

Identification of key meat quality parameters

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ABSTRACT

Objective: To analyze and synthesize the scientific literature related to the main physicochemical and technological parameters that determine meat quality, particularly pH, water-holding capacity (WHC), antioxidant activity, color, and texture.

Design/Methodology/Approach: A narrative review of scientific literature published in indexed journals, specialized books, and technical documents related to meat science and technology was conducted. Studies focusing on post mortem biochemical mechanisms and their influence on quality attributes were selected.

Results: The literature indicates that post mortem pH is a determining factor in protein structure and water-holding capacity, directly influencing texture and color. WHC is closely associated with myofibrillar spacing and the structural state of muscle proteins. Likewise, antioxidant activity plays a key role in oxidative stability, affecting color preservation and sensory profile. Together, these parameters interact dynamically and determine the technological and commercial quality of meat.

Limitations/Implications of the Study: Variability in production systems, management practices, genetics, and post mortem conditions makes direct comparison among studies difficult. Nevertheless, integrating these parameters provides a comprehensive understanding of the factors influencing meat quality and guides future research toward technological improvement strategies.

Findings/Conclusions: Meat quality results from complex biochemical and structural interactions occurring during the post mortem period. Understanding parameters such as pH, WHC, antioxidant activity, color, and texture is essential to optimize production and processing systems, as well as to ensure product stability and overall quality.

Keywords: Quality attributes, meat, physicochemical quality, meat science.

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INTRODUCTION

Meat is a fundamental source of essential nutrients due to its high digestibility and its content of high biological value proteins, heme iron, B-complex vitamins, and minerals such



as zinc and selenium. Its nutritional and functional quality depends on a complex chemical composition that may vary according to intrinsic factors, such as species, age, muscle fiber type, and metabolism, as well as extrinsic factors related to the production system, pre-slaughter handling, processing, and storage. These elements influence postmortem biochemical changes that determine key attributes such as pH, water-holding capacity, color, texture, and oxidative stability. Consequently, variations in these parameters affect not only the nutritional value and shelf life of the product, but also its technological quality and consumer acceptance (Lawrie, 1998).

Among the meats of greatest productive and commercial relevance, pork stands out due to its widespread global consumption, driven by its production efficiency, culinary versatility, and availability across different production systems. The growing market demand is focused not only on volume but also on the overall quality of the product. In this context, both consumers and the industry require meat that is not only safe from a sanitary standpoint and nutritionally adequate, but also exhibits optimal technological and sensory attributes, such as attractive appearance, uniform color, adequate water-holding capacity, tenderness, juiciness, and palatability (Eusse, 2009). These factors directly influence consumer acceptance and the competitiveness of the product within increasingly demanding agri-food supply chains.

pH in meat

The postmortem decline in pH is closely influenced by the predominant type of muscle fibers and by the level of physical activity of the animal prior to slaughter. Muscles with a higher proportion of fast-twitch fibers (type II or white fibers), characterized by predominantly glycolytic metabolism, generally have greater glycogen reserves and, consequently, produce more lactic acid after slaughter, reaching ultimate pH values close to 5.5. In contrast, muscles with a predominance of slow-twitch fibers (type I or red fibers), associated with oxidative metabolism and higher myoglobin content, tend to exhibit higher ultimate pH values, generally above 6.0 (Garrido, 2005).

Likewise, the degree of physical exertion before slaughter can modify muscle energy reserves. When the animal undergoes intense activity or prolonged stress, partial or complete depletion of glycogen occurs, limiting lactic acid production during postmortem glycolysis and leading to higher pH values (Dransfield, 1994). These variations in pH behavior directly influence key technological attributes such as water-holding capacity, color, and meat texture.

