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EFFECTS OF MAGNESIUM ON PORK QUALITY

Krzysztof Lipiński[1], Małgorzata Stasiewicz[1], Cezary Purwin[1], Krystyna Żuk-Gołaszewska[2]

[1]Chair of Animal Nutrition and Feed Management,
[2]Chair of Agrotechnology and Crop Management
University of Warmia and Mazury in Olsztyn

Abstract

Over the recent years, there has been an increasing interest in improving pork quality, which at present often fails consumer requirements. Nutritional regime is one of the key environmental factors affecting fattening results, slaughter value and meat quality. The technological and organoleptic properties of pork can be modified through feeding. Numerous studies have been conducted to determine the effect of diet composition on meat quality.

Consumers prefer lean pork with a bright reddish-pink color, and they object to muscles that are too pale or too dark. An excess amount of meat juice in the package is also considered unacceptable.

The role of vitamins, minerals and feed additives in animal nutrition is an important consideration. Animal production efficiency is dependent upon an adequate supply of nutrients and minerals. Nutrient availability from feedstuffs is a principal factor in improving animal productivity and health as well as meat quality. Organic forms of minerals have been proven to have high bioavailability.

Since the magnesium content of standard diets satisfies the needs of animals, pigs are usually not provided with supplemental magnesium. However, research results show that magnesium compounds have a beneficial influence on selected aspects of pig production. Dietary magnesium supplementation positively affects the behavior of animals, decreases their stress sensitivity and improves pork quality by enhancing meat color, reducing drip loss and increasing acidity.

Key words: magnesium, meat quality, pigs.

dr hab. inż. Krzysztof Lipiński prof. nadz., Chair of Animal Nutrition and Feed Management, University of Warmia and Mazury in Olsztyn, Oczapowskiego 5, 10-718 Olsztyn, Poland; e-mail: krzysztof.lipinski@uwm.edu.pl

WPŁYW MAGNEZU NA JAKOŚĆ MIĘSA ŚWIŃ

Abstrakt

W ostatnich latach dużo uwagi poświęca się jakości mięsa wieprzowego, która w opinii wielu konsumentów jest niska i nie odpowiada ich wymaganiom. Żywienie zwierząt jest jednym z najważniejszych czynników środowiskowych, który ma wpływ na efektywność tuczu, wartość rzeźną i jakość mięsa. W przypadku trzody chlewnej istnieje możliwość modyfikowania zasadniczych cech jakości technologicznej i organoleptycznej mięsa poprzez żywienie. Obecnie prowadzi się wiele badań związanych z wpływem składników pokarmowych na jakość uzyskanego mięsa.

Nabywca wybierając opakowanie mięsa kulinarnego preferuje porcje z dużą zawartością chudej tkanki mięśniowej, o typowej dla wieprzowiny różowoczerwonej barwie. Nie akceptowane są porcje mięsa o barwie zbyt jasnej lub zbyt ciemnej oraz mięso z dużą ilością wycieku soku mięsnego.

Analizując wpływ żywienia na jakość mięsa, często zwraca się uwagę na rolę witamin i składników mineralnych, a także niektórych dodatków paszowych. Prawidłowe zaopatrzenie organizmu w składniki mineralne jest jednym z podstawowych czynników decydujących o efektywności produkcji zwierzęcej. Ważnym problemem jest dostępność składników mineralnych. Decyduje ona o wynikach produkcyjnych, zdrowotności zwierząt, ma również wpływ na jakość mięsa. W ostatnich latach w wielu badaniach wykazano wysoką biodostępność tzw. organicznych połączeń składników mineralnych.

Zawartość magnezu w typowych dawkach pokarmowych jest wystarczająca do pokrycia potrzeb świń. Mając na uwadze powyższe informacje, magnez nie jest zwykle dodawany do mieszanek paszowych dla świń. W piśmiennictwie naukowym znajduje się jednak wiele informacji o korzystnym wpływie dodatku związków magnezu na niektóre aspekty produkcyjne trzody chlewnej. Stosowanie dodatku magnezu w mieszankach dla świń może korzystnie oddziaływać na zachowanie świń, wrażliwość na stres i jakość mięsa, poprzez poprawę barwy, zmniejszenie wycieku soku mięsnego, podwyższenie kwasowości.

Słowa kluczowe: magnez, jakość mięsa, świnie.

