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Identification of influence factors on the quality and shelf life of fresh meat throughout the supply chain

Antonia Albrecht[1]
Lucas Correa Dresch[2]
[1]Institute of Animal Sciences, University of Bonn, Bonn, Deutschland

Abstract

Due to the industrialization and globalization of food production, food supply chains became increasingly complex, which led to a multitude of steps that products must pass during production, processing and distribution. At the same time, the quality standards and requirements for shelf life were raised in order to allow for the most efficient delivery and exploitation of the sales period of fresh products, especially for meat. During the supply, meat is exposed to several environments from farm to fork which might affect the quality and shelf life of the good. This work aims at the identification of the most important influence factors based on a literature review. First, the quality connotation of meat is defined and different aspects of meat quality are analyzed. Second, freshness and the spoilage process of fresh meat are characterized. Then, four main categories of factors influencing quality and shelf life of meatare identified, namely animal-specific, product-specific, process-specific and environmental factors. The impact of these factors is discussed by means of examples as well as graphs based on the literature review. The results are summed up in the conclusion leading to an outlook which points to future research prospects and the actual lack of investigations.

Keywords: supply chain management, fresh food, food distribution, from farm to fork

Introduction

The supply chain of fresh food is comprised of a complex set of processes that ensure quality and safety of the products, and at the same time maintain a sustainable, environmentally friendly production [1], [2]. There are several different parameters to be controlled, observed and communicated from production until the product reaches the final consumer [3], [4], [5]. In the case of the fresh meat industry, the requirements for an effective quality control over the supply chain and all its processes have increased in complexity over the last decades. Especially because several intrinsic properties can influence the quality of the final product [6], [7]. Additionally, Schulze-Ehlers and Anders [7] showed that the production focus of the meat industry tends to overlook the sensory quality of the final product and this can lead to variations in quality at the retail level.

As the food market outgrew local markets, the food industry shifted from single protagonists to supply chains; organizations, practitioners, consultants, and academics recognized that only enhancing performance throughout in-house practices within their industry is not sufficient [8]. The effective quality management of fresh food products, like meat, require an information exchange and cooperation between actors of the supply chain [4], [9]. In this sense, Juan Ding et al. [10] argue that a meat supply chain should focus on cooperation, customer demands, information sharing, information quality, and lean systems. By focusing on these aspects, the authors imply that the meat industry would increase the efficiency of production, improve the quality of the end product, and also better satisfy the customers. So, for a saturated market like the meat industry, it is clear that effective quality and safety control of the entire supply chain (along with assurances) can be a competitive advantage in industry and market [3], [4].

Another important requirement for the meat industry is an environmentally friendly and sustainable production [3], [6], [11]. However, Dohlen et al. [1] state that the lack of quality control and information exchange throughout meat supply chains can lead to an increase of food being wasted at the retail and consumer levels, increasing the environmental foot print of the whole sector. As the authors point out, not only are the products lost, but also large amounts of energy, water, and other resources used during production. So, to achieve a sustainable meat production, companies of the meat industry require a holistic view of the entire supply chain, from production to retail [2].

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This research intends to analyze and clarify the parameters that influence quality and shelf life of fresh meat products throughout the supply chain. First, meat quality will be defined and the characteristics and influences on the spoilage process of meat are elucidated. Next, it will present and define important parameters that should be considered when managing quality and safety of meat through the supply chain, from farm to fork, while elucidating at the same time their influence on production, marketability, and overall food waste.

Quality parameters and the spoilage process of fresh meat

A high quality of fresh food is crucial for the subsequent processing, stability, and salability of the products. With an increasing complexity of production and supply chains, the persistence of food quality and suitability for storage is an important requirement for every actor in the chain. As quality is one major driver for the purchase decision, there is an increasing sensitivity in the food production industry that competing on price alone is not sufficient to satisfy the refining consumer demands [12].

> The quality of food is defined as
>
> "the sum of value-determining properties of food, which define the degree of utilization for the prescribed purpose" [13].

