Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2026-223

Review Article

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Nutritional Profile of Meat and the Biological, Environmental, and Processing Factors Affecting its Composition: A Review

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Received: December 14, 2025
Accepted: February 16, 2026
Published: February 20, 2026

Citation: Skoumpa S, Cunha-Neves A, Cleary J, Phelan D. 2026. Nutritional Profile of Meat and the Biological, Environmental, and Processing Factors Affecting its Composition: A Review. *J Food Chem Nanotechnol* 12(1): 17-32.

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Published by United Scientific Group

Abstract

This literature review focuses on the factors affecting nutritional value of meat and meat products. Between 2024 and 2025 there was an estimated meat production increase of 5,386 carcass weight equivalents worldwide. Meat is rich in essential nutrients, including fats, proteins, minerals, vitamins, and carotenoids. These nutrients are essential for the regulation of daily biochemical functions in the human body and their consumption at appropriate levels is essential for human survival. Animal feed provides essential nutrients for growth and development. Various production systems are used for animal raising, alongside different animal husbandry practices used to manage these systems. These systems vary depending on country regulations, animal types, breeds, and market demand. Consumer trends and preferences have shifted to more sustainable, traceable and health-oriented meat product choices, while price of meat products is also a factor of importance. The availability of organic and conventional meat products has had a preponderant mediatic and societal impact, while the distinction between conventional and organic meat products is evident on multiple labels on most retailers' shelves. This raises questions about the health, economic, and ethical benefits of choosing meat products from different origins. The social implications of choosing the origin of meat products are also subject to debate, such as the market's approach to advertising and labeling meat products and how consumers can be educated to evaluate the nutritional benefits of meat products.

Keywords

Meat, Nutritional value, Meat supply chain, Consumers

Introduction

Globally, meat is a basic element of everyday diet, with some exceptions throughout the world, highlighting regions where meat consumption is limited and where restrictions on animal slaughter exist [1]. According to data collected by the European Statistical Office in 2024, about 6,584.01 thousand tons of bovine and 21,091.62 thousand tons of pig meat were produced, while data on poultry, sheep and goats remain confidential [2]. In addition, global meat production in 2024 reached 378,145 carcass weight equivalents, of which around 39.7% attributed in poultry meat, around 33.1% attributed in pig meat and around 20.7% attributed in bovine meat [3]. Brazil came first in meat exports, while China was first in total meat, pig meat and chicken meat production worldwide for the year 2024 [3].

Animals must consume nutrients such as fats, proteins, carbohydrates, minerals, and vitamins to survive and perform biological functions. Their dietary intake corresponds to the energy required for internal biochemical processes, physical and kinetic movement, growth and repair of tissues. Humans also require nutrients in order to perform certain daily biological processes and functions [4]. Nu-

trients obtained from diet are essential for energy production in animals. Animals consume plants, which contain nutrients that pass through trophic networks (food chain) to animals and then humans.

Nutrients are classified into macronutrients and micronutrients. Macronutrients include carbohydrates, proteins and lipids [5], while micronutrients include vitamins, minerals and antioxidants [4, 6].

Macronutrients are required in larger quantities than micronutrients and are used in energy conversion, hormone production, molecule synthesis and metabolic regulation [5]. Micronutrients are essential compounds required in smaller amounts. They protect from oxidative stress, assist in gene transcription and are catalysts for enzymatic reactions [4, 6]. However, nutrient intake must be balanced, as both deficiency and excess can lead to severe chronic health issues [7]. Different feed types offer different nutritional advantages, drawbacks and final outcomes. Several factors, such as age, species, breed, and sex, can significantly influence in determining the required nutrient intakes. The aim of this review is to evaluate and compare data from studies assessing the multiple factors influencing meat nutritional composition. Numerous studies have examined the nutritional profile of meat and supply chain dynamics. This review synthesizes these findings, with the purpose of creating a coherent summary and highlighting unexplored areas.

Macronutrients

Meat is one of the most nutrient-rich food sources and has played a significant role in human evolution [8]. Meat provides water, carbohydrates, fats and proteins as macronutrients [9]. Muscles can grow at different rates at different animal development stages, which in turn affects composition (e.g., muscles that develop early and accumulate more fat will continue to do so in a certain age compared to other muscles that mature later) [10]. Meat composition depends on several factors, including species, breed, sex, age, diet, and production system [11]. Meat is typically sold as standard cuts corresponding to different muscles. The nutritional profile also strongly varies between these cuts, even in the same animal [11]. Carbohydrates are mainly present as glycogen in animal tissues, and their presence significantly affects on meat quality characteristics such as tenderness, texture, color, and water retention, raw meat products generally contain little to no carbohydrates [9]. Therefore, this review focuses on fat, protein, and water content.

Fats are compounds that are insoluble in water and are structural parts of cellular membranes [12]. They can be categorized into saturated fatty acids (SFA) and unsaturated fatty acids (UFA), with the latter further divided into monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) fatty acids [13]. Fats can be consumed in the form of triglycerides, cholesterol, and phospholipids, while certain fatty acids such as linoleic acid (C18:2n-6) and alpha-linolenic acids cannot be synthesized from the human body, therefore characterized as essential fatty acids [12]. Among fats, the ratio of omega-6 (n-6 including C18:2n-6 and arachidonic acid) and omega-3 (n-3 including alpha linolenic, eicosapentaenoic, and docosahexaenoic acid), otherwise symbolized as n-6:n-3, has been assessed for the various benefits it presents for the human body when it is low (prevention of diseases such as cancer, cardiovascular disease, type-2 diabetes and depression) [14]. On the contrary, when this ratio is high and dietary intake includes higher concentration of SFA, n-6 PUFA and cholesterol, there are increased risks for human health such as coronary heart disease, arteriosclerosis and even Alzheimer's disease [15-18]. Studies suggest that, for fatty acid intake from a food source to be considered safe, the recommended ratio between PUFA:SFA should be above 0.4 [19], while the previously mentioned n-6:n-3 ratio should be below 4 [20]. Other fatty acids, such as C18:0 and C18:2, play an important role in meat sensory characteristics such as firmness of fat tissue [19].

