywołanego transportem na jakość mięsa tuczników [Effect of transport stress on meat quality of fattening pigs]. Acta Acad. Agric. Tech. Olst., Zootech., 35, 91–99. [in Polish]

Milligan, S.D., Ramsey, C.B., Miller, M.F., Kaster, C.S., Thompson, L.D. (1998). Resting of pigs and hot-fat trimming and accelerated chilling of carcasses to improve pork quality. J. Anim. Sci., 76, 74–86. DOI: 10.2527/1998.76174x.

Murray, A.C., Jones, S.D.M. (1994). The effect of mixing, feed restriction and genotype with respect to stress susceptibility on pork carcass and meat quality. Can. J. Anim. Sci., 74, 587–594. DOI: 10.4141/cjas94-086.

Murray, A.C, Robertson, W., Nattress, F., Fortin, A. (2001). Effect of pre-slaughter overnight feed withdrawal on pig carcass and muscle quality. Can. J. Anim. Sci., 81, 89–97. DOI: 10.4141/A99-129.

Nanni Costa, L., Lo Fiego, D.P., Dall'Olio, S., Davoli, R., Russo, V. (1999). Influence of loading method and stocking density during transport on meat and dry-cured ham quality in pigs with different halothane genotypes. Meat Sci., 51, 391–399. DOI: 10.1016/S0309-1740(98)00160-0.

Nanni Costa, L., Lo Fiego, D.P., Dall'Olio, S., Davoli, R., Russo, V. (2002). Combined effects of pre-slaughter treatments and lairage time on carcass and meat quality in pigs of different halothane genotype. Meat Sci., 61, 41–47. DOI: 10.1016/S0309-1740(01)00160-7.

Nanni Costa, L., Lo Fiego, D.P., De Grossi, A., Russo, V. (1996). Effect of loading method, stocking density and temperature on carcass and meat quality in heavy pigs. [In] Proc. EU Seminar on: New information on welfare and meat quality of pigs as related to handling, transport and lairage conditions. Braunschweig-Voelkenrode, Germany, 83–94.

Nielsen, S.S., Alvarez, J., Bicout, D.J., Calistri, P., Canali, E., Drewe, J.A., Garin-Bastuji, B., Rojas, J.L.G, Schmidt, C.G., Michel, V., Chueca, M.A.M., Padalino, B., Pasquali, P., Roberts, H.C., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., Winckler, C., Earley, B., Edwards, S., Faucitano, L., Marti, S., de La Lama, G.C.M., Nanni Costa, L., Thomsen, P.T., Ashe, S., Mur, L., van der Stede, Y., Herskin M. (2022). Welfare of pigs during transport. EFSA J., 20, 7445. DOI: 10.2903/j.efsa.2022.7445.

Obiedziński, M.W., Pisula, A., Płonka, S., Różycki, M., Węglarzy, K., Czubała, A., Florowski, T., Obiedziński, M.M. (2009). System gwarantowanej jakości żywności QAFP. Kulinarne mięso wieprzowe cz. 2 [QAFP food quality guarantee system. Culinary pork part 2]. Gospod. Mięsna, 12, 19–22. [in Polish]

Offer, G. (1991). Modeling the formation of pale, soft and exudative meat: Effects of chilling regime and rate and extent of glycolysis. Meat Sci., 30, 157–184. DOI: 10.1016/0309-1740(91)90005-B.

Offer, G., Cousins, T. (1992). The mechanism of drip production: formation of two compartments of extracellular space in muscle post mortem. J. Sci. Food Agr., 58, 107–116. DOI: 10.1002/jsfa.2740580118.