INTRODUCTION

Pork consumption has a high share of total meat consumption in the EU member states including Poland. In 2008, the estimated total household consumption of meat and fish in Poland was as follows: poultry meat – 17.8 kg, pork – 16.8 kg, fish – approximately 12 kg. Quality attributes are the key factors affecting consumer purchasing decisions for pork. Over the recent years, there has been an increasing interest in improving pork quality, which often fails to meet consumer requirements. Consumers pay particular attention to the external appearance of pork portions, which is generally regarded equivalent to quality. At the moment of purchase, consumers evaluate the proportions of muscle, bone and connective tissue, meat color and the presence of meat juice in the package. Consumers prefer lean pork with a bright reddish-pink color, and they object to muscles that are too pale or too dark. An excess amount of meat juice in the package is also considered unacceptable (Aaslyng et al. 2007, Pisula, Florowski 2009).

MEAT QUALITY

Quality attributes determine the processing suitability and consumer perception of meat and meat products. They describe the sensory, nutritional, technological and sanitary quality of meat (Słowiński 2006). Consumers make their purchasing decisions based on an evaluation of the sensory properties of meat, including color, palatability, consistency and juiciness.

Color is one of the most important meat quality characteristics. It is a visual sensation that depends on the presence of pigments, the tissue composition and texture of meat. If consumers find the color of meat unacceptable, all other quality attributes become relatively unimportant. There is some correlation between meat color and the pH of muscles. Changes in meat color are in 50% determined by pH values measured 24 hours post mortem. The average value of color lightness L* of *m. longissimus dorsi*, measured with a Minolta colorimeter, is 44 (ranging from 38 to 48). Meat color is positively affected by nutritional factors, such as the content of vitamin C, vitamin E, selenium and magnesium (Arihara et al. 1993, Brewer, Novakofski 1999, Cole, Close 2005, Kłossowska, Tyszkiewicz 2000, Kołczak 2007a).

Palatability is a sensory attribute of meat defined as a combination of taste, aroma (flavor), consistency, temperature and acidity. Meat owes its characteristic taste mainly to a mixture of volatile compounds. Raw muscle tissue is the main source of flavor precursors and a few aroma- and taste-active compounds. Raw meat has a delicate, blood-like, slightly sweet, slightly sour, slightly salty and slightly bitter taste, depending on its biochemical composition and origin. The aroma of raw meat is weak and subtle, similar to that of commercial lactic acid. Between ten and twenty substances involved in the development of meaty, beef-like, fresh and blood-like aroma have been recently identified in raw meat. The meat of older animals has a more intense flavor than the meat of younger animals. Meat palatability is significantly affected by intramuscular fat. Different muscles from the same carcass and animal species differ with respect to the optimal levels of intramuscular fat. Neither excess nor insufficient intramuscular fat contributes to desirable flavor effects. Muscle types vary in their palatability attributes.

Meat with a high pH seems to be less salty and less palatable than meat with a low pH, most probably due to differences in the amount of free, unbound water. The palatability and flavor of meat enhance during postmortem aging (Kołczak 2007b, Troy, Kerry 2010), and they change as a result of heat treatment. Flavor precursors are water- and fat-soluble compounds, including peptides, amino acids, nucleotides, reducing sugars, aliphatic hydrocarbons, fatty acids and their oxidation products. Cooked, fried, stewed and roasted meat products differ in taste and aroma. The flavor precursors present in raw meat are probably responsible for the development of palatability characteristics in heat-processed meat (KOŁCZAK 2007b, TROY, KERRY 2010).

Consistency is referred to as the sum of visual impressions regarding the color and texture of meat, determined by the quality of raw materials and the course of the technological process (ANDERSEN et al. 2005, TROY, KERRY 2010).

Juiciness is closely related to the water-holding capacity and intramuscular fat content of meat. Meat with a high water-binding capacity is more juicy and, in consequence, more palatable. Raw pork should not have any visible symptoms of water loss or become stringy and dry upon processing. Meat juiciness increases during cold storage (aging) because cell membranes lose their permeability and release cellular fluids (ANDERSEN et al. 2005, TROY, KERRY 2010).

In addition to its nutritive value, consumers are known to pay considerable attention to the palatability, tenderness and juiciness of meat (TROY, KERRY 2010).