Proteins are the second most abundant component in vertebrate bodies after water and are structured by chains of amino acids [12]. Meat proteins and their building blocks, amino acids, are of high biological value for human consumption because the amino acid content in meat is similar to that of human muscles, while meat also contains essential amino acids that the human body cannot synthesize [21]. Wu [22] reported that amino acid content in meat is higher and more balanced than in plant-based foods. When it comes to the health benefits of adequate protein consumption, there are multiple categories of body functions which benefit from adequate and balanced amino acid consumption. Some of these functions' relation to fatty acid oxidation metabolism are listed below:

- Regulation of oxidation of fatty acids and glucose (i.e., metabolic enzyme synthesis) [23].
- Protection of cells and tissue from oxidative stress and inflammation (glutathione, taurine, glycine, proline, and hydroxyproline in balanced levels in human body) [24].
- Maintenance of healthy levels of thyroid hormones (product of tyrosine) [25].
- Storage of energy (as phosphocreatine) to ensure adequate muscular and neurological function (through creatine) [26].
- Transportation of long-chain fatty acids to mitochondria for β-oxidation and yield of acetyl-coenzyme A [27, 28].
- Inhibition of cytokines to ensure health of adipose tissue and regulation of food intake and behavior (through serotonin and melatonin, metabolites of tryptophan) [29].

Finally, the moisture content of meat typically ranges from 70 – 75%, with variations usually being observed in inverse correlation to fat content within the same meat tissue [21].

In terms of macronutrients, a distinction is typically observed between ruminant and monogastric animals, with ruminants demonstrating lower PUFA content in muscle due to PUFA biohydrogenation during ruminant digestion, while monogastric animals reach higher concentrations of PUFA and higher n-6 PUFA content in their muscle (resulting in high n-6:n-3 ratio) [30, 31].

According to the Food and Agriculture Organization of the United Nations [32] for the years 2023 and 2024 poul-

try, pig, and bovine meat were respectively first, second, and third in terms of global meat production. In addition, 90% of the world's poultry meat production can be attributed to chicken production. Therefore, this review focuses on the nutritional composition of these three meat types, even though we acknowledge that many other animals are regularly or occasionally consumed for their meat around the world. Table 1 summarizes the previously mentioned most important health benefits of macronutrient consumption for the human body.

Beef

Fat or intramuscular fat (IMF) in raw beef cuts has been shown to account for 1 - 8%, protein for 20 - 24%, moisture for 69 - 75% and ash for 1 - 1.2% of the total cut, while these percentages show variations depending on the cut, diet used, animal breed, sex and origin [33-39]. The proximate composition of beef has been evaluated extensively in literature. A United Kingdom (UK) study assessed the fatty acid content in steak muscle beef and pork and found that beef had lower total fat percent content, 18:2n-6 linoleic content and n-6:n-3 ratio than pork, while the higher in concentration fatty acids for both were palmitic acid (C16:0), stearic acid (C18:0) and oleic acid (C18:1n-9) [19, 40]. The presence of C16:0, C18:0 and C18:1n-9 as most abundant in beef is confirmed by further studies [41-43], while research has also shown high content of C18:2n-6 in beef [44]. As previously mentioned, n-6:n-3 ratio lower than 4 indicates benefits for human health, therefore, the difference observed in the study from Enser et al. [40] between beef (n-6:n-3 = 2.11) and pork (n-6:n-3 = 7.22) can signal beef as a healthier option for consumers compared to pork.

As discussed above, fat shows the greatest variation among macronutrients across studies (1 - 8%). This variation can be attributed to differences in age and diet, which influence fat deposition [45], but also to the fact that each breed has different fat compositions [46].

Beef also presents better amino acid content compared to other meat types, since it contains more branched-chain amino acids such as valine, leucine and isoleucine and amino acids that can cross the blood-brain barrier [22].

Pork

Pork shows similar nutritional composition to beef. The key difference between them, however, is the fact that pigs are monogastric while bovine are ruminants. This implies a significant effect of animal feed/diet on the fat content and fatty acid composition of pork meat [11]. Toldrá et al. [47] fed a mixture of barley, wheat, corn, and soya to a Landrace x large white pig crossbreed. They found a mean of moisture of around 75.6%, a protein proportion around 21.8% and a total lipid content around 2.86% in the longissimus dorsi muscle which corresponds to the pork loin cut. The IMF fatty acid composition showed the highest concentrations for C18:1, C16:0, C18:2 and C18:0 and a mean n-6:n-3 ratio of 16.64. Noticeably the n-6:n-3 ratio for pork is very high compared to previously mentioned results of the ratio for beef. These results are in accordance with a number of other publications, reviewed by Reig et al. [11], investigating the fatty acid composition of pork meat [40, 47-50]. The same review focused on different pig diets (barley and soya, tallow, barley, wheat and corn, standard feed, and acorn diets) and observed differences for the n-6:n-3 ratio, with the tallow diet noticeably resulting to the highest ratio [11]. Results from the Portuguese food information resource online database [51] presented nutritional value for different meat cuts, with pork chops containing the highest amount of total fat, MUFA, and PUFA (g/100 g) and pork loin containing the highest amount of protein.

Another important distinction of fat content in pork cuts is between the IMF (i.e., longissimus dorsi muscle) and the backfat of the pig. Research on the effects of genotype and dietary oil supplementation for pigs evaluated that longissimus dorsi muscle IMF ranged from 1.29 - 2.64% depending on the genotype [52]. In the same research, the effect of genotype on the fatty acid content of longissimus dorsi showed significant differences for C16:0, C18:0, C18:1, and C18:2, which were the most abundant fatty acids, and in n-6:n-3 ratio between the breeds, with no significant differences observed in backfat for these fatty acids. Different oil supplementation in feed showed significant differences for C18:1, C18:2, and n-6:n-3 ratio in both longissimus dorsi and backfat, with soybean supplementation resulting in the highest ratio and C18:1 concentration [52]. This highlights the importance of animal breed and diet on IMF composition.

Finally, protein in pork meat has been proven to range between 14 - 27% and moisture content between 49 - 71% depending on the cut (belly and ham loin) [53-55].

Chicken

Chicken is the most widely consumed meat worldwide; therefore, it can be assumed that its nutritional value impacts on the diet of more consumers than the other types of meat. Chicken is an important source of fat and protein in many cultures worldwide [56]. Nevertheless, as for previously mentioned meat types, chicken meat nutritional composition can

Table 1: Summary of macronutrient composition of beef, pork, and chicken meat and their main function in the human body.

Macronutrient	Function	Ref.
Fat	Structural part of cellular membranes plays an important role in sensory meat characteristics such as firmness of fat tissue	[12, 19]
n-6:n-3 MUFA ratio	When below 4 helps in prevention of diseases such as cancer, cardiovascular disease, type-2 diabetes, and depression	[14, 19, 20]
Protein	Regulation of oxidation of fatty acids and glucose, protection of cells and tissue from oxidative stress and inflammation, maintenance of healthy levels of thyroid hormones, storage of energy, transportation of long-chain fatty acids to mitochondria, and inhibition of cytokines	[23-29]
Moisture	Water is essential for survival, inverse correlation to fat content within the same meat tissue	[21]

vary depending on age, muscle cut (e.g., thigh, breast, and drumstick) and the animal feed the broilers receive as they develop [57] as well as their breed and sex [58].