Oliver, M.A., Coll, C., Faucitano, L., Gispert, M., Diestre, A. (1996). The effect of ante mortem treatment on blood parameters and carcass damage and its relationship with pig meat quality. [In] Proc. 42nd ICoMST. Lillehammer, Norway, September 1–6, 35–37.

van Putten, G. (1982). Handling of slaughter pigs prior to loading and during loading on a lorry. [In] Transport of animals intended for breeding, production und slaughter. Martinus Nijhoff Publ., The Hague, The Netherlands, 15–27. DOI: 10.1007/978-94-009-7582-8_3.

van Putten, P., Lambooij, E. (1982). Handling of slaughter pigs prior to loading and during loading on a lorry. [In] Transport of animals intended for breeding, production and slaughter. Martinus Nijhoff Publ., The Hague, The Netherlands, 105–114.

Rey-Salgueiro, L., Martinez-Carballo, E., Fajardo, P., Chapela, M.J., Espiñeira, M., Simal-Gandara, J. (2018). Meat quality in relation to swine well-being after transport and during lairage at the slaughterhouse. Meat Sci., 142, 38–43. DOI: 10.1016/j.meatsci.2018.04.005.

Roseiro, A., Fraqueza, L.C., Almeida, M.J., Matias, J., Santos, E., Sardinha L. (1996). Influence of lairage temperature and time on postural attitude in pigs [In] Proc. 42nd ICoMST. Lillehammer, Norway, September 1–6, 442–443.

Rosenvold, K., Andersen, H.J. (2003a). Factors of significance for pork quality – a review. Meat Sci., 64, 219–237. DOI: 10.1016/S0309-1740(02)00186-9.

Rosenvold, K., Andersen, H.J. (2003b). The significance of pre-slaughter stress and diet on colour and colour stability. Meat Sci., 63, 199–209. DOI: 10.1016/S0309-1740(02)00071-2.

Rosenvold, K., Essen-Gustavsson, B., Andersen, H.J. (2003). Dietary manipulation of pro and macroglycogen in porcine skeletal muscle. J. Anim. Sci., 81, 130–134. DOI: 10.2527/2003.811130x.

Rosenvold, K., Laerke, H.N., Jensen, S.K., Karlsson, A.H., Lundström, K., Andersen, H. J. (2001a). Strategic finishing feeding as a tool in the control of pork quality. Meat Sci., 59, 397–406. DOI: 10.1016/S0309-1740(01)00092-4.

Rosenvold, K., Petersen, J.S., Laerke, H.N., Jensen, S.K., Therkildsen, M., Karlsson, A.H., Møller, H.S., Andersen, H.J. (2001b). Muscle glycogen stores and meat quality as affected by strategic finishing feeding of slaughter pigs. J. Anim. Sci., 79, 382–391. DOI: 10.2527/2001.792382x.

Rybarczyk, A., Gardzielewska, J., Natalczyk-Szymkowska, W., Karamucki, T., Jakubowska, M. (2007). Effects of feed withdrawal on meat quality in PEN AR LAN hybrid pigs. Anim. Sci., (Proc. 1), 122–123.

Rybarczyk, A., Karamucki, T., Drozd, R., Polasik, D., Łupkowska, A., Michalecka, A. (2015). Influence of selected factors upon the blood loss from the carcasses of pigs free of the stress susceptibility gene (RYR1T). Animal Science Papers and Reports, 33 (2), 177–184.

Rybarczyk, A., Łupkowska, A., Hartuna, B., Sulerzycka, A. (2017). Effect of pre-slaughter fasting and gender on pork quality. Fleischwirtschaft, 7, 92–97.

Schaefer, A.L., Murray, A.C., Tong, A.K.W., Jones, S.D.M., Sather, A.P. (1993). The effect of ante mortem electrolyte therapy on animal physiology and meat quality in pigs segregating at the halothane gene. Can. J. Anim. Sci., 73, 231–240. DOI: 10.4141/cjas93-025.

Stephens, D.B., Perry, G.C. (1990). The effects of restraint, handling, simulated and real transport in the pig. Appl. Anim. Behav. Sci., 28, 41–55. DOI: 10.1016/0168-1591(90)90045-F.