The nutritional value of meat is a quality attribute that cannot be visually assessed, but it does affect consumer buying decisions. Meat is a valuable source of nutrients that are an important part of the human diet. Consumers generally show a distinct preference for lean, low-calorie meat with a high content of protein, vitamins and microelements (PURCHAS et al. 2009, ZULLO et al. 2003).

The chemical composition of meat can vary according to animal species, age, live weight and sex, carcass cut and postmortem changes in the muscles.

Meat is a good source of minerals. The mineral content of meat may vary widely depending on the muscle, carcass part, animal species and nutritional regime. Nutrients present in meat in larger amounts (above 0.1%), referred to as macroelements, are potassium, phosphorus, sodium, chloride, magnesium, calcium and sulfur, whereas nutrients found in smaller quantities (below 0.1%), referred to as microelements, include iron, zinc, copper, manganese and molybdenum. Mineral compounds affect the technological and sensory properties of meat. Phosphorus concentrations determine the water-holding capacity of meat, and sulfur content influences sensory attributes. Due to high levels of phosphorus and sulfur, meat and meat products belong to acid-forming foods. Meat and edible offal supply magnesium, sodium and potassium.

Inorganic compounds found in tissues are predominantly in the ionized form. They are involved in the regulation of osmotic pressure and electrolyte balance inside and outside the cells. The majority of calcium and potassium ions are bonded with proteins, mostly myosin. Calcium and magnesium ions help regulate muscle contraction. Magnesium is also an activator for many enzymatic reactions.

The content and composition of mineral salts affect the processing suitability (water-holding capacity) and organoleptic properties of meat (PURCHAS et al. 2009, ZULLO et al. 2003).

Processing suitability is determined by the technological quality attributes of raw materials, including the stage of meat aging, water-holding capacity, pH, pigment content, the proportion of muscle tissue, the method of meat preservation. The quality of raw materials influences the quality of end products. It is difficult, or even impossible, to manufacture high-quality products from poor-quality raw materials (SŁOWIŃSKI 2006).

Water-holding capacity is a key indicator of the processing suitability of meat. It is defined as the ability of muscle to retain its water (juice) and to absorb or bind extra water added to the product during the technological process. The retained (bound) water contributes to the juiciness and palatability of meat. The water-binding capacity of meat is affected by various factors, including the physical state of proteins and pH, primarily the rate of post mortem pH decline and ultimate pH values. A high water-holding capacity is observed in dry, firm and dark (DFD) meat, while meat with a low water-holding capacity tends to be pale, soft and exudative (PSE) (COLE, CLOSE 2005, VAN DE PERRE 2010).

A decrease in acidity (a rise in pH) and an increase in salt concentrations improve the water-holding capacity of meat. A high water-binding capacity is desirable if meat is to be marinated or pickled in a marinating or pickling medium. The ultimate pH of meat usually ranges from 5.65 to 5.80. The optimum pH level is 5.7-5.9. Drip loss may be effectively reduced by adding vitamin C, vitamin D, selenium, magnesium, calcium and conjugated linoleic acid (CLA) to animal diets (COLE, CLOSE 2005, D'SOUZA et al. 1999).

The sanitary quality of meat is evaluated based on microbiological contamination (total microbial counts, quantitative and qualitative composition of pathogenic microflora), the presence of residues of drugs, heavy metals, pesticides and mycotoxins, and the presence of parasites (SŁOWIŃSKI 2006, TROY, KERRY 2010). The quality characteristics of pork intended for human consumption are affected by genetic factors and environmental conditions, including nutrition (LAMMENS et al. 2007, PISULA, FLOROWSKI 2009).

The most common quality defects of fresh pork are color deviations, excessive drip loss and too high acidity. The quality attributes of meat measured most often are pH, color, water-holding capacity, tenderness and marbling.

Major research efforts are currently focused on investigating the effect of nutritional regime on meat quality and the impact of stress on production results. The role of vitamins, minerals and feed additives in animal nutrition is also an important consideration.

MAGNESIUM IN PIG NUTRITION

Macroelements and microelements are needed for the normal growth and development of all living organisms. Magnesium is a macronutrient – it is required in large quantities. Magnesium plays a vital role in numerous metabolic and enzymatic reactions as it is involved in more than 300 enzyme systems. It is also essential to build the bones. Magnesium metabolism is closely related to calcium and phosphorus metabolism. In animal organisms, around 60% magnesium is stored in the bones, 40% migrates into soft tissues and approximately 1% is found in bodily fluids.

