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EFFECT OF ENVIRONMENTAL CONDITIONS ON PORK MEAT QUALITY – A REVIEW*

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Pigs, as husbandry animals, are very susceptible to stress, which in turn can influence their meat quality. Environmental factors present during breeding, transport and processing, influencing meat quality, are presented in this study along with results obtained by other authors.

Most important factors are: environmental building conditions, level and system of feeding, transport conditions (type, distance, temperature), stunning, debleeding and handling of carcass after slaughter.

In order to provide meat of highest quality to final consumers, in accordance with the latest normalization changes, it is essential to pay special attention to the whole set of environmental factors, embracing the entire production process (from breeding, transport, processing, distribution and sales).

INTRODUCTION

Meat quality is difficult for unequivocal determination. Broadly speaking, the notion of 'quality' embraces a complex of all traits and attributes important for a given product and affecting its functional value and clearly indicating what a given product is and what degree of perfection it has achieved. It follows from the above definition that meat quality is determined by those of its properties, which distinguish this product as human food. From this standpoint, meat quality will be affected by: the economy of its production, processing and distribution, salubrity, shelf-life, demand, nutritive and biological value as well as other similar properties [Pikielna & Szczucki, 1970]. In recent years, much attention has been paid to the quality of pork meat. Pigs, as one of the species of domestic animals, are exceptionally sensitive to stress, which affects the after-slaughter quality of the meat obtained (Table 1).

In addition, pork meat quality depends on both genetic and environmental factors as well as interactions between them. The reduction of the frequency of the occurrence of defective meat should be achieved by the selection of animals that is aimed at the elimination of genes responsible for the occurrence of meat defects and by the creation of appropriate environmental conditions, both during the period of rearing and in the course of pre-slaughter and slaughter handling [Koćwin-Podsiadła, 1998; Łyczyński & Pospiech, 1999]. Kauffman [1996] claims that the latter can have a stronger impact on meat quality variations than genetic factors. Koćwin-Podsiadła [2002] claims that environmental factors play a key role in influencing pork quality with 15–25% of this effect associated with the handling of animals and 40% – with the process of animal slaughter. That is why so much attention is paid to maintaining appropriate environmental conditions during all stages of pork production, in particular, in the case of swine breeds characterised by high meatiness [Wajda, 1994; Różycki, 1995; Myczko, 1999].

TABLE 1. Traits characterising musculature and meat quality in pigs susceptible and unsusceptible to stress [Różycki, 1995 after Różycki & Pasieka, 1994].

Trait	Stress susceptible	Stress unsusceptible
Backfat thickness (mean from 5 measurements) (cm)	2.73	2.94
Loin eye area (cm^2)	55.30	49.10
Weight of the proper ham meat (kg)	7.27	6.41
Weight of the loin meat (kg)	4.93	4.43
Meat weight of the primal cuts (kg)	22.70	20.40
pH45 min of loin	5.41	6.15
pH45 min of ham	5.57	6.12
Bound water (%)	34.80	37.00

The environmental conditions influencing the quality of the produced meat can be classified depending on the place they occur, namely: during the rearing and fattening (microclimate of facilities and feeding), during loading and transport (type of transport, temperature and distance), in the slaughter house (stunning, bleeding out and handling after slaughter), during distribution and sale of meat and its products and during different culinary treatments and operations.

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ENVIRONMENTAL FACTORS

One of the key factors, which can assure proper meat quality, is the provision of suitable environmental conditions for animals in housing facilities (microclimate of facilities, veterinary and zootechnical prophylaxis) [Verstegen & Hartog, 1998; Myczko, 1999; Lebret *et al.*, 2002] which is connected with maintaining the animals in good health conditions [Larsen, 1997; Schultz, 1997] and feeding them according to their requirements [Blanchard 1994, 1995a,b,c; Fandrejewski, 1995, 2002]. Swine feeding is among one of the important environmental factors influencing both fattening results and the quantity and quality of the meat obtained. Already in 1935, Konopiński [1935] reported that feeding plays a crucial role affecting the quality of slaughter products. Further on, he also discussed relationships between the levels of proteins and carbohydrates in diets and referred them to the after-slaughter meat-to-fat ratio.