Compared to other fresh products, meat is a product that is characterized by a particular complexity. The term meat quality comprises a set of different inherent characteristics. Meat quality is defined by the compositional quality, the functional quality, and the palatability [14], [15]. The compositional meat quality covers attributes such as the nutritional value, intramuscular fat, marbling, the lean-to-fat ratio, and the meat percentage. The functional quality of meat determines the ability for processing as well as storage and covers, among others, the oxidative stability, water holding capacity, the pH-value and muscle fiber shortening. Finally, meat quality is characterized by the palatability and eating quality which are specified by the appearance, the color, tenderness, flavor or juiciness of the product [14], [15]. Besides this general definition, the expectations linked to the term meat quality are differing between the supplying sector and the consumers [16]. Consumer concerns about ethical issues, animal welfare, health and product safety are rising [12], [17]. Additionally, the environmental impact, production characteristics and origin of the animals are increasingly integrated in the consumer perception of high-quality meat [18], [19].

Since fresh meat is no stable product but undergoes different biological, physicochemical and microbial activities, meat quality is a dynamic state which is continuously moving to reduced levels [20]. The degradation is variable between different meat types. While 'white meat', such as poultry, is very susceptible to deterioration, 'red meat' (e.g. pork, beef, lamb) shows a slower loss of quality [21]. Freshness describes the state of highest quality of the product directly after slaughter, without any signs of deterioration. With increasing time, the meat product will degrade in freshness until the product is spoiled.

> In general,
>
> "spoilage of food involves any change which renders food unacceptable for human consumption and may result from a variety of causes" [22].

Spoilage can have several causes, such as microbial growth and metabolism, insect harm, physical damage, the activity of intrinsic enzymes as well as chemical processes. For fresh meat, most quality changes during spoilage are initiated by three main mechanisms [23]. As a result of microbial activity, the major deteriorative changes which are perceived organoleptically by the consumer are off-odors, the release of metabolites, and the formation of slime on the meat surface. Second, lipid oxidation and color changes are biochemical processes related to the spoilage of meat [24]. Finally, autolytic enzymatic mechanisms change the appearance of the meat [23].

Fresh meat is distinguished by a high water content, a large amount of nutrients, and an optimal pH-value for the growth of microorganisms. The nutritional value may vary between different meat types, but is generally constituted by the main component water (70%), followed by protein (20%), lipids (<10%) and ash (1%) [25], [26], [27], [28]. Additionally, low molecular weight substances such as glucose, lactic acid, amino acids, nucleotides, and urea are main energy resources for metabolic activities [29], [30]. Due to its physicochemical properties and composition, fresh meat is very susceptible to spoilage processes with microorganisms being one major actor during deterioration [22], [31]. The intermediate and final products of microbial metabolism characterize the spoilage of meat by off-odors, discoloration or slime production [32], see table 1.

Table 1: Characteristics of sensory alteration for different products and the causing organisms - table based on Dainty and Mackey [33], Russell et al. [34], Borch et al. [35], Nychas et al. [32], Erkmen and Bozoglu [36], Iulietto et al. [37]; LAB: Lactic acid bacteria, AP: aerobical packaged, MAP: modified atmosphere packaged, VP: vacuum packaged

Alteration	Product	Aetiology
Off-Odors		
sweet, fruity	AP meats	*Pseudomonas* spp., *Pseudomonas fragi*
cheesy, rancid	AP meats	Enterobacteriaceae, *B. thermosphacta*, *Lactobacillus* spp.
	MAP meats	*B. thermosphacta*
putrid, sulphury	AP meats	*Pseudomonas* spp.
	VP meats	*Clostridium* spp., *Hafnia* spp.
	Ham	Enterobacteriaceae, *Proteus* spp.
H_2S	Cured meats	Enterobacteriaceae, *Vibrio* spp.
Ammonia	AP meats	*Pseudomonas* spp., *Alcaligenes* spp.
Cabbage odor	Bacon	*Protidencia* sp.
Sour, acid	Ham	LAB, *Alcaligenes* spp., *Micrococcus* spp., *Bacillus* spp.
	VP meats	LAB
Blown pack (H_2, CO_2)	VP meats	*Clostridium* spp., *Alcaligenes* spp., LAB
Discoloration		
H_2O_2 greening	Meats	*Weissella* spp., *Leuconostoc* spp., *Enterococcus* spp., *Lactobacillus* spp.
H_2S greening	VP meats	*Shewanella* spp.
Blue color	Fresh beef	*P. syncyanea*
red spots	Fresh beef	*Serratia marcescens*
Slime production		
Slime	Meats	*Pseudomonas* spp., *Lactobacillus* spp., *Enterococcus* spp.
	Fresh beef	*Acinetobacter* spp., *B. thermosphacta*, *Leuconostoc* spp.
Surface slime	Sausages	*Bacillus* spp., *Lactobacillus* spp., *Leuconostoc* spp.
	Dried meats	*Micrococcus* spp.
Ropy slime	VP cured meats	*Lactobacillus* spp., *Leuconostoc* spp.
Greenish slime	Meats	*Weissella viridescens*