Magnesium forms organic compounds and participates in carbohydrate and fat metabolism. Protein synthesis depends on optimal magnesium concentrations. Magnesium is essential for oxidation-reduction reactions and phosphorylation processes (formation of high-energy compounds, e.g. ATP, synthesis of H_2 and electron carriers); it is involved in the synthesis and activation of enzymes; it is the main activator of enzymatic processes in the cells and it affects the storage of catecholamines (KANIA 1998, DUGAN et al. 2004).

In monogastric animals, magnesium is absorbed primarily from the small intestine, at approximately 60%, mostly via passive transport. Potassium, calcium and ammonia are magnesium antagonists. Magnesium homeostasis is not controlled by any specific hormonal system, but the process can be indirectly regulated by the parahormone calcitonin, aldosterone, thyroxine and insulin. Magnesium levels in the body are regulated by intestinal absorption, excretion through the kidneys, excretion in feces and dietary supply. The exact magnesium requirements are difficult to determine. Plasma magnesium concentrations are not a reliable indicator of the bodily magnesium state since the extracellular fluid contains only small quantities of this element. The symptoms of magnesium deficiency are well documented, particularly in ruminants (tetany). They include a strong response of the nervous system (hypersensitivity, anxiety, fear), muscle contractions and a drop in productivity (a slower growth rate, loss of appetite). A decrease in plasma magnesium concentrations reduces the magnesium content of bones.

Toxic magnesium concentrations in pigs remain unknown, but the maximum tolerable level of magnesium has been set at 0.3% (NRC 1980). In other animal species, toxic magnesium concentrations (due to an accidental Mg oversupply) lead to a decrease in feed intake and production efficiency, drowsiness, locomotor disorders and death.

Magnesium can be found in all types of feed, including green forage, feed of animal origin and mineral feed. Concentrated feed is a richer source of magnesium than roughage. Wheat bran, dried yeast, linseed meal and cottonseed meal are good sources of magnesium. The average magnesium content (mg/kg d.m.) of cereals, oil meals and fish meals is 1.1-1.3 g, 3.0-5.8 g and 1.7-2.5 g, respectively. The magnesium content of animal meals is directly proportional to the magnesium content of bones.

Magnesium levels in roughage may vary greatly, depending on plant species, the abundance of magnesium in the soil and climatic conditions. Legumes are usually richer in magnesium than grasses. Magnesium occurs in various forms in mineral feed (Table 1).

Table 1

Magnesium content of mineral feed

Specification	Content (%)
Magnesium oxide	50.5 - 52.0
Magnesium hydroxide	36.0 - 38.0
Magnesium phosphate	24.0 - 33.0
Magnesium chloride	12.0
Magnesium sulfate	10.0

Little is known about the availability of magnesium from different sources, but it is usually higher in monogastric animals than in ruminants. In chickens, the actual absorption of dietary magnesium is as follows: maize – 55.7%, wheat – 56.8%, oat – 82.7%, barley – 54.5%, soybean meal – 60.3%, skim milk powder – 63.0% (Gunter, Sell 1974, Sell 1979).

Diets containing the above feed components meet the magnesium requirements of monogastric animals.

The availability of magnesium from mineral feed may also vary. The availability of magnesium oxide (MgO) is determined by particle size and the temperature of the production process. Magnesium oxide is obtained by heat processing of magnesium carbonate. Large particles of MgO (>0.5 mm) and low temperature (< 800°C) during the process reduce magnesium absorption in the small intestine. The average availability of magnesium oxide, compared with magnesium phosphate, is around 20% vs 45%. The above information comes from studies on ruminants which need larger quantities of magnesium than monogastric animals. Research on the role of magnesium in poultry and pig nutrition remains scanty.

Dietary magnesium demand is relatively low in pigs. Dietary magnesium intake of 0.04% is considered sufficient, and 500-650 mg magnesium per kg complete diet is recommended for pigs and poultry. Research results show that the magnesium requirement of artificially raised piglets is 300-500 mg kg^{-1} diet (min. 325 mg kg^{-1} d.m.), and that milk provides adequate amounts of this macronutrient (NRC 1998). Dietary magnesium intake of 400-450 mg is recommended in weaned piglets for optimal growth and magnesium deficiency prevention. The demand for magnesium increases proportionally to the protein content of the ration. The magnesium requirement of weaners and growing-finishing pigs is probably similar to that of piglets. It is difficult to determine precisely the exact dietary magnesium demand in farmed animals, yet magnesium intake of 0.04-0.09% (pregnancy) and 0.015-0.065% (lactation) had no effect on production efficiency (NRC 1998).