The decline in ultimate pH is closely associated with the accumulation of lactic acid in muscle tissue, resulting from anaerobic glycolysis that occurs after the interruption of oxygen supply following slaughter. During this process, muscle glycogen is degraded to generate energy in the form of ATP, leading to progressive lactic acid production and intracellular acidification. Both the rate of pH decline and the ultimate pH value are critical determinants of meat quality, as they directly influence protein denaturation, the structural integrity of myofibrils, and the stability of muscle pigments. Consequently, postmortem pH behavior affects essential properties such as color, texture, water-holding capacity, and technological yield. Alterations in this process may result in quality defects such as PSE

(pale, soft, exudative) or DFD meat, which negatively impact consumer acceptance and the industrial functionality of the product. When pH declines rapidly during the first hours postmortem, reaching values below 6.0 while muscle temperature remains high, or when the ultimate pH falls below 5.6, the meat may develop characteristics associated with the PSE condition (pale, soft, exudative). This phenomenon occurs as a result of accelerated glycolysis and excessive lactic acid accumulation, leading to denaturation of myofibrillar and sarcoplasmic proteins, reduced water-holding capacity, and color alterations due to changes in light scattering within the muscle tissue. The occurrence of PSE meat is closely linked to stress factors affecting the animal prior to slaughter, such as high environmental temperatures, improper handling, prolonged transport, overcrowding, or inadequate stunning methods. In addition, genetic components may predispose certain animals to a more intense metabolic response to stress. These conditions not only compromise the sensory and technological quality of the product but also generate significant economic losses in the meat industry (Bendall & Swatland, 1998; Ledward, 1992).

Water-holding capacity

According to Rosenfold & Andersen (2003), water-holding capacity (WHC) is a technological attribute highly sensitive to multiple pre- and post-slaughter factors. Among the most relevant is the stunning system used. Electrical stimulation can accelerate postmortem glycolysis, leading to a more rapid pH decline while muscle temperature remains elevated, thereby promoting protein denaturation and, consequently, lower WHC compared to methods such as CO₂ stunning, which tend to induce more gradual metabolic changes. Dietary supplementation with vitamin E has also shown positive effects on cellular membrane stability and reduction of oxidative damage, contributing to improved water retention in pork. Pre-slaughter fasting may influence muscle glycogen reserves; a moderate reduction in these reserves can increase ultimate pH at 24 hours postmortem, favoring WHC, although excessive depletion may lead to DFD-like conditions. Furthermore, carcass chilling conditions play a decisive role. Excessively rapid chilling, particularly when the muscle retains high energy levels, can induce cold shortening, altering myofibrillar structure and negatively affecting water-holding capacity. Overall, these factors demonstrate that WHC does not depend on a single mechanism, but rather on the complex interaction between postmortem metabolism, structural integrity of proteins, and technological conditions applied during processing.

All these factors, associated with the occurrence of PSE or DFD meat and with alterations in postmortem metabolism, decisively influence not only WHC, but also other fundamental quality attributes such as ultimate pH, color, and texture. Changes in the rate of glycolysis, glycogen availability, and muscle temperature affect the structure and functionality of myofibrillar proteins, directly impacting the stability of muscle tissue. In this context, PSE meat is characterized by a rapid decline in pH while muscle temperature remains elevated, leading to protein denaturation and a marked reduction in WHC, resulting in greater exudative losses. In contrast, DFD meat exhibits a high ultimate pH due to prior glycogen depletion, which promotes greater water retention and a darker, firmer appearance (Hoffman, 1987; Warner *et al.*, 2009). These differences affect not

only technological yield and shelf life, but also sensory perception and the commercial acceptance of the product.

Variations in WHC are primarily explained by changes in the spacing of myofibrillar filaments, which are closely related to modifications in the electrical charge and structural conformation of myofibrillar proteins, particularly myosin and actin. When the pH approaches the isoelectric point of these proteins, electrostatic repulsion between filaments decreases, reducing the intermyofibrillar space and limiting the muscle's ability to retain water. Additionally, contraction or expansion of muscle fibers alters the volume of intracellular and extracellular compartments, promoting the movement of water toward the extracellular space and eventually its loss through exudation. These structural changes explain why small variations in pH and in the physical state of proteins can generate significant differences in juiciness, yield, and the technological quality of meat (Offer & Knight, 1998).