Multiple studies have determined the macronutrient content in chicken meat, with fat ranging between 0.2 - 9%, protein between 17 - 25%, moisture content between 71 - 80% and ash between 0.3 - 4.4% [16, 59-64], with breast usually having higher protein and lower lipid content than drumstick. The effects of age, gender and breed on chicken nutritional composition have also been studied [59, 60, 62, 64]. Finally, the most abundant fatty acids in chicken breast, thigh and drumstick were the C16:0, C18:0, C18:1, and C18:2n-6 [59].

Chicken also appears to have lower levels of serum cholesterol in the dark meat parts (thigh and drumstick) compared to beef [65]. However, cholesterol has been found to be higher than beef and pork in a different study [21]. In the same study by de Almeida et al. [65], proximate composition of dark chicken meat was found around 77.49% moisture, around 18.83% protein and around 4.08% fat, while the concentrations of n-6 and n-3 PUFAs in chicken were also compared to their concentration in semimembranosus and biceps femoris beef cuts and were found significantly higher in chicken. The increased concentration of MUFA and PUFA (e.g. linolenic, C18:2n-6 and docosahexaenoic acid) in chicken, when compared to other meat species and especially ruminant meat, is further confirmed by Riovanto et al. [66].

In a study from da Silva et al. [67] protein content was found to be higher in free-range than industrial chicken thigh, while fat content was higher for industrial thigh and drumstick. This perfectly illustrates the effect that production systems can have on the meat product nutritive value. Thus, free-range broilers are expected to be more physically active, which typically results in higher protein content, especially in the leg muscles. Based on this information, consumers seeking higher protein intake in their diet should focus on free range chicken meat products, with free-range production system also often associated with more ethical raising practices and improved animal welfare. However, other parameters on nutritional value of meat products such as micronutrients should be considered in customer choices.

Micronutrients

As previously mentioned, micronutrients, including minerals and vitamins, are required in small quantities and their presence in adequate levels is essential for regulated function of the human body. Minerals account for approximately 5% of human dietary requirements [12]. Meat foods mentioned in this review can be classified according to their mammal (beef and pork) or avian (chicken) origin or according to their iron (Fe) concentrations, the latter of which would classify them as red meat (high Fe content) or white meat (low Fe content) [31].

Minerals assist in hormone and energy production, neurotransmission, contraction of muscles, digestion as well as pH, cholesterol and blood sugar regulation. Zinc (Zn) intervenes as a cofactor in more than 100 enzymatic reactions, Fe is essential in the prevention of anemia and selenium (Se) inhibits the toxicity of toxic metals such as mercury (Hg), cadmium (Cd), and lead (Pb) [68]. Fe plays an important role in oxygen transportation, energy production, enzyme synthesis, regulation of immune system and healthy brain development [69-71]. Sodium (Na) and potassium (K) are essential electrolytes used in maintenance of plasma volume and regulation of blood pressure respectively [72], while they also assist neuronal activities as the main contributors to the electrical potential difference between the axon and the extracellular environment of the neuron [73]. Copper (Cu) is an essential trace element in ensuring cardiovascular health, elasticity of lungs, healthy growth, neovascularization, neuroendocrine function and Fe metabolism [74]. Manganese (Mn) is an essential mineral that acts as a cofactor for metalloenzymes and cellular reactions (ornithine cycle, gluconeogenesis, eradication of oxygen free radicals, mucopolysaccharide synthesis, development of bones, digestion, reproduction antioxidant defense, production of energy, regulation of neuronal activity and response of immune system) [75]. Magnesium (Mg) and calcium (Ca) play an essential role in bone health and muscle motion, while Mg is also a cofactor for synthesis and activation of vitamin D [76, 77]. Minerals have an important effect on beef appearance and texture, since they have an immediate effect on meat tenderness and color [78].

On the other hand, vitamins are compounds which assist in DNA synthesis, neutralization of free radicals and macronutrient metabolism, while they can be separated into fat-soluble (vitamins A, D, E, and K) and water-soluble vitamins (vitamin B complex and vitamin C) [12].

Retinol (vitamin A), ascorbic acid (vitamin C) and α-tocopherol (vitamin E) operate as antioxidants against free radicals [79], while calciferol (vitamin D), alongside vitamin A help in maintenance of epithelial tissues and control of mineral deposition [80]. Vitamin D is essential for absorption and healthy level maintenance of Ca, whereas B-group vitamins are also of importance, with folate (vitamin B_9) assisting in nucleotide methylation and growth of tissue and cobalamin (vitamin B_{12}) being essential in DNA, RNA, and protein synthesis [70].

Thiamine (vitamin B_1) serves as a cofactor of many important enzymes related to the metabolism of carbohydrates and branched-chain amino acids [81]. Vitamin B_1 is essential for other cellular processes such as synthesis of nucleic acid precursors, myelin, and neurotransmitters, while it also assists in antioxidant defense [82]. Riboflavin (vitamin B_2, which includes multiple flavoproteins) is participating in synthesis of coenzyme A, Q_2 heme, pyridoxal 5-phosphate, and various hormones, while niacin (vitamin B_3) is a precursor for nicotinamide adenine dinucleotide (NAD) and NAD phosphate (NADP), both of which work as cofactors for reduction and oxidation reactions in the human body [81].

Meat is rich in micronutrients such as Fe, Se, Zn, and vitamin B_{12} [83]. However, it can also accumulate certain minerals that are harmful for human health even in small concentrations. Toxic heavy metals such as arsenic (As), Cd, Hg, Pb, and tin can enter the human body through the food chain. Their presence in food is often linked to environmental pollution, but these minerals can also be naturally present in high concentrations in certain environments. For example, the levels

of Cd in approximately 15% of Irish soil have been found to exceed the European Union (E.U.) regulation limit of 1 mg/kg, especially in counties Dublin, Meath, Kildare, Westmeath, North Tipperary, and Roscommon. These levels are not always attributed to environmental pollution but can sometimes originate from natural sources such as limestone [84]. Long-term exposure to heavy metals can lead to toxicity [85], with considerably negative consequences on human liver, kidneys, thyroid, colon, bladder, and rectum [86]. Heavy metals in animals are mostly accumulated in tissues such as liver and kidneys [84, 87]. environmental awareness can influence consumer decisions regarding meat consumption in areas where high soil concentrations of heavy metals have been recorded.