Among nutritional factors modifying the tissue composition as well as the quantity and quality of the meat products obtained are, primarily: the levels of protein and metabolisable energy [Fandrejewski *et al.*, 1995], the employed nutritional systems taking into account two fattening periods, and the possibility of diet selection by animals [Falkowski *et al.*, 2001].

The protein requirements concern mainly exogenous amino acids, that is to say those which should be supplied to animals in diets. On the other hand, carbohydrates provide animals mainly with energy. The balancing of the diet on the basis of amino acids allows, additionally, cutting down the level of dietary protein, especially during the second period of fattening, which reduces production costs of fattening. It must be remembered that protein is the most expensive feed constituent and feeding makes up approximately 70% of production costs of porkers. Therefore, the appropriate balancing of the feeding ration with regard to energy and protein supplemented with crystalline amino acids, is essential for the optimal coverage of animal demands in relation to their nutritional requirements which will take into account their physiological condition, genotype and period of development in their post-natal life. Generally speaking, it is assumed that during the first period of fattening, the level of metabolisable energy (ME) should range from 13 to 13.5 MJ and that of crude protein from 16 to 17% and once the animals exceed 80 kg body weight, respectively: 12.5 MJ and 15% crude protein. Levels of dietary energy and proteins depend, primarily, on the capability of animals to accumulate protein in their bodies and this is affected mainly by the animals' genotype and appetite [Blanchard, 1994, 1995a,b,c; Fandrejewski *et al.*, 2002].

The possibility of reducing the level of protein in the diets and balancing amino acids was confirmed by a number of authors, among others by: Łyczyński *et al.* [1998], Rzosińska & Łyczyński [2001] and Rzosińska *et al.* [2005].

Another important factor is the quality of components applied to manufacture feed mixtures as this also exerts a direct effect on the animal health and, consequently, on the production results [Jarczyk, 2002]. The banning of antibiotics from complete diets as growth promoters may lead to the increase of their application for therapeutic purposes in swine [Rekiel, 2002], as confirmed by Wheelock [2002]. Experiments carried out by Wheelock [2002] in Denmark led him to the conclusion that, following the withdrawal of antibiotics as growth stimulators, the level of their utilization for therapeutic purposes increased. He also claims that the use of antibiotics in Great Britain as growth promoters, in comparison with the level of their application for therapeutic purposes, in the period from 1993 to 2000 was very low. Therefore, it can be presumed that the complete withdrawal of antibiotics as feed additives stimulating growth by reducing the bacterial flora *in vivo*, may result in a temporary deterioration of the health of animals until they develop some active resistance. This, in turn, will be associated with the increase of production costs of fatteners accompanied by the quality reduction of the meat raw material.

In the wake of the growing interest in the production of 'safe food' observed in the last decade, also the research concerning the modification of feed rations in swine feeding has intensified. The main interest of such research is focused on the substitution of a part of the dietary metabolisable energy by unsaturated fatty acids. It is presumed that by doing so, it will be possible to obtain the composition of fats in the pork meat which will be more favourable for humans and to apply alternative to antibiotics various feed additives positively affecting the health and productivity of animals as well as the quality of their meat and fat [Mc Keith, 1998; Wood *et al.*, 1998; Barowicz & Pieszka, 2001; Migdał *et al.*, 2001; Wiesemuller, 2001; Fandrejewski, 2002; Koczanowski *et al.*, 2002; Rekiel, 2002; Wajda *et al.*, 2004b].