The shelf life of meat or meat products is described as the time of storage until the product is spoiled. The point of spoilage is defined as

"a certain maximum acceptable bacterial level, or an unacceptable off-odor/off-flavor or appearance. The shelf-life depends on the numbers and types of microorganisms, mainly bacteria, initially present and their subsequent growth" [35].

During slaughter and processing, fresh meat is contaminated with microorganisms emerging from animal microbiota as well as microorganisms of human or environmental origin. The bacteria are transferred to the product via contaminated machines, surfaces and the aerosols in the slaughterhouse [38], [39], [40], [41]. Furthermore, the diversity and extent of microbial contamination is also dependent on animal health and husbandry characteristics. The microflora colonizing meat covers a variety of species, connected to the predominant microflora in slaughter and processing facilities [40], [41]. The initial bacterial flora on meat comprises for example *Pseudomonas* spp., lactic acid bacteria, coryneform bacteria, *Bacillus* spp., *Flavobacterium* spp. and *Brochothrix* spp. [30], [35], [40], [42]. Besides, the presence of pathogenic bacteria such as *Salmonella* spp., *Listeria* ssp., *Campylobacter* spp., *Escherichia coli* or *Staphylococcus aureus* can lead to safety issues in the meat supply chain [40], [43], [44]. After the initial colonization of the meat, only a small fraction of microorganisms will multiply [24], [32]. As little as 10% of the initial microflora is able to grow at refrigeration temperatures [35]. Thus, especially psychrophilic bacteria succeed to compete against others and lead to the deterioration of the final product. These organisms form the microbial 'spoilage association' and are determined by a set of different parameters [38], [45].

For the growth potential of specific microorganisms on the product, Mossel [38] defined the **intrinsic**, **extrinsic** and **processing factors** as major impact factors. Additionally, the **implicit factors** combine all factors caused by the development of microorganisms, their interaction, competition, symbiosis as well as the effect of their metabolites. On a particular product, the specific spoilage organism (SSO) is the microorganism which grows dominant and provokes the changes leading to sensory rejection [45].

By knowing a few physical and chemical properties of the food, the prediction of the SSO and their growth is possible [45]. For this purpose, predictive microbiology is a powerful tool to calculate the spoilage process and the remaining shelf life of the product at every step in the chain [46], [47]. Due to the fast generation time and metabolic characteristics, *Pseudomonas* spp. is the SSO for unprocessed, aerobically packaged meat products [33], [48]. Apart from the velocity of deterioration, the spoilage processes of fresh poultry and pork meat are very similar and can be calculated by using the same mathematical models [21], [48]. This is of particular interest, since these are the meat markets showing the highest growth on a global scale [49]. In Europe, the annual meat consumption is 76.5 kg/capita, with pork (34.2 kg/capita) and poultry (21.9 kg/capita) representing the major markets [18]. A low price of the product is still an important driver of consumer choices, but quality and sustainability are gaining in importance [49], [50]. On top, a high storage stability and long shelf life is required in increasingly complex supply chains and especially demanded by retailers. A long shelf life of the product offers the opportunity to reduce food waste and enhance the sustainability of meat supply chains. As a result, the meat industry forces an improvement of meat quality and shelf life while maintaining a highly efficient production with fast animal turnover rates.

Influence factors on meat quality and shelf life

The factors influencing meat quality and shelf life can be subdivided into four major categories. These factors comprise the complete value-added chain, from the animal production to consumption. Each of the four categories can be assigned to one essential element in the production or storage process, including also the properties of the product itself. The influence factors on meat quality and shelf life are subdivided into the **animal-specific factors**, **product-specific factors**, **process-specific factors** and **environmental factors** (figure 1).