Finally, the effect of cooking on the final mineral composition of meat products is noteworthy. Various cooking methods have different effects on the mineral content of meat. Oz et al. [88] for instance, observed the highest mineral content loss from beef steak samples from microwave cooking when compared with methods such as deep-fat frying, boiling, hot plate cooking, oven cooking, pan-frying and pan-frying without fat or oil.

As expected, micronutrient composition varies significantly between the three main meat types consumed in the world with each of them presenting particularities that make them attractive to the consumer in function of their needs. Table 2 and table 3 summarize the minerals and vitamins most commonly found in meat and their functions in the human body.

Beef

Belonging to the red meat category, beef provides essential micronutrients such as vitamins A, pyridoxine (B_6), B_{12}, D, and E as well as Fe, Zn, and Se [89-91]. Beef is a naturally abundant source of Na and K, which are very important in regulation of fluid balance in the human body [92]. A study from Patel et al. [93], analyzed the mineral composition in beef samples produced in Italy according to the E.U. regulations. These samples were found to contain concentrations of 390 - 480 mg Na, 166 - 192 mg Mg, 2742 - 2900 mg K, 39 - 56 μg Mn, 11 - 17 mg Fe, 0.4 - 0.52 mg Cu, 34 - 45 mg and 48 - 75 μg Pb, per kg of meat respectively [93]. In this study, the authors made a distinction between macrominerals (Na, Mg, K, Ca, phosphorus (P), and sulphur (S)) and microminerals (essential being chromium, Mn, Fe, Cu, and Zn), discussing further that microminerals like Zn, Fe, and Mn can show variations depending on the muscle cut, while total mineral content in beef cuts depends on factors such as animal breed, physiology, market demand, and animal husbandry practices. These factors impact the final product's profile and explain the differences in mineral concentrations between meat samples.

Concerning vitamins, Lombardi-Boccia et al. [94] found vitamins from the B-complex in raw beef cuts, with concentrations ranging between 0 - 0.9 mg/kg for thiamine (B_1), 0.8 - 1.8 mg/kg for riboflavin (B_2 and 46.5 - 66.5 mg/kg for niacin (B_3). More reviews reported similar results in Australian beef for vitamins B_1, B_2, and B_3, as well as levels of vitamins B_6 (5.2 mg/kg), B_{12} (25 μg/kg), and A (<50 μg/kg) and minerals Na

Table 2: Summary of the most important minerals and their main function in the human body.

Mineral	Function	Ref.
Fe	Prevention of anemia and oxygen transportation	[68-71]
Cu	Ensures cardiovascular health, elasticity of lungs, healthy growth, neovascularization, neuroendocrine function, and Fe metabolism	[74]
Zn	Cofactor tole in more than 100 enzymatic reactions	[68]
Se	Inhibition of toxicity of toxic heavy metals (e.g., Hg, Pb, and Cd)	[68]
Na	Maintenance of plasma volume, assist neuronal activities	[72, 73]
K	Regulation of blood pressure, assist neuronal activities	[72, 73]
Mn	Cofactor in gluconeogenesis, eradication of free radicals, mucopolysaccharide synthesis, development of bones, digestion, reproduction antioxidant defense, production of energy, regulation of neuronal activity and response of immune system	[75]
Mg	Improves bone health and muscle motion, cofactor for synthesis and activation of vitamin D	[76, 77]
Ca	Improves bone health and muscle motion	[77]

Table 3: Summary of the most important vitamins, their chemical name and their main function in the human body.

Vitamin	Scientific name	Function	Ref.
Vitamin A	Retinol	Maintenance of epithelial tissues, antioxidant activity against free radicals	[79, 80]
Vitamin B_1	Thiamine	Cofactor of enzymes related to the metabolism of carbohydrates, helps in synthesis of nucleic acid precursors, myelin, neurotransmitters, and antioxidant defense	[81, 82]
Vitamin B_2	Riboflavin	Participating in synthesis of coenzyme A, Q, heme, pyridoxal 5-phosphate, and various hormones	[81]
Vitamin B_3	Niacin	NAD and NADP precursor both of which work as cofactors for reduction and oxidation reactions in the human body	[81]
Vitamin B_9	Folate	Assisting in nucleotide methylation and growth of tissue	[70]
Vitamin B_{12}	Cobalamin	It is essential in DNA, RNA and protein synthesis	[70]
Vitamin C	Ascorbic acid	Antioxidant activity against free radicals	[79]
Vitamin D	Calciferol	Maintenance of epithelial tissues and control of mineral deposition, assisting in absorption and healthy level maintenance of Ca	[80]
Vitamin E	α-tocopherol	Antioxidant activity against free radicals	[79]

(510 mg/kg), K (3630 mg/kg), Ca (45 mg/kg), Fe (18 mg/kg), Zn (46 mg/kg), Mg (250 mg/kg), Cu (1.2 mg/kg), and Se (0.17 mg/kg) [95-97]. A study from Pretorius et al. [98] found that beef rump had significantly higher concentration in heme Fe (19.5 mg/kg) compared to beef shoulder and prime rib (16.5 mg/kg and 16.9 mg/kg respectively).

Research by Blanco-Penedo et al. [99] determined differences of mineral content between beef from intensive, conventional and organic production systems produced in Spain. They found significantly higher Zn content (mg/kg) in Montederramo organic compared to the rest of the farms in this study, while the highest content of Cu, Fe, Mn, and Se concentrations (mg/kg) was found in Vilalba Intensive farms. This again indicates the significance of animal husbandry practices in final micronutrient composition of meat.

Pork

Pork is a meat source with certain nutritional properties due to its B-complex vitamins, minerals and trace elements [10, 11]. As mentioned before, pork is also classified as red meat. Studies have established the overall mineral and vitamin profile, with Fe levels ranging between 0.1 - 23 mg/kg, Zn levels ranging between 13 - 50 mg/kg, Cu levels ranging between 0.1 - 3.8 mg/kg, K levels ranging between 2430 - 15046 mg/kg, Na levels ranging between 450 - 1426 mg/kg, Mg levels ranging between 261 - 958 mg/kg, Ca levels ranging between 43 - 145 mg/kg, vitamin B_1 levels ranging between 5 - 10 mg/kg, B_2 levels ranging between and B_3 levels ranging between 2.4 - 6 mg/kg, for various raw cuts [72, 94, 100-104].