Water activity

Water activity (*aw*) influences the different chemical reactions occurring in the product, as well as the survival and resistance of microorganisms; therefore, *aw* is a fundamental parameter for food preservation. Reducing water activity improves the shelf life and safety of meat products, as lower *aw* levels limit the growth of microorganisms responsible for spoilage and foodborne illness. To prevent microbial proliferation, various preservation methods such as salting, freeze-drying, and others are applied. These techniques increase the osmotic pressure within the food matrix, which effectively reduces water activity (Zigerlig, 2008).

Antioxidant activity

In meat products, oxidation represents one of the primary mechanisms of deterioration during storage. Lipid oxidation leads to the formation of secondary compounds such as aldehydes, ketones, and alcohols, which are responsible for rancidity, off-odors, and flavor loss (Falowo *et al.*, 2014; Min & Ahn, 2005). Meanwhile, protein oxidation can cause structural modifications in myofibrillar and sarcoplasmic proteins, affecting attributes such as texture, color, and water-holding capacity, in addition to reducing nutritional value and shortening shelf life (Lund *et al.*, 2011).

In the case of wild boar meat, greater physical activity and a natural diet influence muscle composition. It generally exhibits higher concentrations of myoglobin and heme iron, as well as a greater proportion of polyunsaturated fatty acids (PUFAs). These factors may increase susceptibility to oxidation (Wood *et al.*, 2004; Min & Ahn, 2005), since iron acts as a catalyst in pro-oxidative reactions and PUFAs are more prone to free radical attack. Nevertheless, a diet based on natural resources may provide phenolic compounds and other endogenous antioxidants that could partially counteract these oxidative processes (Descalzo & Sancho, 2008; Falowo *et al.*, 2014).

Studies evaluating indicators such as thiobarbituric acid reactive substances (TBARS), total antioxidant capacity, or oxidative stability are still limited, making it difficult to establish definitive conclusions (Huang *et al.*, 2019). This knowledge gap highlights the

need for systematic research to better understand the oxidative behavior of both species and its impact on meat quality and shelf life (Huang *et al.*, 2019).

Texture

Texture is one of the most relevant sensory attributes in meat quality, as it directly influences the perception of tenderness and consumer acceptance. Several studies indicate that the production system and the animal's level of physical activity play a determining role in the mechanical properties of muscle. Graziotti *et al.* (2000) and Bote *et al.* (2000) report that in semi-extensive or outdoor production systems, increased physical activity promotes greater firmness or toughness of the meat, mainly associated with a higher proportion of type IIA muscle fibers, which exhibit intermediate characteristics between oxidative and glycolytic fibers.

On the other hand, Bosselmann *et al.* (1995) point out that collagen is the main component of intramuscular connective tissue and plays a fundamental role in determining meat texture. The total amount of collagen, its solubility, and its structural characteristics are closely related to the animal's age and physiological development (Fang *et al.*, 1999). As the animal ages, modifications occur in the predominant type of collagen along with a progressive increase in the number and stability of intermolecular cross-links. These cross-links, especially those of a non-reducible nature, increase thermal resistance and reduce collagen solubility during cooking, resulting in greater rigidity of muscle tissue and, consequently, tougher meat. Moreover, the more developed connective tissue in animals with high physical activity may intensify this effect.

Color

Color is one of the most important attributes in the evaluation of meat quality, as it constitutes the primary visual criterion influencing consumer purchasing decisions. This attribute is mainly due to the presence of myoglobin, a water-soluble sarcoplasmic protein whose physiological function is to store and facilitate oxygen transport in living muscle. The concentration of myoglobin in muscle tissue is determined by several factors, including species, animal age, level of physical activity, and the predominant muscle fiber type (Livingston & Brown, 1981).