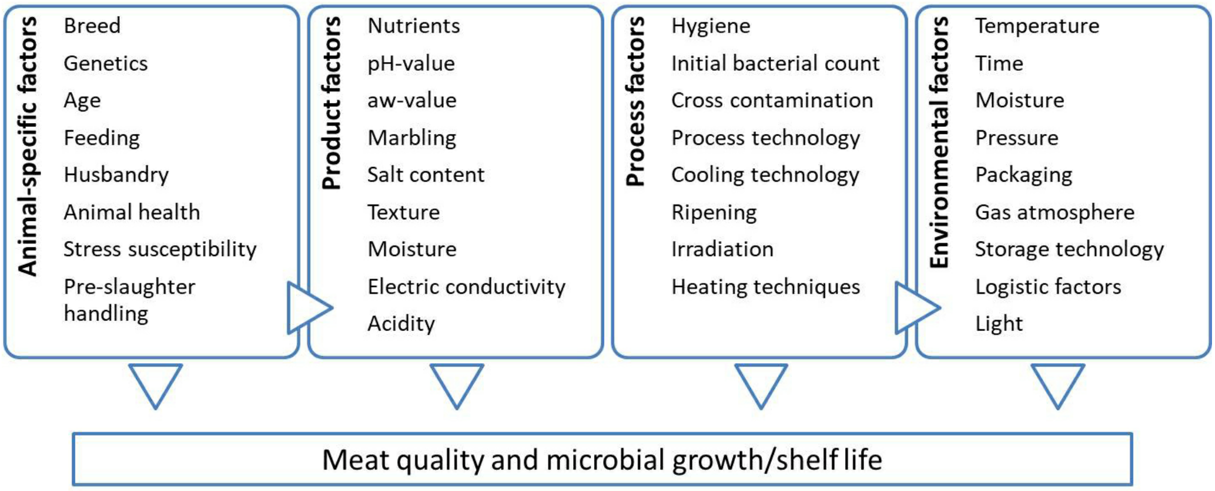


Figure 1: Influence factors on the quality and shelf life of meat (modified after Kreyenschmidt and Ibald[51])

The **animal-specific factors** focus on the first steps in the meat production. Even though the effects of genetic selection and adjusted diets are well-investigated, a comprehensive view on meat quality and shelf life from farm to fork is often not considered. The choice of breed has a crucial impact on the meat composition, the fat and protein content, and, as a result, the meat quality, as well as nutritional value [52]. For the last decades, genetic selection focused on a high growth velocity and enhanced meat yields in the commercial production of pork and poultry, but also led to meat failures such as White Striping or PSE meat [53], [54], [55]. The glycolytic potential of the muscle at slaughter and therefore the ultimate pH of the meat were shown to be highly heritable, which includes the potential of a targeted selection for particular meat quality parameters in combination with a satisfying meat yield [56], [57]. Additionally, particular production lines are very susceptible to pre-slaughter stress, which leads to a rapid initial pH decline and has direct implications for the subsequent technological processing capabilities and storage stability of the meat [58], [59], [60]. Genetic analyses have revealed some of the genes causing the characteristic traits of poultry and pork breeds. For pork, the halothene gene has been identified as an important driver for feed efficiency, carcass yield, meat quality, as well as the stress resistance of the animals [61], [62].