The magnesium content of maize-soybean diets ranges from 0.14 to 0.18%, and it is sufficient to meet the needs of pigs. However, according to some authors, the availability of magnesium from natural sources reaches 50-60%. Magnesium supplements are usually not fed to pigs, although numerous literary sources point to a beneficial influence of magnesium compounds on selected aspects of pig production. Supplemental magnesium may positively affect the behavior of animals, decrease their stress sensitivity, and improve pork quality by enhancing meat color, reducing drip loss and increasing acidity (DUGAN et al. 2004).

THE EFFECTS OF MAGNESIUM ON MEAT QUALITY

As a result of stress during transport and slaughter, glycogen is converted into lactic acid and the pH of meat decreases, leading to the occurrence of PSE meat defects. Magnesium inhibits stress-induced glycolysis, thus improving meat quality (APPLE et al. 2000, OTTEN et al. 1992).

The addition of magnesium to finisher diets decreases the blood levels of cortisol and catecholamines in transported pigs, and it helps calm the excited animals (HEUGTEN, FREDERICK 2004, KUHN et al. 1981).

D'SOUZA (1998) demonstrated that magnesium contained in feed reduced the plasma levels of the stress hormones norepinephrine and epinephrine. Plasma magnesium concentrations were higher in highly stressed animals than in those subjected to minimal pre-slaughter stress.

Early post-mortem changes in the muscles include pH decline. Under natural conditions, the ultimate pH is reached upon the completion of glycogenolysis, within the first 24 hours post mortem. The ultimate pH of normal muscles is 5.3-5.7, and the critical pH value determining the suitability of meat for storage is 5.4. Fast acidification during glycogenolysis (pH decline below 5.4) contributes to the development of PSE meat characterized by a low water-holding capacity, a pale color and low protein solubility. The occurrence of PSE defects is related to the fast rate of post-mortem glycogenolysis in the muscles. Too slow glycogenolysis and glycogen depletion may produce DFD meat (VAN DE PERRE et al. 2010).

Organic magnesium supplementation (Bioplex-Mg) has been found to reduce the incidence of PSE meat from 50 to 15% carcasses. The studied animals received 1.6 g elemental magnesium daily, for only two days before slaughter (COLE, CLOSE 2005).

According to reference data, supplemental magnesium decreases drip loss and improves meat color. Various effects of magnesium on the glycogen and lactate content of meat and post-mortem pH have been reported (Apple et al. 2000, D'Souza et al. 1999). In a study by Cole and Close (2005), short-term administration of organic magnesium (Bioplex-Mg) to animals reduced drip loss (from 6.6 to 3.6%) and improved meat color. Magnesium may have a beneficial influence on meat quality by decreasing drip loss (-0.53%) and the incidence of PSE meat (Dugan et al. 2004, Schaefer et al. 1993, D'Souza et al. 1998, 1999).

Schaefer et al. (1993) demonstrated that magnesium had no effect on the color, texture and pH_{45} of pork (the animals were supplemented daily with 40 g magnesium aspartate product containing 1.3% magnesium aspartate). The same magnesium compound applied at a 64-fold higher dose supported an improvement in meat color and water-binding capacity, and reduced the incidence of PSE meat (Duga et al. 2004, D'Souza et al. 1998, 1999, Schaefer et al. 1993).

Similar observations were made by Hamilton et al. (2002). Drip loss in meat from pigs fed magnesium-supplemented diets decreased in one experiment, but not in all groups. Reduced drip loss was noted when the animals were supplemented with magnesium for two or five days, but it was not observed when pigs were received the supplement for three days. Magnesium exerted a more stable effect on pork color than on drip loss (Apple et al. 2000, 2001).

Hamilton et al. (2003) studied the effect of magnesium propionate, magnesium sulfate and magnesium proteinate added to diets for finishing pigs on meat color stability. Meat from pigs fed magnesium propionate had higher values of color lightness, redness and yellowness, compared with meat from animals receiving magnesium sulfate and magnesium proteinate. Magnesium sulfate was found to improve color stability.

