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A Comprehensive Review of Nutritional Benefits of Minerals in Meat and Meat Products

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Abstract

Minerals are chemical elements that organisms require as a necessary nutrient to sustain good health at various stages of life. To support human biochemical processes, including structural and functional activity in the body, at least twenty mineral elements are required. However, inadequate consumption of these essential minerals in the human diet can result in metabolic problems, organ damage, chronic diseases, and death. Mineral deficiency affects roughly two billion people globally, the bulk of whom live in third-world nations. Among those, infants and pregnant women are more susceptible to the mineral shortage in the body. To avoid these deficiencies, humans need to consume muscle foods, which are superior sources of essential minerals, particularly zinc, selenium, phosphorus, iron, etc. compared to plant-based foods. Minerals derived from muscle foods are easier to absorb in the body than minerals derived from plant foods. However, the amount of essential minerals in muscle foods varies widely and depends on several factors, including nutrition, species, breed, sex, age at slaughter, muscle types, physiological status, production system, and post-mortem factors such as processing and analytical methods. The present study discusses the mineral composition of different muscle foods, factors affecting the mineral contents in different muscle foods and the beneficial and important roles that minerals play in human health.

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Introduction

Minerals are chemical elements required as an essential micronutrient by organisms (livestock and humans) to maintain sound health throughout life. Minerals are needed for the regulation of cellular function, growth, mechanisms of neuromodulation and other biochemical and physiological functions in the body [1, 2]. Therefore, the lack of essential minerals in the human diet can cause metabolic disorders, organ damage, chronic diseases and ultimately death [1]. Minerals cannot be synthesized biochemically by living organisms; therefore, their deposition in animal muscle depends on factors such as feeding regimen (diet/nutrition), breed, season (edaphic and climatic conditions) and muscle type. The reports have shown that not less than 2 billion people are suffering from mineral deficiencies worldwide, with most of these estimates residing in third-world countries [3, 4]. Infants and pregnant women have been reported to be more vulnerable to the risk of deficiency of essential minerals in the body [5, 6]. For instance, iron deficiencies are known to cause severe anaemia, lower immunity to infections and induce pregnancy complications (such as babies with low birth weight) [5, 6]. Severe anaemia has been implicated in causing maternal and child mortality [6, 7].

There is a need for dietary diversification to improve the intake of critical micronutrients, especially minerals. At least twenty mineral elements are needed to support human biochemical processes by serving structural and functional roles as well as electrolytes [8]. Some of these mineral elements such as Ca, P, K are required in large amounts, while others, like Fe, Zn, Cu, I and Se, are required in trace amounts because higher concentrations can be harmful [9]. Tomovic et al. [10] reported that humans require macro elements in amounts >50 mg/day and microelements in amounts <50 mg/day. Minerals such as iron and zinc are low in plant-based diets (cereal, legume and tuber) and can only be provided through consumption of muscle foods to meet the daily recommended level for a healthy life [11]. FAO [11] indicated that the daily intake of about 50 g of either meat, poultry, or fish in a staple-based diet will increase the total iron content as well as the amount of bio-available iron in the body. Generally, muscle foods are considered an excellent source of several minerals, particularly zinc, selenium, phosphorus and iron in the human diet. This review aimed to highlight the mineral composition of muscle foods, factors affecting their content levels in muscle foods and their role in human health.

Classification of minerals

Minerals are usually obtained from ash after the combustion of muscle food and plant tissues [10]. Minerals can be categorized into three subgroups including:

1. Macro-minerals
2. Micro-minerals (trace elements)
3. Ultra-trace elements

The macro-minerals include sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), phosphorus (P) and sulphur (S). The micro-minerals include iron (Fe), iodine (I), fluoride (F), zinc (Zn), selenium (Se), copper (Cu), manganese (Mn), chromium (Cr), molybdenum (Mo), cobalt (Co) and nickel (Ni). Other elements, which are referred to as ultra-trace element include aluminium (Al), arsenic (As), boron (B), bromine (Br), cadmium (Cd), germanium (Ge), lithium (Li), lead (Pb), rubidium (Rb), silicon (Si), etc.