A previously mentioned study found no significant differences in the heme Fe content between pork rump and loin, with corresponding values of 8.2 mg/kg and 6 mg/kg respectively [98].

A recent survey by Pinchen et al. [105] has compared old and new data on vitamin concentrations in different key pork meat cuts, with vitamin D ranging between 0.5 - 1.4 mg/kg, vitamin E ranging between 0.1 - 3.3 mg/kg, vitamin B_1 levels ranging between 4.1 - 11.9 mg/kg, vitamin B_2 levels ranging between 0.8 - 3.3 mg/kg, vitamin B_3 levels ranging between 61 - 101 mg/kg, and B_{12} ranging between 0.3 - 1.4 mg/kgv [105-106]. However, these values refer to muscle cuts and can demonstrate variations when analyzing pork meat by-products such as offal [107].

It is worth mentioning that vitamin E levels detected in pork muscle may not be representative of the animal body vitamin E levels, as vitamin E is retained more by the liver, suggesting that certain parts of the animal can demonstrate variations due to natural biochemical occurrences [108]. However, it is possible to increase these levels in postmortem muscles with supplementation of animal diet [109].

Chicken

Studies for chicken have shown levels of Fe ranging between 3 - 11 mg/kg for breast, 6.4 - 9.9 mg/kg for drumstick and 6 - 8 mg/kg for thigh, levels of Zn ranging between 5.5 - 7.5 mg/of for breast, 137 - 157 mg/kg for drumstick and 161 - 171 mg/kg for thigh and levels of Cu ranging between 0.3 - 51 mg/kg for breast [16, 94, 100]. Badis et al. [110] detected Fe, Cu, Zn as well as heavy metals Pb, Cd, and Hg in chicken produced in different regions in Algeria. In addition, heme Fe content in chicken cuts was evaluated, with breast having significantly lower heme Fe content (4.2 mg/kg) than drumstick (6.2 mg/kg), and thigh (7 mg/kg).

Chicken is a good source of B-complex vitamins [111], while data also demonstrate chicken as having the highest concentration of vitamin E when compared to beef and pork, B1 levels in chicken being poorer than pork, chicken breast and thigh having proximate B_1 concentrations and B_2 being significantly higher for chicken thigh instead of breast [101]. The presence of these vitamins in food has multiple health benefits as mentioned above, therefore it is to the interest of the consumer to acquire meat cuts with more favorable vitamin concentrations. Lombardi-Boccia et al. [94] also published data on raw chicken breast, with B_1 levels ranging between 0.3 - 0.5 mg/kg, B_2 levels ranging between 0.2 - 0.4 mg/kg and vitamin B_3 levels ranging between 77 - 83 mg/kg. Chicken meat has been studied for its carotenoids content, a category including compounds such as lutein, zeaxanthin and meso-zeaxanthin, which possess anti-inflammatory, antioxidant and optical properties [112, 113].

Animal feed

Animal feed plays a major role in animal health and meat nutritional composition, with various animal feed types offering different advantages, drawbacks and final outcomes. The nutrient richness and composition of the animal diet influence strongly the quality of the meat and especially the nutritional value for the person consuming this meat [114]. According to the encyclopedia Britannica, animal feed can be classified in two main categories, the concentrates and the roughages. Concentrates include barley, corn, oats, rye, wheat, soybean, canola, linseed, palm oil, coconut oil, sunflower seeds, sugar beets, sugarcane, brewers' grain, distillers' grain and brewer's yeast, while roughages include pasture grass, hay, silage, root crops, straw and cornstalks [115]. Feed selection must be carefully considered, as usually feed accounts for 60 - 70% of total production cost [116].

Most of the above feedstuffs can be purchased upon demand by farmers and/or provided by farm surroundings. In addition, many animals have the opportunity to feed in pastures, which are pieces of land covered in grass and low plants, suitable for animals to graze. As outdoor, uncultivated parcels of land, pastures are usually host to important plant biodiversity [117]. Depending on climate, geographic location, and region, the plant species composition of pastures can vary. Studies have explored how the variations of plant consumption could impact the nutritional values of animal feed [118]. Petron et al. [119] separated grazing pastures in intensive ryegrass, botanically diverse and Leguminosa rich, while they found that the Leguminosa rich pasture has significantly higher levels of minerals such as Ca, Cu, Na, and Zn compared to the other two pasture types. Another research conducted in Brazil showed that pasture-fed steers had higher meat concentrations of MUFA and PUFA, n-3 as well as lower n-6 :n-3 ratio, compared to grain-fed steers [120]. Findings by Stanton et al. [121] further confirmed this observation. Bjorklund et al. [122] assessed the fatty acid profiles of meat from

dairy steers between organic, grass-fed organic and conventional production systems and measured higher n-3 and lower MUFA and SFA for grass-fed steers, while the n-6:n-3 ratios were 12.9, 10 and 1.4 for conventional, organic and grass-fed steers respectively. In contrast, Esterhuizen et al. [123] determined that cattle raised in feedlots grew faster and produced bigger carcasses compared to cattle raised in conventional and organic pastures. Consequently, the feedlot production system could introduce several benefits for farmers, as cattle could reach the desired weight faster. However, the nutritional composition of the meat product and associated health benefits should be taken into consideration in order to define the true value for consumers.

Study from Cömert et al. [124] observed that organic diet affected positively levels of protein and omega-3 fatty acids in female broilers in comparison to the conventional diet. Lipid content in chicken breast from broilers fed low energy diets was found to be higher when compared to broilers fed high energy diets [125]. Long et al. [126] found significant differences in the n-6:n-3 ratio in thigh and breast from broilers fed corn diets fortified with different supplements (i.e., soybean oil or microalgae with linseed oil with soybean oil or fish oil with soybean oil), while microalgae-fortified diet resulted in the most favorable n-6:n-3 ratio. These findings further emphasize the effect of feed on animal muscle composition.

A study on the effects of diet on pork nutritional composition and quality determined that soybean meal with rapeseed oil and distillers' grains with coconut oil diets resulted in higher protein content in the longissimus muscle of crossbred pigs, compared to distillers' grains with rapeseed oil and distillers' grains with beef tallow diets, while fat content was higher for pigs fed distillers grains with beef tallow diet [127]. In addition, soybean meals with rapeseed oil diet resulted in significantly lower n-6:n-3 ratio, while no significant differences were observed for C18:0 and C18:1n-9 fatty acids. Pires et al. [128] concluded that reduced dietary protein in finishing pigs resulted in IMF increase, while Čítek et al. [129] found values of n-6:n-3 ratios significantly lower for linseed and corn with linseed diets compared to corn diet for IMF and backfat of pigs.