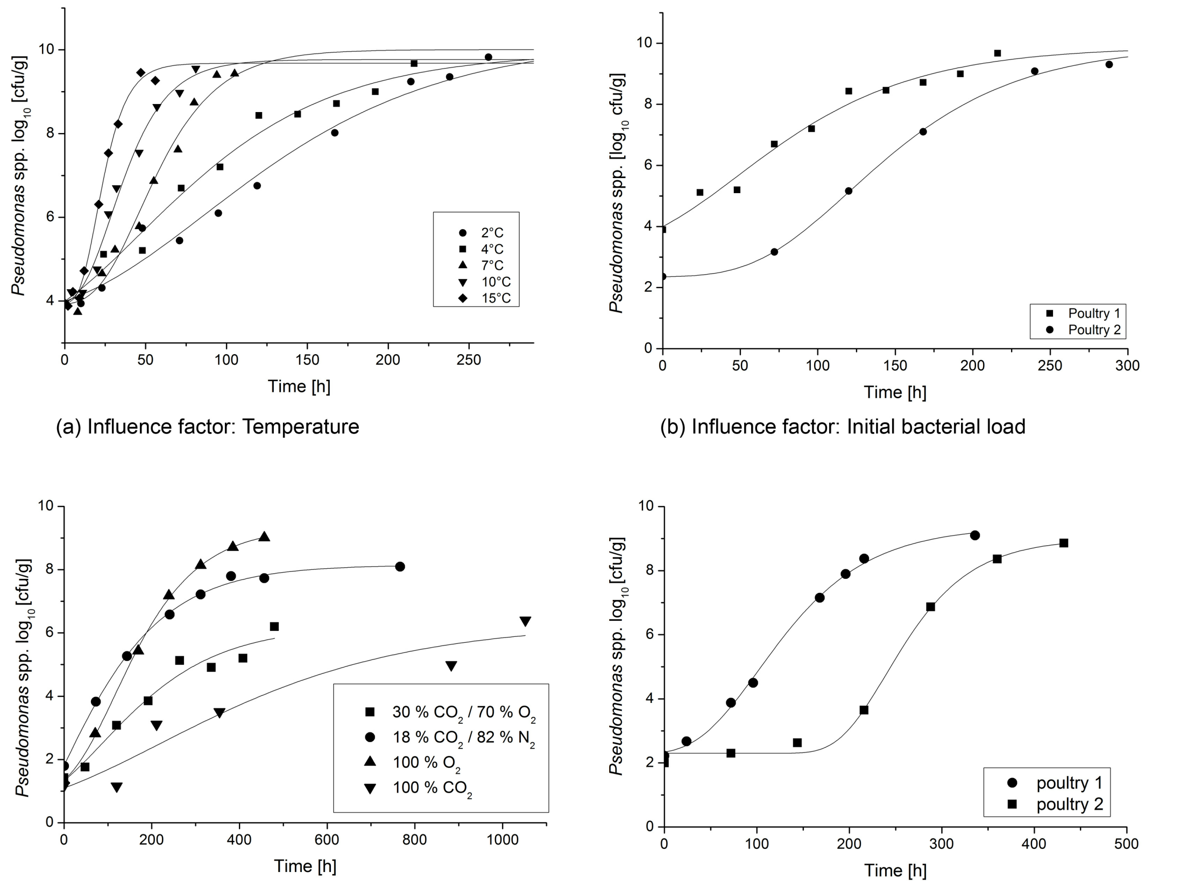
Next to pre-slaughter stress, the diet has a noticeable impact on the color and color stability of meat [63]. Also the leanness, carcass characteristics and fat composition are influenced by the nutrition [64]. Particular feeding strategies can be used to manipulate the muscle protein turnover, which is closely related to meat tenderness. Second, the glycolytic potential of the muscle can be regulated by the diet. The glycogen content is a measure for the muscle energy levels and determines the pH decline postmortem, the water-holding capacity, as well as the sensory properties of the meat [61], [65]. For the short-term regulation of the ultimate pH, advanced feeding strategies are applied before slaughter [66]. Furthermore, the supplementation of high levels of magnesium shortly before slaughter can reduce the occurrence of PSE meat during pork production [64].

The addition of essential amino acids in broiler diet, such as methionine or lysine, enhances performance parameters, meat yield and final body weight. Furthermore, the diet also regulates the final pH, drip loss and color of poultry meat [67], [68], [69].

The adjustment of the diet is often accompanied by a changed growth velocity and performance of the animals, which is also considered during the development of alternative husbandry systems. Organic production systems with outdoor access, enhanced roaming, adjusted nutrition and the targeted choice of slow growing races result in significant differences in certain meat quality parameters, compared to the conventional industrial meat production [70], [71], [72]. The opportunity of gaining outdoor access as well as the application of fast or slow growing races has a considerable influence on the palatability, more precisely the color or tenderness, and also on the nutritional value by affecting the fat or protein content of the meat [73]. Additionally, the complex impact of animal welfare on meat quality variation has been receiving more attention from producers and consumers [17], [74], [75]. Next to other authors, Klauke et al. [76] and Rocha et al. [77] showed the influence of animal health and welfare on performance, carcass composition and meat quality traits, especially in the first steps of production.