Minerals in muscle foods and their role in human health

The importance and deficiencies of mineral elements in humans have been well reported in the literature [6, 9]. Minerals, in a way, also contribute to food flavour, color and texture of food. They also form essential components of enzyme systems in the body [9]. Here we discuss roles, deficiency symptoms and recommended per day dose of important minerals.

Calcium

Calcium is the most abundant mineral in the body. The body needs it every day for vascular contraction, vasodilation, muscle functions, oocyte activation, blood clotting, nerve transmission, intracellular signalling, and hormonal secretion in the human body [6]. It is also needed in the body for regulating heartbeat and fluid balance within cells. Calcium functions as a constituent of bones and teeth [6]. It plays a huge function inactivation of enzymes such as adenosine triphosphatase (ATPase), succinic dehydrogenase, lipase, etc. [6]. The demand for calcium is highest during the period of growth such as childhood, and other physiological states such as pregnancy and lactation [12]. Mainly, calcium makes up 920 to 1200 grams of adult body (*i.e*., about 1.5% of body weight) weight, with 99% found in bones and teeth and 1% in serum [1]. Calcium deficiency in the body is reported to cause osteoporosis in which the bone deteriorates with an increased risk of fractures [6]. In both children and adults, it affects their dentition. On estimate, the recommended daily allowance for calcium is reported between 700-1300 mg per day [13, 14]. Depending on the physiological status of the body, an adult may require about 10 mg of calcium per kilogram of body weight [12]. For instance, pregnant and lactating women may require higher calcium intake due to the rapid depletion of calcium because of their status [12].

Phosphorus

Phosphorus consists of about 1% of human body weight, of which 29% is found in bone, and less than 1% is in the blood [15]. Phosphorus is an essential mineral needed for several biological processes such as bone mineralization, energy production as adenosine triphosphate (ATP) and adenosine diphosphate (ADP), metabolism, kidney functioning, cell growth, cell signalling through phosphorylation reactions, and regulation of acid-base homeostasis [9]. Phosphorus is regarded as an important aspect of DNA and RNA as DNA and RNA contain phosphate. Phosphorus deficiency is rare. Its symptoms are only noticeable in cases of near-total starvation or inherited disorders involving renal phosphorus wasting. Symptoms such as loss of appetite, muscle weakness, bone fragility, numbness in the extremities, and rickets in children have been observed. While high phosphorus intake can cause vascular and renal calcification, renal tubular injury, and premature death. The phosphorus daily recommended intake for ages between 0–6 and 7–12 months is estimated 100 and 275 mg, respectively. While in adults, an adequate intake of phosphorus is 800–1300 mg on daily basis [14].

Magnesium

Magnesium is readily available in the body. It is the second most abundant intracellular cation (after potassium) and the fourth most abundant cation in the body [16]. It is widely used for metabolic processes in the body. Some of its main functions include energy production, cell growth and synthesis of biomolecules [17]. It equally acts as a cofactor to enzymatic reactions in the body and partakes in the synthesis of H_2 transporters (particularly in all reactions involving the formation and use of adenosine triphosphate). It often participates in the metabolism of glucose, lipids, proteins, and nucleic acids as well as cellular antioxidative defense in the body [18]. The deficiency of Mg in the body can directly impair reactions that require ATP, such as protein synthesis, muscle contraction and glucose utilization [1]. The recommended intake of magnesium is estimated at 200–420 mg per day [14, 16]. The Institute of Medicine recommends 310–360 mg and 400–420 mg for adult women and men, respectively [16]. While about 350 mg per day is recommended for pregnant and lactating women [16,19].