These examples highlight the diversity of animal feed types and the impact they have on meat nutritional characteristics. This highlights the complexity of assessing the impact of individual feed components on meat nutritional profiles. Feed can be natural or processed, in the latter case supplementation can also be included in the feed mixture. Examples of supplementation include, but are not limited to, addition of herbs rich in antioxidants called phytochemicals, which actively participate in animals' healthy growth, while they can boost the immune system, increase feed intake and improve feed digestibility of animals [130]. Vitamin E has antioxidant abilities and boosts the immune system by stabilizing free radicals. Its addition as a supplement in animal feed plays a major role in optimizing meat product nutritional composition [109]. A study from Leonhardt [101] showed that supplementation with 200 mg α-tocopherol acetate per kg of feed significantly increased the α-tocopherol content in pig and hen meat products, while vitamin E dietary supplementation did not result in elevated levels of vitamin E in meat. In addition to the yield and the quality of meat, other parameters, such as animal husbandry, are often taken into consideration to characterize the elaboration of meat products.

Animal husbandry and livestock farming

Animal husbandry refers to the cultivation, management and production of domestic animals including the techniques used to improve animal qualities are often selected by animal breeding [131]. Animal husbandry also refers to the techniques used in animal breeding. Animal husbandry practices can include the origin, legislation, resources (e.g., animal feed, available space), production system (i.e., organic, free-range, and conventional) and rearing period. Therefore, it is evident that animal husbandry can influence meat product yield and sensory attributes. It is therefore of relevance to assess the influence of animal husbandry practices on the nutrient profile of meat products.

Beef cattle husbandry practices can be categorized into two main categories: indoor systems with pasture access, with the indoor systems animals being more confined and outdoor system animals having more access to outdoor space, grazing pastures and outdoor feedlots (i.e., with or without shelters) [132]. Cattle are large animals and need more time and resources in order to reach the desirable size and fat score for slaughter, compared to smaller animals like broilers. Usually, beef slaughter ages range between 24 - 30 months [133], while broilers take up to 6 - 7 weeks to reach the required market weight [134]. Cattle slaughter can take place at various ages, depending on fat score, which is highly influenced by the animal breed (e.g., Charolais vs Fresian) or sex (e.g., male and female Simmental cattle). For example, Simmental male cattle are slaughtered at 18 months of age while female Simmental cattle at 17 months [135]. Charolais x Friesian male cattle can have a slaughter time between 19 to 29 months of age, depending on their feeding regime and whether they are castrated or not (bulls or steers) [136].

Broiler chicken (i.e., chicken bred and reared for meat production) can, in contrast, be kept on floor systems (indoor), floor systems (indoor) with covered veranda, floor systems with free-range and mobile systems with free-range, while the age of rearing can vary, between organic systems slaughtering broilers at 8 - 12 weeks of age and conventional ones at 28 - 42 days [137]. In the free-range system poultry feed freely in large open areas or rotated through different pastures. Nevertheless, it is worth making the distinction between free range and organic production system. In the latter, producers need to certify animal feed, pasture and processing facility as organic [138]. In E.U. organic meat is produced in a farming system which prohibits the use of chemicals such as fertilizers, pesticides, drugs, antibiotics [139, 140] and anthelmintics, while in the Republic of Ireland feed should consist of "organic or in-conversion sources", ideally produced within the farm and when required, the use of organic grains is also allowed [141].

Pigs are also raised in various husbandry systems, which can be categorized in indoor group housing, indoor system with access to an outdoor area (hybrid) and outdoor paddock systems, while the finishing period starts at around 10

weeks of age [142]. These different examples emphasize how environment, animal biology and animal husbandry influence yield and nutritional composition of meat [143].

Antibiotics and growth promoters

Growth promoters are supplementary compounds used to improve meat production and can be administered by feed or by directly implanting to animals. Animal growth promoters can be grouped in antibiotics, hormones, and natural alternatives (e.g., probiotics, phytogenic). Antibiotics are often used in meat industry because they lower the threat caused by pathogenic microorganism infections, are effective in promoting animal growth and increase animal feed efficiency [144, 145]. A survey from De Briyne et al. [146], including data from 25 E.U. countries, showed that the most commonly used antibiotics for cattle and pigs were cephalosporins, macrolides and (fluoro)quinolones. Specific antibiotics are used in animal husbandry because they provide certain benefits. For example, cloromycetin has been suggested to have a favorable effect on sows reproducing performance and embryo survival [147]. Feed supplementation with aeromycin (chlortetracycline) has been shown to promote growth of turkeys from early years [148]. However, excessive use of antimicrobial compounds in animal feed has resulted in increased antibiotic resistance of various pathogens (*Escherichia coli, Campylobacter coli, Salmonella typhimurium,* and *Enterococci faecium*) [149] thus introducing animal health and ecological risks. It has also been shown that antibiotic resistant microorganism strains could pass, through animal product consumption, into humans, making this issue a potential major public health concern [150].

Ionophore antibiotics (e.g., Monensin) are used as growth promoters and for treatment of coccidiosis (parasitic disease) and acidosis (metabolic disorder of rumen) in cattle, however Ensley [151] and Hall [152] emphasized the negative effects of ionophore use in cattle such as toxicosis, as well as the high risks introduced by errors during mixing with animal feed.

Nevertheless, the use of alternative antimicrobial compounds rather than conventional antibiotics in animal feed is possible. Thyme, for instance, contains phenolic components, such as carvacrol and thymol, possessing antibacterial, anticoccidial, antifungal and antioxidant abilities [153]. A study showed that 200 mg/kg of thyme oil showed higher efficacy as an antioxidant in broiler diets, when compared with vitamin E supplementation [154]. However, a study from Mathlouthi et al. [155] indicated that supplementation of broiler feed with essential oil additives did not provide sufficient antimicrobial activity. We can therefore conclude that antibiotics possess useful properties for regulating animal health, however their use should be carefully planned.

Hormones have also been used as additive growth promoters in animal feed. Anabolic steroids (i.e., natural and synthetic steroids; and xenobiotics) and β-agonists have been used to improve the metabolic integration of nutrients in cattle, pork, and chicken [156-159] as well as increase lean growth rates [160]. E.U. banned the use of β-agonists in 1981 with "Directive 81/602/EC" [161]. E.U. directive 96/22/EC prohibited substances such as oestradiol 17β and ester derivatives, thyrostatic substances, stilbene and stilbene derivatives, testosterone and progesterone, with the exception of use for therapeutic purposes and zootechnical treatment [162]. The same prohibitions are in place in the UK [163]. However, not all countries are applying these prohibitions. In the United States (US) for example, the use of certain of these growth promoters is still in effect [164].