The **product-specific factors** comprise all intrinsic properties which are typical for fresh meat. The meat composition and the nutritional value influence the storage stability through the availability of nutrients and key substrates, such as glucose [29], [35]. Since meat is a heterogeneous food system with a complex microstructure, its texture and composition also has an impact on microbial growth. The access to nutrients is dependent on mass transport, concentration gradients and diffusion rates in the media [78], [79]. Due to contamination pathways and the access to gaseous compounds, microbial growth originates from the meat surface. Therefore, the structure and moisture of the meat surface significantly affect the colony expansion during the proliferation of microorganisms [79]. Besides moisture, also the water activity (a_w-value) is of significance for the metabolism, survival and reproduction of microorganisms on meat [80], [81]. The reduction of the water activity by drying, ripening or fermentation prolongs the shelf life. Increasing the salt content in meat is another technique to reduce the a_w-value and decelerate microbial growth. Moreover, adding sodium chloride affects the growth of microorganisms via increasing the osmotic pressure, reacting with alpha-amino groups or iron-containing compounds and blocking sulfhydryl groups, respectively [23].

The pH-value is one further product-specific factor with major importance for the growth rate of microorganisms [35], [33], [82]. After slaughter, the metabolic supply of the muscles collapses leading to an adjustment to anaerobic metabolic pathways. The metabolism of glycogen via pyruvate leads to an accumulation of lactic acid in the cells, which results in a decrease of the meat pH-value in the first 24h postmortem [23], [83]. These metabolic processes during rigor mortis transform the muscle of the animal into meat, a food product suitable for human consumption [23]. The final pH-value depends on the part of the carcass, the fat content, the pre-slaughter handling of the animal, as well as the cooling technology during processing [23], [35], [33]. Based on the glycolytic potential of the muscle, the pH-value is closely related to the color, the water-binding capacity and texture of the meat. Depending on the meat type, high pH levels (>6.0 for red meats) result in 'Dark', 'Firm' and 'Dry' (DFD) meat, which is caused by long-term stress and deficient pre-slaughter handling [84]. The high pH in DFD meat is related to an elevated water-binding capacity, a dark color and reduced shelf life. Consumers often reject DFD meat due to the appearance and bland taste [85]. An ultimate pH lower than normal leads to 'Pale', 'Soft' and 'Exudative' (PSE) meat, with remarkable consequences for processing and disposal [86]. Besides the stocking density, transportation time, and stress prior to slaughter, a few genetic markers have been identified, which can determine the susceptibility of the animal for PSE meat [54], [87].



(a) Influence factor: Temperature

(b) Influence factor: Initial bacterial load

(c) Influence factor: Atmosphere

(d) Influence factor: Different product origin and cooling technology, identic storage conditions

Figure 2: Influence factors on the quality and shelf life of fresh poultry meat (modified after Kreyenschmidt and Ibald [51])

The **process-specific factors** include influence factors within the slaughter and processing facilities. The education of employees, industrial hygiene, equipment, and the cleaning routines significantly affect the initial contamination of the product [38], [39], [40]. The level of carcass contamination is directly associated with the level of meat contamination, at which a dissemination of microorganisms over the product takes place during different processing steps [88]. Optimizing hygienic conditions can lead to a significant reduction of microbial contamination, resulting in a prolongation of the shelf life for fresh poultry filets by two days (figure 2.b, [21]). Furthermore, cooling technologies are critical for meat hygiene, safety and decelerating microbial growth [89]. The rate of chilling directly after slaughter, evisceration and processing significantly effects the muscle structure, pH decline and protein denaturation of the meat [23]. Thus, products processed with different cooling technologies can show varying microbial spoilage processes (figure 2.c). Several technological enhancements and food processing treatments have been developed for the preservation of food. For fresh meat, ionizing radiation has the potential to reduce the initial microbial population [90]. Even though **radiation preservation** is proved to increase storage stability of fresh food and a lot of research has been done to disprove possible health risks, it is not approved in all countries [91]. Heat steps during food processing are often interconnected for reducing the microbial counts in food [38]. Next to this physical treatment, further processing techniques, such as smoking, lead to a chemical preservation of fresh meat [38]. The applicability of physical and chemical treatments as well as the supplementation of additives are limited for fresh, unprocessed meat. Thus, enhanced hygiene management, cooling technology, ripening, process technology, and environmental factors build the foundation for high-quality products and long shelf life.