Sodium

Sodium is one of the most principal elements that the body needs in relatively large amounts. It is referred to as a body electrolyte and it is mostly found in the blood and fluid around the cells. It is required for the maintenance of plasma volume, acid-base balance, transmission of nerve impulses and normal cells. It also functions to preserve normal irritability of muscles and cell permeability [6]. Its metabolism is mainly regulated by aldosterone. The minimum intake level of sodium necessary for proper bodily function has not been well defined; however, it is estimated to be as little as 200–500 mg/day [19, 21].

Potassium

Potassium is an essential mineral and a major electrolyte found in the human body. The human body contains about 3500 mmol potassium, of which 2% is in the extracellular fluid. Adequate dietary potassium intake is important for the regulation of electrolytes, blood pressure, insulin secretion, creatine phosphorylation, carbohydrate metabolism, protein synthesis and as a co-factor for many enzymes [22]. Nutritionally, He and MacGregor [21] opined that high dietary intake of potassium can lower blood pressure in individuals with a record of high blood pressure, prevent or reduce the progression of renal disease, lowers urinary calcium excretion, decrease the risk of cardiovascular disease and decrease the risk of osteoporosis in human. It is also believed that an increased potassium intake can improve bone mineral density and mitigate the negative consequences of high sodium consumption [23] in the body. According to Bellows and Moore [24], potassium deficiency, although not common, may result in excessive fluid loss due to severe diarrhea, strenuous exercise, or the use of diuretics. Low serum potassium has been associated with glucose intolerance, risk of lethal ventricular arrhythmias in patients with ischaemic heart disease, heart failure and left ventricular hypertrophy [21]. To meet daily requirements, a potassium intake between 3500-3510 mg per day has been recommended for adults [14, 23]. However, another study had recommended potassium daily intake of 4,700 mg for males and females from ages fourteen through adulthood, as well as pregnant women for healthy living [24, 25].

Iron

Iron plays a crucial role in human health. It is needed for numerous metabolic processes such as synthesis of deoxyribonucleic acid (DNA), transportation of oxygen and nutrients, formation of heme enzymes and other iron-containing enzymes that are involved in electron transfer and oxidation reductions [26]. Almost two-thirds of the body iron exists in the circulating erythrocytes as haemoglobin while the remaining is attached to myoglobin in muscle tissue and different enzymes that are involved in oxidative metabolism and other cell functions [26, 27]. Iron is essential for proper myelination of the spinal cord and white matter of cerebellar folds in the brain [6, 28]. It is required in the synthesis of the neurotransmitter, their uptake and degradation into other iron-containing proteins, which may directly or indirectly influence brain function [6, 29]. Iron deficiency can cause severe anaemia, lower immunity against infections and pregnancy complications (such as babies with low birth weight) [5, 6]. The recommended intake of iron is 8–18 mg per day [14].

Manganese

Manganese (Mn) is an essential element for intracellular activities in the body. It acts as a cofactor for a variety of metalloenzymes and cellular reactions, including arginase (involved in the ornithine cycle), pyruvate carboxylase (works in the gluconeogenesis pathway), superoxide dismutase (helps to eradicate oxygen free radicals), glutamine synthetase, and glycosyltransferases (play a role in mucopolysaccharide synthesis) [30]. Besides these functions, manganese is known to play important roles in bone development, digestion, reproduction, antioxidant defense, energy production, immune response and regulation of neuronal activities in the body [30]. The deficiency of manganese can lead to osteoporosis, diabetes, and epilepsy**.** The daily intake of 3 mg Mn is recommended for an infant up to 6 months of age, while 1.2 and 1.5 mg for children between 1-3 years and 4-8 years, respectively [19, 30]. On average, an estimated 2-6 mg of Mn per day has been recommended for adults [19, 30].