One of the main reasons for these European prohibitions is that animal hormones can be released in the environment as waste or as animal secretion products and can have negative ecological effects due to their increased chemical stability [150]. Human health implications such as food poisoning, cardiovascular and central nervous system disorders have also been correlated with β-agonist consumption [165, 166].

It is also worth mentioning that E.U. regulation (EC) No 2018/848 prohibits the use of a number of chemical compounds, such as growth promoters, fertilizers, pesticides, drugs and antibiotics in the organic meat production for similar ecological and public health reasons [122, 139, 140]. This confirms previous statements regarding the various effects animal husbandry can have on animal welfare.

To conclude on antibiotics, one should mention that they should be utilized carefully to benefit from their properties without inducing negative effects such as resistance of pathogens. Hormone use in E.U. is strictly prohibited. This is also why European legislation imposes to indicate the origin of meat products in stores. This information should also serve as an important guide for influencing the choice of consumers, if they are motivated by ecological and health concerns.

Meat processing and additives

Meat processing

In figure 1, the meat supply chain stages are shown. Upon reaching the desired body weight and meat composition, animals are transported from the production site/farm to a slaughterhouse. Dehydration, increase of stress, muscle fatigue and decrease in body weight have been observed in cattle undergoing transportation before slaughter, causing significant animal welfare concerns [167]. This can degrade nutritional value and sensory attributes of meat [168, 169]. To reduce the stress factors and for ethical reasons, the procedure of killing of animals needs to follow certain regulations and guidelines, which differ for each country. In some countries,

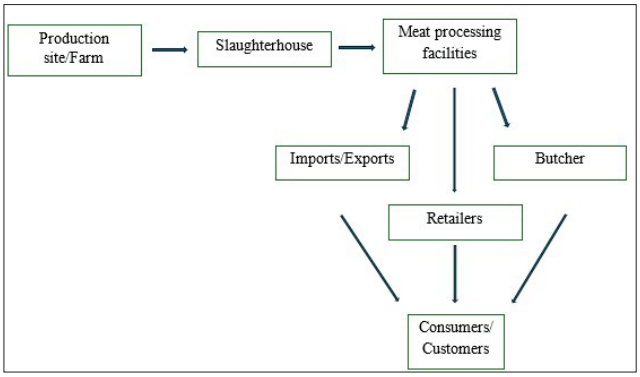


Figure 1: Stages of the meat supply chain.

animals slaughtered for meat have to be killed under certain conditions in order to fulfill a religious value (i.e., kosher, halal) [170]. In E.U. regulation (EC) 1099/2009 describes the necessary steps in animal killing/slaughtering, with attention to the promotion of animal welfare and the safe transportation, handling and care of animals during slaughter [171]. Under the same regulatory guidelines, animals need to be stunned before slaughtering for ethical reasons, such as elimination of suffering and distress. Pork and poultry slaughters are mostly mechanical; cattle slaughter however relies on human labor and mechanical devices [172]. After slaughter, animals are bled, defeathered (in the case of feathered animals), eviscerated, matured and frozen/chilled after slaughter, in order to preserve meat and reduce microbial contamination [172, 173]. Notably, freezing has been shown to have a significant impact on meat quality, moisture content and sensory characteristics such as color [174, 175]. Postmortem ageing/maturation can vary depending on the animal. Maturation has major effects on myofibrillar proteome and palatability characteristics such as color and tenderness [176]. After the step of maturation, carcasses are transported to meat processing facilities, in order to be cleaned, cut and packed for retail and commercial supply. Commercial muscle foods can undergo multiple postmortem processing steps, which can in turn lead to protein oxidation [177]. Lipid oxidation of meat can also take place during processing, which can impact greatly the sensory and nutritional quality of meat products [178]. In addition, slaughterhouses and processing facilities host multiple pathogenic bacteria (e.g., *Campylobacter* and *Salmonella* spp.), usually originating from animal microbiota from certain tissues (e.g., digestive tract). When animals are slaughtered and processed these microorganisms can contaminate their carcasses and cuts [173].

Packaging is an important element of meat processing, as the correct technologies implemented can expand the preservation of meat quality, prevent contamination and offer correct storage. Meat products are prone to the growth and spread of pathogenic microorganisms [179], therefore packaging can be used for protection of product quality. Packaging can also allow the display of advertisements and guidelines to ensure correct preparation and cooking of meat and avoid the ingestion of pathogens [179, 180]. Appearance, water content, nutritional value, lipid stability, color, texture and flavor of meat products were established early on as important factors consumers take into consideration when purchasing products [181-185]. All this information has to be displayed on the package of the product, serving as decision support indications to help the consumers in their choice of product purchase [181, 186, 187]. Packaging types for processed and raw meat can be mainly separated, depending on the levels of oxygen they allow in the product, into air-permeable, vacuum and modified atmosphere packaging (MAP) [181, 188]. Air-permeable packaging allows oxygen from the atmosphere to be in contact with the materials due to its film pores, vacuum packaging involves removal of air under pressure followed by seal of packaging under these conditions, while MAP involves removal of air and replacing it with other gases such as oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2) or carbon monoxide (CO), usually in gas combination mixtures [189]. Each gas has different properties, with O_2 creating oxymyoglobin red pigments that oxidize to brown, N_2 preventing pack collapse, CO_2 providing antimicrobial protection and CO creating red carboxymyoglobin pigment that remains stable longer compared to oxymyoglobin pigment [181, 189].

Packaging can play a crucial role in preservation of nutrients in meat. Oxygen MAP has been shown to lead to high protein oxidation in beef muscle and consequently, to increased carbonyl content [190]. Dalle-Donne et al. [191] emphasized the health risks associated with carbonylated proteins (e.g., chronic renal failure, Alzheimers disease, diabetes). Protein oxidation can also be caused by radicals produced during lipid oxidation [192]. Delles and Xiong [193] discovered that thiobarbituric acid reactive substances, which are products of lipid oxidation in tissues, were higher for permeable polyvinylchloride overwrap and oxygen-enriched atmosphere packaging than for partial vacuum packaging of pork Longissimus lumborum. Lipid oxidation can lead to meat color and odor degradation [194].