As mentioned earlier, meat quality is also strongly affected by the applied feeding system. Employing specific feeding systems, *e.g.*: *ad libitum* feeding in contrast to dosed feeding during the entire period of rearing and fattening of animals or only during a definite period, it is possible to obtain excessive fattening (marbling) of meat and its specific tenderness and juiciness, which can, from the technological and consumers' point of view, be a very welcome feature [Zessin *et al.*, 1961; Blanchard, 1995b; Wood *et al.*, 1998; Kristensen *et al.*, 2001; Wiesemuller, 2001; Łyczyński *et al.*, 2001a; Daszkiewicz *et al.*, 2003]. The optimum level of the intramuscular fat in the *musculus longissimus* dorsi should be about 2.2%, although opinions on this subject are conflicting [Wiesemuller, 2001; Daszkiewicz *et al.*, 2003]. Frequently, especially in the dosed and restricted systems of feeding, the level of fat in this muscle is lower (1.3–1.9%). Łyczyński *et al.* [2004] reported less defective meat in carcasses characterized by higher levels of intramuscular fat than in those which were found to contain less intramuscular fat.

Furthermore, meat can also be affected by various thermal treatments employed in the course of different culinary procedures (*e.g.* cooking, frying, baking, stewing *etc*.) influencing its quality, especially tenderness and juiciness. It is not very uncommon that good quality pork, following improper culinary treatment, becomes tough and dry (stringy). Obviously, it is easier to prepare a tender dish from good quality raw material than to try and improve the bad quality raw material. Tenderness belongs to the basic meat sensory traits which is decisive in influencing its quality. However, this trait is by no means easy for organoleptic evaluation [Zessin *et al.*, 1961; Wood *et al.*, 1998]. When purchasing meat, consumers have to rely on their previous experiences associated with the preparation of a given dish from different kinds of

meats and their sensations or impressions in the course of its consumption or else they must rely on the information of the seller or specialised nutritionist. Recent observations indicate that tough meat reaches the market more and more frequently. Meat variations concerning this trait do not depend on whether the evaluation of tenderness is conducted on the raw material intended directly for culinary purposes or on ready--to-eat (processed) products whose production process takes several days [Wood *et al.*, 1998].

Factors modifying the quantity and quality of pork meat are associated with such traits as: growth rate [Eckert *et al.*, 2001; Łyczyński *et al.*, 2001b; Kapelański *et al.*, 2002; Czyżak-Runowska *et al.*, 2005] expressed by the daily growth rate, slaughter weight and the level of after-slaughter carcass meatiness (Table 2). The animal growth rate and the rate of tissue formation associated with it may affect meat tenderness [Pospiech *et al.*, 2000; Łyczyński *et al.*, 2001b]. Results of experiments presented by numerous authors [Pospiech *et al.*, 2000; Szalata *et al.*, 1999, 2002] indicate that the main factor affecting meat tenderness is, most probably, the rate of protein synthesis process as the main component of the muscle tissue. Presumably, the influence of protein synthesis processes on meat tenderness can be associated either with variations in the activity of proteolytic enzymes taking part in protein transformations or with the structural properties of meat tissue affecting the sensitivity of this structure to meat tenderization. It is also possible that the two factors can act simultaneously.

Łyczyński *et al.* [2001b] reported that the meat of porkers exhibiting very high live weight gains was characterized by slightly worse quality indices after slaughter (pH, electrical conductivity, colour) but, at the same time, contained more intramuscular fat in comparison with animals characterised by lower daily gains.

Grześkowiak *et al.* [1998], Szalata *et al.* [1999], Pospiech *et al.* [2000] maintain that, under the environmental conditions of Polish farms, the after slaughter meatiness of more than 55% can have a negative influence on the sensory traits of the meat assessed.

In other investigations [Wajda *et al.*, 2004a], it was reported that with an increase in the EUROP class, the content of crude protein and non-protein compounds increased, while the content of fat decreased in the meat examined. In addition, the highest proportion of PSE meat was observed within the E class carcasses.

TABLE 2. Meat quality of porkers depending on the meatiness range [Łyczyński *et al.*, 2002].