Zinc

Zinc is one of the most abundant trace elements that have multiple biochemical functions in the body. It is involved in cell growth, development and differentiation. It also plays a major role in the cell-mediated immunity, bone formation, brain function and pathogenesis of some dermatological disorders [31]. Zn is effective in liver function and regeneration, sperm maturation and motility, and gene regulation [31]. In some cases, Zn acts as an antimicrobial by inhibiting the coagulation of plasma by *Staphylococcus aureus* cells or suppressing their attachment to coverslips. It can also act as an antioxidant by protecting cells against free radicals produced as a by-product of immune activation [31]. Zinc deficiency has been implicated in many diseases, including acrodermatitis, cirrhosis of the liver, sickle cell disease, diabetes, and hypogonadism in male adolescents [31, 32]. Recommended daily Zn consumption ranges from 8–11 mg for adults [14].

Copper

Copper is an essential trace element that is needed for adequate growth, cardiovascular integrity, lung elasticity, neovascularization, neuroendocrine function, and iron metabolism [19]. It helps the thyroid gland to function properly in the body. They help to maintain the strength of the skin, blood vessels, epithelial and connective tissue throughout the body. Besides, copper can act as an antioxidant by scavenging/neutralizing free radicals or inhibiting free-radical damage to cell and organ proteins, membrane lipids, and nucleic acids [33]. Copper also acts as a cofactor for certain enzymes that are involved in energy production, connective tissue formation, and iron metabolism [33]. Severe deficiencies of copper are relatively rare in humans. However, its deficiency is associated with mental retardation, anaemia, hypothermia, neutropenia, diarrhea, cardiac hypertrophy, bone fragility, impaired immune function, weak connective tissue, impaired central-nervous-system functions, peripheral neuropathy and loss of skin. The recommended intake of copper for adults is estimated between 1-1.6 mg per day [14]. On average, the human body contains 100 mg of copper

[33].

Selenium

Selenium is a trace element that is found in small amounts in the organism. It is required in a small amount for good health. Selenium is an antioxidant mineral element that forms a major structural component of several enzymes including glutathione peroxidase, thioredoxin reductase and deiodinases as well as selenoproteins. It plays important roles in antioxidation defense, reproduction, muscle function, thyroid hormone formation, DNA synthesis, fertility and tumor/cancer prevention [34]. Usually, selenium deficiency does not result in obvious clinical illness but may participate in Keshan disease and Kashin-Beck disease.

Mineral composition of selected muscle foods

In comparison to plant food sources, muscle food is considered an excellent source of certain macro and microminerals in the diet, especially iron, zinc, phosphorus and potassium. Some of the muscle food minerals are more readily absorbed in the body compared to plant foods. As presented in Table 1, muscle food is very rich in calcium and fish meat contained the highest calcium concentration ranging from 190-8810 mg/kg among the meat types. Chicken muscle is reported to contain 17.8-31.5 mg/kg calcium. Raw beef, pork, mutton, chevron, turkey and rabbit meat is reported to contain between 20.4-43.9 mg/kg, 43-145 mg/kg, 58.1-63.3 mg/kg, 110-118 mg/kg, 1960-2280 mg/kg and 90 mg/kg, respectively. The amount of calcium in the meat types, except fish meat, is relatively lower compared to those reported by Mart´inez-Ballesta et al. [9] for different vegetables, where it ranges from 87 to 1000 mg/kg.

Phosphorus is found in both muscle food and plant sources. As shown in Table 1, chicken meat exhibited the highest phosphorus concentration (6619-9352 mg/kg) compared to other meat types. Raw fish contains about 680-5500 mg/kg phosphorus level while beef, pork, mutton, chevron, turkey and rabbit contain about 2112-2276 mg/kg, 2230 mg/kg, 2105-2856 mg/kg, 1555-458 mg/kg, 1960-2280 mg/kg and 2350 mg/kg, respectively. The amount of phosphorus in chicken and fish meat is relatively higher than that found in vegetables (167-4370 mg/kg) while the phosphorus content in beef, chevron, mutton, pork, turkey and rabbit are relatively lower than those reported in vegetables [9].