New emerging packaging materials addressed as "active packaging" have also been investigated, as they offer antimicrobial and antioxidant protection and can improve meat quality, although more future studies are needed to expand this field [179, 195]. In the US, use of chlorine dioxide releasing agents in raw meat for their antimicrobial activity are allowed and Food and Drug Administration approved, as long as their produced levels of chlorite remain below 2.71 μg/cm^2 in low density polyethylene packaging [196]. Finally, consumer approach to packaging is not negligible, as a study in the Republic of Ireland showed that the majority of consumers, especially those between 12 - 18 years old, want the packaging industry to adopt more environmentally friendly practices [197].

Meat supply chain includes multiple stages from slaughter until production of final meat products. The timeframe of slaughter and processing can have significant impacts on the quality of meat products. In addition, the meat sector is characterized as one of the biggest polluters in food supply, by consuming multiple materials and natural resources as well as producing inorganic and organic waste [198]. This becomes evident if the consumption of materials needed and emissions produced during meat production (i.e., natural resources, wastewater, greenhouse gas emission, electricity consumption, meat by-products) and packaging (i.e., paper, plastic, cardboard) are considered.

Additives

Meat production can be a time-consuming process. Therefore, preservation of quality of meat products from the time of slaughter until the date of sale and consumption is of interest to meat producing facilities. As mentioned before, meat products are preserved in chilling/freezing conditions after slaughter, to prevent spoiling and prolong preservation of nutritional composition. Additives are a category of compounds added in meat products for preservation and enhancement of meat products, however their use should be carefully planned, as some of them have been found to have negative impacts on human health [199]. Currently, more than 3000 additives are used for their antioxidants and anti-microbial action in market products, with nitrates (E251, E252), nitrites (E249,

E250) and sodium chloride being the most used, for their anti-microbial action and their inhibitory action against bacterial spoilage [200]. Nitrites enhance sensory attributes such as color and polyphosphates are added in meat products to improve their texture [199]. Nitrites also prevent the growth of the bacteria *Clostridium botulinum*, which generates the harmful botulin toxin (muscle paralysis, neuronal problems) [201], while nitrites also react with myoglobin and generate mononitrosylhaemochrome, a compound which provides a red color to meat products [202]. Nitrates on the other hand, present good anti-microbial action [203] and serve as a precursor for nitrites (i.e., nitrates are reduced through microbe enzymes) [204]. Sodium chloride is also efficient in preventing microbial growth [205] and contributes to conversion of nitrates to nitrites by altering the pH conditions [200].

Regulated use of additives in meat products can ensure food safety, product preservation and therefore affordable product prices [206]. However, the previously cited examples show that overuse of these products induces some risks to human health. As alternatives, it has also been shown that use of natural additives (i.e., tomato, green tea leaf extract, rosemary extract, oregano, grape extract, cinnamon, thyme, whey protein, flaxseed, tomato, and dietary fiber) can be incorporated and some of them can have roles in the control of lipid oxidation, spoilage, and pathogenic microorganisms [207, 208].

Consumers

Following processing and packaging, meat products are distributed to retail markets, butchers, businesses, exports, and finally consumers. The purpose of the label is to provide nutritional information on the meat product, as well as information on the product origin. Sustainability labels are more commonly appearing on meat products, which is no coincidence as a study from Van Loo et al. [209] found that high-income consumers were more prone to spend 50% higher prices for sustainably labeled chicken breast products compared to low-income consumers. A survey from Skoumpa et al. [210] determined that "traceability" as well as "price" of meat products were considered important to participants of the study. Organic production systems generally contribute to better animal welfare compared to conventional systems, with room for improvement regarding animal health in some cases [143]. The sustainability aspects of organic meat production could make these products more appealing to consumers with increased environmental awareness [211, 212]. Aweke [213] in a survey study found that consumers' willingness to pay for organic meat products was significantly correlated with the health and environmental benefits of organic meat. A study from Vigar et al. [214] has already associated consumption of organic food with reduced risk of multiple diseases such as infertility, metabolic syndrome, allergic sensitization and more. This evidence provides insight into how the meat market demand is being restructured in response to ethical considerations, while promoting transparent practices regarding product origin and production system.

Conclusion

In this study, the nutritional value of meat, animal husbandry practices and meat supply chain have been reviewed, with the goal of understanding the various factors influencing nutritional composition of meat products. Meat is a nutritionally rich food source consumed worldwide. Many species of animals are reared for their meat, which has led to the distinction of different meat types in function of their nutritional characteristics, with beef, pork and chicken being the most consumed meat types in the world. Data from studies assessing the macronutrient and micronutrient content in beef, pork and chicken were reviewed here, to understand the benefits and drawbacks associated with consumption of each type for human health. This study presents the differences of nutritional composition among these meat types for the nutrients fat, protein, water, minerals and vitamins, with noticeable differences in omega 3 polyunsaturated and Fe content. It is acknowledged that animal husbandry practices, which vary depending on legislation and choice, influence the nutritional composition of meat. Husbandry practices have a huge impact on animal welfare and development, as well as the origin and conditions of living for animals. They influence their body composition and muscle proximate composition. Organic and free-range production systems usually allow more outdoor space for animals which in turn can favor locomotory activity and can influence animal body composition (e.g., myogenesis instead of lipogenesis) compared to confined conventional production systems which limit activity of animals. Animal feed is a part of animal husbandry practices and can vary in nutritional composition and origin, it can have a huge effect on animal health and metabolism and is also a highly important factor for the final meat's nutritional composition. Growth promoters have also been used to enhance growth performance and increase production and are in some cases prohibited. Postmortem conditions and meat processing also drastically affect meat quality and can be responsible for introducing microorganism contaminations, lipid and protein oxidation and sensory alterations, if carcasses are not handled with caution. Choice of additives and packaging can expand the preservation of meat products. Packaging has also been shown to have an important role in informing customers of the characteristics of the products and also has an important power of persuasion by attracting the eye of the customer depending on its design and features.

This review provides a preliminary overview into the nutritional composition of meat products and the factors affecting the latter. In this review, emphasis is placed upon the multiple effects different production systems have on meat nutritive value, however existing studies comparing the nutritional composition of conventional, free-range and organic meat products remain limited. Consumer preference is shifting towards sustainably produced meat products, influenced by a number of perceived health and environmental benefits. While some studies have assessed the nutritional composition differences between organic, free-range and conventional meat products, further work is essential regarding assessing and comparing the nutritional composition of meat products originating from different production systems.

Acknowledgements

This review paper was completed without any extra fund-

ing, other than the President's Fellowship funding, provided to the primary author in a quarterly stipend, from South East Technological University, Republic of Ireland.

Conflict of Interest

None.

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