D'Souza et al. (1998, 1999 and 2000) reported decreased drip loss, good stability of meat color and pH when magnesium from magnesium aspartate, magnesium sulfate or magnesium chloride was supplemented at 1.6 or 3.2 g day^{-1} for two to five days before slaughter. The beneficial influence of magnesium on meat quality due to decreased drip loss and improved color has been also described by other authors (Dugan et al. 2004).

Apple et al. (2002) demonstrated that supplemental magnesium inhibited lipid oxidation in meat during storage. However, the benefits of magnesium supplementation are not always observed, and the positive effects of magnesium are often questioned. In an experiment by Guo et al. (2003), the inclusion of magnesium proteinate or magnesium oxide (0.5, 1.0 or 2.0 g kg^{-1} feed) in poultry diets contributed to the oxidative stability of the liver. Magnesium proteinate was found to be more effective than magnesium oxide (Guo et al. 2003).

The efficiency of magnesium absorption is significantly affected by stunning method. Electrical stunning causes the greatest stress, which is why carbon dioxide stunning is more advantageous. In the USA, heavy-weight pigs are stunned using electric current. The favorable effect of magnesium supplementation is less evident in Austria, where the slaughter weight of pigs is lower and the animals are stunned with carbon dioxide (HEUGTEN, FREDERICK 2004).

Shortening the duration of exposure to carbon dioxide or electric current and the time between stunning and bleeding prevents the released stress hormones and metabolites from reaching skeletal muscles, thus reducing the incidence of PSE meat even by 50% (KOĆWIN-PODSIADŁA, KRZĘCIO 2005).

Most of the authors cited above reported that supplemental magnesium had no effect on production results even if applied at nearly 10 g/animal/day.

Magnesium supplementation is a relatively inexpensive method of improving pork quality since magnesium supplements are economical and can be administered over short periods of time (several days). Most data point to the benefits of short-term magnesium supplementation (1-5 days) with regard to meat quality traits, whereas the information on long-term effects of magnesium use in pig nutrition is scarce. The use of selected magnesium compounds improving the quality of pelleted feed (magnesium-mica – 8% Mg) in the amount of 1.25 or 2.5% over the entire feeding period may have a beneficial influence on carcass characteristics and meat quality, with no adverse effects on productivity (APPLE et al. 2000).

The above relationships have also been observed in other studies (MAXWELL et al. 1999, WATSON et al. 1999). The findings of some authors do not confirm the benefits of magnesium-mica application during pig fattening (APPLE 1999), but it should be remembered that pigs not always respond to short-term magnesium administration, either. This suggests that the effectiveness of magnesium supplementation is determined by a variety of factors, in particular the stress sensitivity of pigs and stress levels during the experiment.

Irrespective of some inconclusive research results, it seems that both short-term and long-term magnesium supplementation has a positive effect on pork quality. Magnesium is usually applied at 2 to 4 g/animal/day or 1 to 2 g kg^{-1} feed. Animal diets can be supplemented with organic (proteinate, aspartate) or inorganic (oxide, sulfate, chloride, phosphate) magnesium. If magnesium is to be used over a long period of time, a good choice is magnesium phosphate, which provides a combination of magnesium and highly available phosphorus (13.5%). In contrast to some other magnesium sources, magnesium phosphate has no laxative effect.

The application of magnesium through feed for brief periods before slaughter may pose certain difficulties (the need to produce a special feed mix, pre-slaughter fasting). A good solution is to add magnesium to drinking water. Adding 600 mg magnesium per liter of water for two days before slaughter has been found to be most effective (FREDERICK et al. 2004, 2006). In the cited studies, the magnesium compound added to drinking water offered to animals was magnesium sulfate. Both the dose and duration of magnesium supplementation are important considerations as long-term magnesium administration through drinking water may have a prooxidative effect.

SUMMARY AND CONCLUSIONS

Many efforts are being made to improve pork products so that they meet consumer expectations regarding quality and nutritive value. Pig nutritional programs, including an adequate dietary supply of micronutrients and macronutrients, may have a significant effect on pork quality. Magnesium is a mineral involved in numerous vital functions in the body. Since the magnesium content of standard diets satisfies the needs of animals, pigs are usually not provided with supplemental magnesium. However, research results show that magnesium supplementation positively affects carcass traits and meat quality, and decreases the stress sensitivity of pigs. Therefore, application of magnesium through feed or drinking water at the final stage of fattening or several days before slaughter may contribute to improving pork quality.

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