Sodium is found naturally in a variety of foods, including milk, meat and vegetables. Chicken meat possessed the high sodium content of 1273-1755 mg/kg compared to other meat types (Table 1). However, beef, pork, mutton, chevron, rabbit, fish and contain 352-741 mg/kg, 450-1426 mg/kg, 685-793 mg/kg, 644-782 mg/kg, 660 mg/kg, 300-1340 mg/kg and 667-1000 mg/kg, respectively. The concentration of sodium in meat samples in these reported studies is greatly higher than those reported for raw vegetables (22.8-940 mg/kg) [9]. Potassium is found naturally in milk, meat and plants. Chicken meat is reported to possess the highest potassium concentration (9531-14777 mg/kg) compared to others meat types (Table 1). Fish contains about 190-5020 mg/kg potassium level while beef, pork, mutton, chevron turkey and rabbit meat contain about 3204-4301 mg/kg, 4000-15046 mg/kg, 3295-3368 mg/kg, 3500-3920 mg/kg, 3530-4370 mg/kg and 3870 mg/kg, respectively. The presence of potassium is relatively higher in meat types than that of vegetables and other food products except for seed and nuts (200-7300 mg/kg) [9].

Magnesium (Mg) has a strong presence in muscle foods. Chicken possessed the highest content of magnesium (780-1216 mg/kg) while mutton has the lowest level of magnesium (215-257 mg/kg; Table 1). Beef, pork, chevron, rabbit, fish and turkey contain 236-320 mg/kg, 261–58 mg/kg, 197-261 mg/kg, 260 mg/kg, 45-4520 mg/kg and 257-393 mg/kg, respectively. Vegetables and fruits are known to contain higher magnesium content ranging from 55-1910 mg/kg fresh weight compared to meat types [9]. Zinc, iron, manganese, copper and selenium are found in small quantities in vegetable and muscle food among others. In this study, beef exhibited highest content of zinc (25.7-62.7 mg/kg), iron (17.6-217 mg/kg) and copper (5.2-6.3 mg/kg) compared to other meat types (Table 1). Beef has been reported as one of the richest natural sources of Zn and iron [53]. Mutton, pork, chevron, chicken, turkey and fish are reported to contain 24.0–50.8 mg/kg, 32.5-36.1 mg/kg, 32.1-35.1 mg/kg, 22.3-75.9 mg/kg, 10.5 mg/kg, 10.1-34.6 mg/kg and 2.3-21 mg/kg, zinc respectively. Zinc concentration in plant-based foods (0.5-118 mg/kg) is generally higher than that in muscle food [9]. In addition, the iron concentration in mutton, pork, chevron, chicken, turkey and fish is estimated to be 14-22 mg/kg, 9.7-17.6 mg/kg, 15.7-43.7

Table 1 Mineral content (mg/kg) of muscle foods of different animals.

Elements	Beef	Chevron	Pork	Mutton	Chicken	Rabbit	Fish	Turkey
Macro								
K	3204[a] - 4301[b]	3500[c] - 3920[d]	4000[e] - 15046[f]	3295 - 3368[g]	9531 - 14778[h]	3870[j]	190-5020[k]	3530-4370[m]
Na	352[a] - 741.00[b]	645[c] - 782[d]	450[e] - 1426[f]	685- 793[g]	1273 - 1755[h]	660[j]	300-1340[k]	667 - 1000[m]
Mg	237[a] - 320[a]	197[c] - 261[d]	261[e] - 958[f]	215 - 257[g]	780 - 1216[h]	260[j]	45-4520[k]	257 - 393[m]
Ca	20.4[a] - 43.9[a]	110[c] - 118[d]	43[e] - 145[f]	58.1- 63.3[g]	17.8 - 31.5[h]	90[j]	190-8810[k]	66-77[m]
P	2112[b] - 2276[b]	1555[c] - 2458[d]	2230[e]	2105 -2856[g]	6619 - 9352[h]	2350[j]	680-5500[k]	1960-2280[m]
Micro								
Zn	25.7[a] - 62.7[b]	32.1[d] - 35.1[c]	24[e] - 50.8[f]	32.5 - 36.1[g]	22.3 - 75.9[h]	10.5[j]	2.3 - 21[k]	10 - 35[m]
Fe	17.7[a] - 217.8[b]	15.7[d]- 43.7[c]	14e - 23[f]	9.7 - 17.6[g]	26.1 - 43.1[h]	5.36[j]	10 - 56[k]	5 - 12[m]
Mn	1.2[b] - 5.9[b]	0.13[d] - 0.87[c]	0.47 - 0.69[f]	1.0 - 2.1[g]	2.7 -3.6[h]	0.35[j]	0.003-2520[k]	-
Cu	5.2[b] - 6.3[b]	1.31[d] - 3.00[c]	1.0[e] - 1.8[f]	6.4 - 7.3[g]	-	0.89[j]	0.01- 37[k]	-
Se	0.07[n]		0.15 - 0.29[f]	0.04[n]	0.13[n]			0.13[n]