For the length of shelf life, the **environmental factors** are of major importance. They are determined by a set of different drivers referring mostly to the storage conditions of the meat. Intensive research efforts focused on the impact of environmental factors on fresh meat in order to control the cold chain and prolong the shelf life with advanced packaging technologies. The temperature is supposed to have the highest influence on the stability of meat products (figure 2.a). Due to its ability to accelerate microbial growth and metabolism as well as biochemical and physical processes, temperature has a crucial impact on the quality, safety and shelf life of meat [24], [32], [38]. Although the initial contamination of meat covers mesophilic and cold-tolerant species, only the latter, especially the psychotropic and psychrophilic bacteria, are found in the spoilage flora of chilled products [35], [83]. A further selection of the proliferating bacteria will result from the gaseous atmosphere [31], [38]. In aerobically packaged meat products, *Pseudomonas* spp. rapidly grows dominant during the competition with other spoilage bacteria [35], [33], [92]. The development of vacuum and **modified atmosphere packaging (MAP)** has derived advantage from the significant influence of the gaseous atmosphere on microorganisms (see figure 2.c, [35], [93]). The atmosphere of the packaging significantly affects the microbial composition, competition, and likewise the velocity of growth. For MAP, different levels of oxygen, carbon dioxide, nitrogen and inert gases affect the spoilage process leading to a shift of the SSO [35], [94].

For fresh poultry stored at 4°C, the shelf life can be prolonged from 100h (aerob) to 212h by using a 70% O_2-packaging [95]. Moreover, the presence of particular gases considerably influences meat quality and shelf life, for example with carbon dioxide by reducing the pH of meat and high oxygen levels by saving the fresh red color of meat [38], [33], [96]. The absence of oxygen in vacuum packages in combination with microbial activity and a continued respiratory activity of the meat tissue significantly reduces the oxygen content while the tension of carbon dioxide increases [33]. This affects, depending on time and pH, the predominant microorganisms as well as spoilage characteristics [31]. The highest prolongation of shelf life can be achieved by a specifically adjusted atmosphere with respect to the meat characteristics as well as storage conditions [93], [96]. Additionally, innovations in the field of active and intelligent packaging result in further prolongations of the shelf life and optimization of product handling along the meat supply chain [93], [97]. Beside temperature and packaging, the factors pressure, moisture, light and also the storage technology influence the quality and shelf life of meat [24].

Conclusion

As the meat market reached the saturation point in western countries, the requirements from consumers regarding high quality and sustainable products increased [49], [50]. Moreover, ethical concerns on animal welfare and health are important drivers for the purchase decision of the consumer [2], [12], [98], [99], [100], [101]. The challenge the meat industry faces today, to address the aforementioned issues, is how to efficiently produce affordable products with high-quality standards under the consideration of sustainability, animal welfare and health at the same time. The efforts of the production sector to satisfy these conflicting demands led to the establishment of different production systems and continuing improvements [6], [17], [102]. During the optimization of animal production, meat quality investigations mostly focus on carcass characteristics, quality traits, and palatability directly after slaughter. Even though the impact of animal-specific factors on pH, water-holding capacity and especially meat composition is well documented, comprehensive approaches from farm to fork are lacking. The storage capability of the end product is often not considered, even though typical meat quality parameters are known to have a striking impact on microbial growth and shelf life. The influence of animal-specific factors on meat quality is unquestionable, but how they affect the stability of quality or the shelf life of the product is poorly investigated.

Additionally, post-production quality control alone is not sufficient for a food company to stand out on the market as the quality control of fresh meat products requires the facilitation of real-time monitoring processes and intensive communication of relevant information between members of the supply chain [2], [6]. So, in order to ensure the safety and quality level of meat products, the supply chain management of fresh meat products requires information to be readily available and easily exchanged by all actors of the supply chain [4].

Thus, quality and safety schemes for meat products can be adjusted accordingly for a more effective control throughout the entire chain.

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Corresponding authors: Dr. Antonia Albrecht, University of Bonn, Institute of Animal Sciences, Katzenburgweg 7-9, 53115 Bonn, Deutschland, Phone: +49228732819, E-mail: a_albrecht@uni-bonn.de

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