Analysed traits	Meatiness range * (%)	Statistical values		
		$\bar{x}$	SD	V
Meatiness (%)	I (A)	47.78^{BC}	1.73	3.61
	II (B)	52.60^{AC}	1.36	2.59
	III (C)	57.52^{AB}	1.80	3.14
pH_{45min}	I (A)	6.27	0.40	6.35
	II (B)	6.32^{c}	0.47	7.42
	III (C)	6.11^{b}	0.48	7.93
pH_{24h}	I (A)	5.49^{BC}	0.15	2.67
	II (B)	5.42^{A}	0.13	2.37
	III (C)	5.40^{A}	0.11	2.09
$EC_{90\ min}$ (mS/cm)	I (A)	4.85	2.80	57.85
	II (B)	4.67	3.03	64.97
	III (C)	5.91	4.82	81.70
EC_{24h} (mS/cm)	I (A)	6.31	2.93	46.48
	II (B)	6.31	2.96	46.91
	III (C)	7.61	3.70	48.62
L*	I (A)	56.39^{c}	4.44	7.87
	II (B)	56.89^{c}	4.33	7.60
	III (C)	58.85^{ab}	5.02	8.53

* Meatiness range: I – ≤ 49.99; II – < 50 – 54.99 >; III – ≥55
A–C differences significant at p≤0.01; a–c differences significant at p≤0.05

PRE-SLAUGHTER AND AFTER SLAUGHTER FACTORS

It is commonly believed that the handling of slaughter animals, *i.e.* a complex of multiple factors occurring in the pig-house, during the animal transport and in the slaughter -house, is one of the important environmental factors affecting the quality of the meat obtained. Various non-specific factors (fatigue, hunger, thirst, sunlight, noise, beating, climatic factors *etc*.) affect animals during transport. A number of researchers [Bąk & Wajda, 1997; Tereszkiewicz, 2002; Wajda & Denaburski, 2003] reported that the loading of animals, type of transport, stocking rate, temperature and the distance (Table 3) influenced significantly the quality of the meat obtained. Modern swine breeds are characterised by high meatiness and do not adopt easily to new environmental conditions as exemplified by the occurrence of the PSS syndrome with such symptoms as: muscle weakness, shivers, hyperthermia, excess of acid metabolic lactates in blood as well as cardiovascular problems often ending in death.

During transport, particular attention should be paid to such factors as: gentle transfer of animals, transport in groups in which they were reared, type and equipment of transport vehicles (loading and unloading ramps), appropriate loading area and sufficient availability of fresh air. Improper transport accompanied by changing temperatures, excessive transport distances and duration and lack of pre-slaughter rest can lead to the loss of a part of glycogen. This, in turn, affects the course of the process of glycolysis which

TABLE 3. Effect of the transport distance on selected meat quality traits [Bąk & Wajda, 1997].

Traits	Transport distance of pigs		Significance of differences
	50 km	100 km	
Weight of porkers (kg)	104.45	98.85	**
Dressing percentage (%)	79.52	78.97	*
$pH_{45\ min}$	6.35	6.25	*
$pH_{24\ h}$	5.90	5.86	-
Water holding capacity (cm^2)	8.54	8.90	*
Colour (%)	20.16	22.86	**

* – statistical differences at the level of p≤0.05; ** – statistical differences at the level of p≤0.01

ultimately controls the process of meat acidification and constitutes a natural barrier against the development of bacterial microflora [Wajda & Denaburski, 2003]. Transport, even when it is organised perfectly, constitutes a strong stress for animals causing considerable weight losses, diseases or even death (Table 4). Therefore, it is very important to treat animals properly during their handling.

TABLE 4. Effect of different porker purchasing system on body weight losses [Wajda & Meller, 1988].