Sources: [a][57], [b][36], [c][59], [d] [36], [e][47], [f] [10], [g][50], [h][54], [J][49], [K][11], [M][51], [n][58]

mg/kg, 26.1-43.1 mg/kg, 5.36 mg/kg, 5.0-12.3 mg/kg and 10-56 mg/kg, respectively. The iron content in meat is relatively higher than those in vegetables and fruits (1.3-30.1 mg/kg) [9]. Similarly, mutton, pork, chevron, chicken and fish are reported to contain 5.20- 6.30 mg/kg, 1.0-1.80, 6.4-7.3 mg/kg, 1.3-3.0 mg/kg, 0.89 mg/kg and 0.01- 37 mg/kg copper, respectively. The amount of copper in meat is much higher than those reported for vegetable (0.04-2.4 mg/kg), legumes (5.0 mg/kg) and fruits (0.1-2.4 mg/kg) [9]. The manganese concentration is highest in fish meat (0.003-2520 mg/kg) and lowest mutton (1.0-2.1 mg/kg; Table 1). Beef, pork, chicken and rabbit meat contain 1.2-5.9 mg/kg, 0.47-0.69 mg/kg, 0.13-0.87 mg/kg, 2.7-3.6 mg/kg and 0.35 mg/kg manganese, respectively. The manganese content in meat is lower compared to that of vegetables (0.1–0.78 mg/kg) and fruits (0.1–6.6 mg/kg) [9]. The selenium content in beef, pork, mutton, chicken and turkey are 0.07 mg/kg, 0.15-0.29 mg/kg, 0.04 mg/kg, 0.13 mg/kg and 0.13 mg/kg and those are relatively lower than those reported for vegetables and other food of plant origin 10^{-4}-0.6 mg/kg [9].

Factors affecting mineral contents in muscle foods

The mineral content of muscle foods is quite variable and depends on several factors including pre-mortem factors such as nutrition, species, breed, sex, age at slaughter, muscle types, physiological status, production system and post-mortem such as processing methods and method of analysing the mineral content of the meat samples [35, 36]. Most times, the extent of the natural variations in mineral contents of muscle food are not well understood [36]. In plants, for example, variation in mineral contents has been attributed to factors such as diversity of soil and climatic conditions (geographical origin), physiological state and maturity, species and genotype of plant, cultivar and post-harvest treatment [6, 9]. Livestock that depends on plants for food may show significant variation in muscle mineral content due to variation in the chemical composition of plants consumed. Feeds grown on high-selenium soils may present high selenium content deposition in the muscle when used to formulate rations than those grown on low-selenium soil [37]. de Freitas et al. [38] also explained that the concentration of minerals in muscle may also depend on the dietary mineral intake and concentration of minerals in the soil during grazing.