Strzelecki, J. (2006). Rozkład mięsa bladego (PSE) w mięśniach szkieletowych tuszy wieprzowej [Pale meat distribution (PSE) in skeletal muscles of a pork carcass]. Gospodarka Mięsna, 2, 20–26. [in Polish]

Strzelecki, J., Borzuta, K., Grześkowiak, E., Lisiak, D. (2006). Wpływ pór roku na występowanie wad jakości mięsa tusz wieprzowych [Effect of season on frequency of meat quality defects of pork carcasses]. Rocz. Inst. Przem. Mięs. Tłuszcz. 44, 89–92. [in Polish]

Tarrant, P.V. (1989). The effects of handling, transport, slaughter and chilling on meat quality and yield in pigs. [In] Manipulating Pig Production II. Proc. Biennial Conf. Australian Pig Sci. Assoc. Warribee, Victoria, Australia, 1–25.

Tarrant, P.V. (1993). An overview of production, slaughter and processing factors that effect pork quality. [In]] Pork Quality: Genetic and Metabolic Factors. CAB International, Wallingford, UK, 1–21.

Tereszkiewicz, K., Molenda, P., Sokołowicz, Z. (2004). The influence of pre-slaughter rest on the rate of post-slaughter bleeding-off and quality of meat in porkers. Anim. Sci. Pap. Rep., 22 (Suppl. 3), 205–210.

Terlouw, C. (2005). Stress reactions at slaughter and meat quality in pigs: genetic background and prior experience A brief review of recent findings. Livest. Prod. Sci., 94, 125–135. DOI: 10.1016/j.livprodsci.2004.11.032.

Tikk, K. (2007). The influence of feeding and aging on pork quality. Acta U. Agr. Sue., 91. Swedish Univ. Agr. Sci., Uppsala (doctoral thesis).

Tikk, K., Lindahl, G., Karlsson, A.H., Andersen, H.J. (2008). The significance of diet and aging time on pork colour and colour stability. Meat Sci., 79, 806–816. DOI: 10.1016/j.meatsci.2007.11.015.

Trevisan, L., Brum, J.S. (2020). Incidence of pale, soft and exudative (PSE) pork meat in reason of extrinsic stress factors. An. Acad. Bras. Cienc. 92: e20190086. DOI: 10.1590/0001-3765202020190086.

Troeger, K. (1989). Plasma adrenaline levels of pigs after different pre-slaughter handling and stunning methods. [In] Proc. 35th ICoMST. Copenhagen, August 20–25, 975–980.

van der Wal, P.G., Engel, B., Hulsegge, B. (1997). Causes for variation in pork quality. Meat Sci., 46, 319–327. DOI: 10.1016/S0309-1740(97)00026-0.

van der Wal, P.G., Engel, B., Reimert, H.G.M. (1999). The effect of stress, applied immediately before stunning, on pork quality. Meat Sci., 53, 101–106. DOI: 10.1016/S0309-1740(99)00039-X.

Wajda, S., Denaburski, J. (1983). Establishment of optimal keeping time before slaughter of pigs from industrial and individual farms. Pigs News Inf., 2, 157.

Wajda, S., Denaburski, J. (2003). Pre-slaughter handling of pigs. Anim. Sci. Pap. Rep., 21 (Suppl. 1), 173–181.

Warner, R.D., Eldridge, G.A., Hofmeyer, C.D., Barnett, J.L. (1998). The effect of dietary tryptophan on pig behaviour and meat quality-preliminary results. 22nd Biennial Conf. Univ. New England, Armidale, New South Wales, Australia: 22.

Warriss, P.D. (1987). The effect of time and conditions of transport and lairage on pig meat quality. [In] Evaluation and control of meat quality in pigs. Martinus Nijhoff Publ. Boston, MA, USA and London, England, 245–264. DOI: 10.1007/978-94-009-3301-9_19.

Warriss, P.D. (1991). A note on the influence of ambient temperature at slaughter on pig meat quality. [In] Proc. 37th ICoMST. Kulmbach, Germany, September, 1–6, 301–304.