From a chemical perspective, color also depends on the oxidation state of the iron present in the myoglobin molecule. The most relevant forms are deoxymyoglobin (purplish-red color), oxymyoglobin (bright red), and metmyoglobin (brown), whose proportions vary depending on oxygen availability, pH, temperature, and the degree of oxidation. In fresh pork, the characteristic color ranges from pink to light red tones, generally with a uniform appearance within each muscle (García, 2003).

A darker appearance may be associated with various factors, such as higher myoglobin concentration in older animals, greater physiological activity of the muscle (*e.g.*, flexor or extensor muscles with a predominance of oxidative fibers), reduced oxygen penetration at the surface, surface dehydration, microbial contamination, or the presence of the DFD (dark, firm, dry) condition. In contrast, excessively pale meat may be related to the PSE (pale, soft, exudative) condition.

In commercial terms, color is a key indicator of freshness and perceived quality. The bright red tone associated with oxymyoglobin is generally considered desirable by consumers, whereas brownish or excessively dark shades may lead to rejection. In the case of wild boar, the higher myoglobin content derived from greater physical activity may confer a more intense and darker coloration compared to domestic pork, representing both a distinctive characteristic and a potential challenge in terms of acceptance in conventional markets.

Table 1 provides a concise comparison of the main physicochemical, technological, and nutritional parameters of wild boar and domestic pork, based on representative values reported in the scientific literature. The reported ranges reflect variations attributable to differences in analytical methods, type of cut, and pre- and postmortem handling conditions.

Table 1. Comparison of physicochemical, technological, and nutritional parameters between wild boar and domestic pork.

Parameter	Wild Boar Meat (<i>S. scrofa scrofa</i>)	Domestic Pork (<i>S. scrofa domesticus</i>)	Impact/Significance
Ultimate postmortem pH	5.8-6.3 (higher and more variable values)	5.5-5.8 (typical in controlled systems)	Higher pH favors firmness and water-holding capacity; greater variability increases product heterogeneity
Water-holding capacity (WHC)	Moderate-high (depends on pH and handling)	High (more consistent)	Affects juiciness and industrial yield
Water activity (aw)	0.98-0.99 (fresh)	0.98-0.99 (fresh)	Similar values; refrigeration control is critical
Color - L* (lightness)	30-36 (darker)	38-45 (lighter)	Darker meat is associated with wild/game or gourmet products
Color - a* (red)	18-22 (more intense)	14-18	Higher intensity may indicate higher myoglobin levels.
Texture-Shear force (Newtons)	30-45 (higher)	25-35	Related to collagen content and prior physical activity
Intramuscular fat (%)	1.5-3.0 (lower)	2.5-5.5 (higher)	Influences flavor, juiciness, and lipid profile
Total protein (%)	21-24 (higher)	19-22	Leaner meats tend to have a higher proportion of protein
PUFA/SFA ratio	0.45-0.65 (more favorable)	0.30-0.45	Nutritional indicator; higher values are considered beneficial.
n-6/n-3 ratio	4:1-7:1 (more balanced)	8:1-12:1	Lower ratios are associated with nutritional benefits.
TBARS (mg MDA/kg)	0.3-0.6 (variable)	0.2-0.5	Higher values may indicate greater lipid oxidation.
Myoglobin content (mg/100 g)	2.5-3.5 (higher)	1.8-2.8	Influences color intensity and susceptibility to oxidation.
Total collagen (%)	1.8-2.3 (higher)	1.2-1.8	Influences firmness and tenderness.

CONCLUSION

Meat quality is determined by a complex interaction of biochemical and structural processes that develop primarily during the postmortem period. pH regulates the stability and organization of muscle proteins, directly influencing water-holding capacity, texture, and color. In turn, water-holding capacity is closely related to the structural state of myofibrils and serves as a key indicator of color, nutritional value, and product shelf life. Overall, these parameters do not act independently but rather form an interdependent system that defines the final properties of meat. Understanding these mechanisms is essential to optimize production and processing practices, as well as to ensure meat products with greater stability and quality.

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