Effect of animal breed on mineral composition

Genetic variants (breed) have been reported as an important factor determining the composition of minerals in the muscles of livestock raised under the same conditions [35, 39, 40]. Domaradzki et al. [35] in a study reported a significant breed effect on the mineral contents of young bull beef cattle. They found that Polish Holstein-Friesian cattle had lower K, Mg and Ca and higher Mn contents compared to other breeds (such as Polish Red cattle, White-Backed cattle, Polish Black-and-White cattle and Simmental cattle. de Freitas et al. [38] in their study also found that the iron content of *Longissimus dorsi* muscle from 1/4 Brafords steer breed finished on pasture was higher than those found in purebred Herefords and 3/8 Brafords, while Zn content was higher in muscle from purebred Herefords and 1/4 Brafords compared to that of 3/8 Braford steers. The differences in mineral contents between breeds could be attributed to rate of nutrient metabolism, excretion of endogenous minerals and amount/type of diet (pasture/fodder/grains) consumed by individual animals [35]. In another study, Kasap et al. [41] reported higher Ca, K, Na, Cu and Mn in *Musculus longissimus thoracis et lumborum* muscles indigenous Krk sheep breed raised in completely outdoor conditions compared to Rab sheep and Cres sheep.

Effect of animal species on mineral composition

The concentrations of minerals in muscle food vary according to animal type and location (Table 1) [42]. The pork had higher potassium content compared to mutton, beef, poultry, and fish. Chicken is highly rich in sodium than other species of livestock. Fish possessed more calcium content compared to beef, chicken, mutton and poultry. Beef is known to exhibit higher zinc and iron concentration compared to fish, rabbit, mutton, pork and chicken (Table 1). This variation could be due to differences in diet composition, rate of nutrient metabolism and absorption and genetic endowment.

Effect of muscle type on mineral composition

The mineral composition of meat also varies according to the anatomical structure of the animal. Domaradzki et al. [35] found that the *longissimus lumborum* muscle of young bull cattle raised under the same feeding and management condition had higher Zn, Fe, Cu and Mn than semitendinosus muscles. In another study, Tomovic et al. [45] found significant variation in mineral content of six different muscle types (*M. psoas major*, *M. longissimus dorsi*, *M. semimembranosus* and *M. tricepsbrachii*) of Saanen goat male kids raised under the same condition and feeding managements. The same author reported that *M. latissimus dorsi* muscles had the high potassium content while phosphorus, zinc and sodium were higher in *M. semimembranosus*, *M. tricepsbrachii* and *M. psoas major* muscles, respectively, compared to remaining muscle types. Chen et al. [43] in their study reported that the breast muscle of broiler chicken and spent hens exhibits higher content of calcium, sodium, zinc, iron, manganese and selenium than the thigh muscle. The variation in concentration of minerals between muscles has been attributed to different demands of muscles during growth and maturation. For example, Kuhne [44] reported a higher mineral concentration in muscles that are involved in the movement than other muscles.

Effect of nutrition/diet and production system on mineral composition

The deposition of minerals in animal muscle could depend on the nutritional composition (including minerals) of feed ingredients used in the diet and its consumption for the proper development of metabolism. se Freitas et al. [38] in their study found that *Longissimus dorsi* muscle from pasture-fed steers higher concentrations of Mg and lower K content compared to those finished in the feedlot. In another study, Qwele et al. [45] found that *longissimus thoracis et lumborum* muscle of goats fed a diet supplemented with *Moringa oleifera* leaves had more mineral contents (iron, copper, calcium, zinc) than those fed diets supplemented with sunflower cake (SC) and grass hay (GH). In another study, Driskell et al. [46] found that cross-bred steers fed finishing rations containing 40% DM wet distiller's grains plus soluble had higher mineral contents compared to the control group. The reports have also shown that the production system can influence the mineral composition of muscle tissue even though the contents of elements are different in the diets. In a study, Zhao et al. [47] found that pigs fed an organic diet had higher manganese and copper concentrations in muscle tissue (pork) than those fed a conventional diet. The authors attributed this difference of Mn and Cu contents to the soil consumption by the organic pig when roosting. The supplementation of minerals in diets (such as sodium chloride (salt) and mineral premix) to compensate for their inadequacy in plant foodstuffs (including crop residues and low-quality pasture) to meet the animal's dietary needs may increase deposition of minerals in muscle tissue. Provision of molasses or mineral block lick for ruminant animals (especially cattle) may also increase the mineral content of certain elements in muscle tissue.