Warriss, P.D. (1994). Ante mortem handling of pigs. [In] Principles of Pig Science. Nottingham University Press, Nottingham 425–432.

Warriss, P.D. (1998). The welfare of slaughter pigs during transport. Anim. Welfare. 7, 365–381. DOI: 10.1017/S0962728600020923.

Warriss, P.D., Brown, S.N. (1983). The influence of preslaughter fasting on carcass and liver yield in pigs. Livest. Prod. Sci., 10, 273–282. DOI: 10.1016/0301-6226(83)90062-3.

Warriss, P.D., Brown, S.N. (1994). A survey of mortality in slaughter pigs during transport and lairage. Vet. Rec., 134, 513–515. DOI: 10.1136/vr.134.20.513.

Warriss, P.D., Brown, S.N., Bevis, E.A., Kestin, S.C. (1990). The influence of pre-slaughter transport and lairage on meat quality in pigs of two genotypes. Anim. Prod., 50, 165–172. DOI: 10.1017/S0003356100004566.

Warriss, P.D., Brown, S.N., Edwards, J.E., Knowles, T.G. (1998). Effect of lairage time on levels of stress and meat quality in pigs. Anim. Sci., 66, 255–261. DOI: 10.1017/S1357729800009036.

Wassmuth, R., Glodek, P. (1992). The influence of the Hampshire factor on meat quality in pigs. [In] Proc. 43rd Ann. Meet. EAAP. Madrid, Spain, September 13–17. Wageningen: communication n0P2b.2.

Weeding, C.M., Guise, H.J., Penny, R.H.C. (1993). Factors influencing the welfare and carcass and meat quality of pigs: the use of water sprays in lairage. Anim. Prod., 56, 393–397. DOI: 10.1017/S0003356100006449.

Wittmann, W., Ecolan, P., Levasseur, P., Fernandez, X. (1994). Fasting-induced glycogen depletion in different fibre types of red and white pig muscles-relationship with ultimate pH. J. Sci. Food Agr., 66, 257–266. DOI: 10.1002/jsfa.2740660222.

Rybarczyk, A., Tobolska, I. (2023). Pre-slaughter pig welfare and carcass and meat quality. Acta Sci. Pol. Zootechnica, 22(1), 3–16.
DOI: 10.21005/asp.2023.22.1.01

DOBROSTAN ŚWIŃ W OBROCIE PRZEDUBOJOWYM A JAKOŚĆ TUSZY I MIĘSA

STRESZCZENIE

Dla licznej rzeszy konsumentów, przede wszystkim młodych, akceptacja środka spożywczego, jakim jest mięso, jest dzisiaj często powiązana z żądaniami odpowiednich warunków utrzymania zwierząt użytkowych, jak również właściwym, zgodnym z zasadami ochrony, traktowaniem ich podczas transportu i uboju. Sposób obchodzenia się ze zwierzętami użytkowymi i rzeźnymi jest postrzegany przez społeczeństwa coraz bardziej krytycznie. Wzrastająca w ostatnich latach wrażliwość konsumentów na los zwierząt znajduje odzwierciedlenie również w powstawaniu nowych przepisów prawnych. Jakość mięsa wieprzowego w znacznym stopniu zależy od sposobu obchodzenia się ze zwierzętami, a w szczególności od czynników związanych z obrotem przedubojowym oraz warunkami samego uboju. W trakcie obrotu przedubojowego szczególnie niekorzystnie na organizm tuczników i jakość wieprzowiny mają wpływ warunki podczas załadunku, transportu, przetrzymywania w magazynie żywca i uboju. Przeprowadzone nawet w najlepszych warunkach stanowią dla świń silny stres, który powoduje znaczne straty ilościowe, jak i jakościowe.

Słowa kluczowe: tuczniki, dobrostan, stres, transport, odpoczynek przedubojowy, jakość tuszy i mięsa

Artur Rybarczyk https://orcid.org/0000-0002-5963-8418