Trait	Purchasing system		Significance of differences
	Direct	Indirect	
Weight of porkers (kg)	108.22	106.57	-
Transport losses (%)	1.85	4.52	**
Losses caused by keeping live animals before slaughter (%)	4.6	4.1	-
Weight losses until slaughter	6.36	8.43	**

** – statistical differences at the level of $p \leq 0.01$

Improper pre-slaughter handling of animals can result in the development of meat defects. The most frequent meat defects include [Kortz *et al.*, 2001; Pospiech *et al.*, 1998]: PSE (pale, soft, exudative), ASE (acid, soft, exudative) and DFD (dark, firm, dry) meats which occur much more frequently in bovine than in pork meat. The above-mentioned meat defects occur mainly in the best carcass cuts, namely in the loin and ham. It should be remembered that the economical losses resulting from the deterioration of meat quality are very high and affect both the processor and the consumer. According to Pospiech *et al.* [1998], the level of losses attributable only to PSE and RSE meat in Poland reach the staggering figure of 140 million PLZ annually, which constitutes about 2.4% of the live swine value. Therefore, the best solution which will guarantee meat quality is to take good care of the raw material, beginning with the breeding, *via* rearing, fattening, appropriate transport, slaughter, processing and distribution of meat, in other words, to maintain the chain of good quality.

SUMMARY OF FACTORS INFLUENCING PORK MEAT QUALITY

Meat quality assessment can be carried out already on the slaughter line by measuring meat reaction (measured 45 min and 24 h after slaughter), electric conductivity (measured 90 min and 24 h after slaughter) and its colour (measured also 24 h after slaughter). On the other hand, meat laboratory analyses should comprise: its chemical composition (water, protein, dry matter, and intramuscular fat), meat glycolytic potentials and water holding capacity as well as such sensory traits as: meat tenderness and juiciness (texture).

Improper treatment of animals, mainly outside the place of their rearing, *i.e.* during transport and in slaughterhouses [Wajda, 1994, 1998; Marahrens *et al.*, 1997; Costa *et al.*, 1999; Fernandez *et al.*, 2002a,b; Franck, 2002; Łyczyński, 2002], can reduce meat consumer value (Table 5). The treatment of animals prior to the slaughter affects the after-slaughter maturing of meat which influences its technological value.

TABLE 5. Effect of keeping live porkers before slaughter on selected traits [Wajda & Denaburski, 1983].

Traits	A	B	C	Significance of differences
	Slaughter directly after delivery	After 4 h of rest	After 24 h of rest	
Body weight of porkers	101.96	101.52	101.42	–
Dressing percentage (%)	80.41	80.77	79.13	C<A, B**
$pH_{45\ min}$	6.39	6.45	6.43	–
pH_{24h}	5.75	5.76	5.89	C>A, B**
Dry matter (%)	26.43	26.46	26.89	C>A, B**
Water holding capacity	6.95	7.55	7.16	B>A*
Colour	16.79	17.68	17.39	–

* – statistical differences at the level of $p \leq 0.05$; ** – statistical differences at the level of $p \leq 0.01$

It is also worth emphasizing that animals tired by long handling in unsuitable conditions become less resistant to endogenous infections originating from the gastrointestinal tract [Wajda, 1996]. Meat obtained after slaughter is characterised by greater microbiological infections resulting in the occurrence of decaying processes which lead to unfavourable organoleptic changes. The shelf-life of such meat is considerably restricted.

Slaughter factors affecting particularly strongly the meat quality include stunning and bleeding out, as well as the handling of carcasses after slaughter. The stress associated with stunning is the worst pre-slaughter stress animals are exposed to. Borzuta [1996] reported that in the result of electric stunning, the blood pressure of animals increased two-fold and the hormone stresses were secreted with 500–600 greater intensity than in normal physiological conditions. Therefore, the time between stunning and stabbing should be as short as possible. This will prevent, or at least reduce stress hormones reaching skeletal muscles and, hence, limit the frequency of the occurrence of PSE symptoms. When pigs are bled out lying, this time should not exceed 10 s and when hanging – 0.20 s [Litwińczuk *et al.*, 2004]. The new slaughter technologies recommend carcass bleeding out in the lying position. When the bleeding out process begins too late after stunning, especially with electric current, it can result in the development of muscle splashes. The method of stunning can influence the level of carcass bleeding out which, in turn, is associated with the degree of meat acidification and affects the degree of the protection of meat against the development of bacterial microflora. A number of authors report that meat derived from animals stunned with CO_2 exhibits lower water drip than that derived from animals stunned by electric current [Velarde *et al.*, 2000; Channon *et al.*, 2003]. Borzuta [2003] as well as Wajda & Daszkiewicz [1999] agree that meat defects can be limited by minimising stress conditions during animal slaughter in the result of replacing electrical stunning with the carbon dioxide stunning.