Effect of slaughter age, sex, and physiological status on mineral composition

Age at slaughter has been reported to influence the concentration of minerals in muscle food. Hermida et al. [48] found higher concentrations of Na, Ca, Cu and Mn in the rabbit muscles slaughtered at age 50 days compared to those slaughtered at 70 and 90 days. While rabbits slaughtered at age 70 days had higher potassium and zinc than those slaughtered at 50 and 90 days. In addition, meat samples of *longissimus thoracis* muscle of lamb slaughtered at age 5 months were reported to contain higher phosphorus, magnesium, iron and manganese content than those slaughtered at 2 months of age [48]. While those slaughter at 2 months of age had higher potassium and sodium content compared to those slaughter at the age of 5 months [48]. Chen et al. [44] in their study found that breast and thigh muscle of spent hen had lower mineral concentration (Ca, K, P, Zn Mn, Fe, Na, Se) than the commercial broilers. The *longissimus dorsi* and *semimembranosus* muscles from steers cattle were reported to show higher Ca, K and Na and lower Zn contents than the heifer cattle [50]. Gálvez et al. [51] found that the amount of Na in breast samples and Na and Zn in thigh samples of males were higher than those found in females of turkey. In addition, Kasap et al. [41] revealed that meat from female lambs exhibited higher Zn concentration than that of males.

Effect of meat processing techniques on mineral composition

The application of processing techniques to transform raw muscle food into edible products to increase palatability, digestibility and safety has been reported to influence the nutritional content, including minerals of the samples. Processing techniques such as pulsed electric field (low or high) [51] and thermal treatments (roasting, boiling, microwave cooking, sour-vide method) [53, 54] have been reported to either increase or reduce the mineral content of muscle food. Goran et al. [52] explained that water-soluble minerals such as potassium is easy to lose in muscle foods during boiling.

Effect of meat analysis methods on mineral composition

Analytical techniques used for providing information about the total mineral content have been reported to influence their composition. Minerals can be analysed using wet, dry or low-temperature plasma dry ashing methods and quantified using atomic absorption spectrophotometer, microwave and inductively coupled plasma-optical emission spectrometry/ atomic emission spectrometry, inductively coupled plasma-mass spectrometer or energy-dispersive X-ray fluorescence spectrometry [55]. The metal content analysis using dry ashing methods has been reported to be relatively higher in accuracy than that of the wet-ashing samples [56]. The dry ashing method has been recommended for the digestion of food items because it requires a lesser amount of chemical reagents and related hazards, and simple equipment to achieve better recovery [56].

Conclusions

Findings from this study have highlighted muscle food as an excellent source of macro- and micro minerals in the diet. The composition of mineral elements in muscle foods depends on breed, species, meat type, nutrition, thermal treatment, and sampling methods. Humans need to consume muscle foods regularly to prevent the deficiency of important minerals in the body. This is because plant food sources could not adequately supply all the micro and macro minerals need in the body for sound health. Further research is required to determine the influence of organic and inorganic (including conventional agro-food) feeding on micro and macro elements of muscle foods with respect to breed and species of livestock. In addition, more research should be focused on the effects of different sampling methods on mineral composition muscle foods as not many related reports are available in the literatures. It is important that a comprehensive study should be carried out to authenticate the effect of all aforementioned factors affecting the mineral composition of muscle food.

Conflict of Interest

The authors declared no conflict of interest.

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