Another important factor influencing meat quality is the season of the year [Kaczorek *et al.*, 1998; Wajda & Denaburski, 2003]. Kaczorek *et al.* [1998], when analysing meat defects in pigs derived from mass production in central-eastern Poland, found three times more carcasses with the PSE meat in summer than in winter.

It should be stressed that the entire pre-slaughter effort of slaughter animal producers can be wasted by inappropriate pre-slaughter handling of animals.

As to the after-slaughter factors affecting meat quality, the method of carcass chilling is important. It is possible to delay the decline of the pH value in the muscle tissue, if the chilling process of animal carcasses is carried out optimally. Offer [1991] and Jones *et al.* [1993] reported that instant chilling improved meat quality since it slowed down the rate of glycolytic changes and prevented the development of the defect of wateriness. The method of shock chilling of carcasses gained widespread acceptance in practice [Fisher, 2001]. In comparison with the traditional method of chilling, this shock method causes less carcass weight losses, improves the microbiological status of the carcass but results in meat stringiness [van der Wal, 1997]. However, in the case of carcasses with the normal course of the glycolytic processes, too rapid chilling may lead to cold shortening.

It should be stated, that the impact of environmental factors, especially those which are associated with the pre-slaughter handling of animals, is often underestimated. Their improvement does not require high financial input, whereas advantages resulting from their implementation are considerable. Bearing in mind the production of the best quality pork meat complying with the latest standardisation requirements [Pisula *et al.*, 2002] and at the lowest possible costs, it is essential to focus on a complex of environmental factors including the entire production process, beginning from the farmer, through animal transport, slaughterhouse, processing technology as well as the transport of finished products their distribution and sale. Thanks to all these measures, Polish pork and its processed products will become competitive on the European Union markets, not only with regard to their prices but also quality.

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WPŁYW CZYNNIKÓW ŚRODOWISKOWYCH NA JAKOŚĆ MIĘSA WIEPRZOWEGO – ARTYKUŁ PRZEGLĄDOWY

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Świnie jako gatunek zwierząt domowych są bardzo podatne na stres, który może mieć wpływ na jakość pozyskiwanego mięsa. W pracy przedstawiono, w oparciu o własne doświadczenia a także w oparciu o zamieszczone wyniki wielu autorów, oddziaływanie różnych czynników środowiskowych, występujących w miejscu chowu, podczas obrotu tuczników oraz w zakładach ubojowych.

Najważniejszymi czynnikami środowiskowymi, które mają bądź mogą mieć wpływ na jakość wieprzowiny są: mikroklimat pomieszczeń, żywienie (poziom i system żywienia), obrót zwierząt rzeźnych (rodzaj transportu, dystans i temperatura), oszałamianie, wykrwawianie oraz obchodzenie się z tuszami zwierząt po ich uboju.

Dążąc do zapewnienia konsumentowi dobrej jakości wieprzowiny, zgodnie z najnowszymi zmianami normalizacyjnymi, koniecznym staje się zwrócenie uwagi na zespół czynników środowiskowych, obejmujących cały proces produkcyjny, a więc począwszy od rolnika, poprzez transport, zakłady ubojowe, technologię przetwórstwa oraz transport produktów gotowych, ich dystrybucję i sprzedaż.