Chapter

Vitamins and Minerals in Raw and Cooked Donkey Meat

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Abstract

Human health is deeply affected by nutrition. The most important nutritional property of a good diet, able to provide an adequate amount of nutrients, to fulfill growth and development requirements, permitting also health maintenance, is variety of foods. Meat can be included in several diets, particularly when they are based on a restricted choice of plant foods. The inclusion of meat and meat products, even in small amounts, can significantly improve many diets; in fact, meat and derived products are good sources of proteins, vitamins and mineral salts. Thermal processes used for cooking meats represent an important factor which affects the minerals and vitamins meat content. Loss of minerals and water-soluble vitamins in cooked meat may occur, depending on the cooking method used. Previous studies investigated on donkey meat nutritional properties, described interesting characteristics of this alternative red meat, rich in protein and in iron, and with low-fat content. This chapter describes the donkey meat chemical composition, showing a comparison with other traditional red meats. The effects of cooking methods on donkey meat vitamins and minerals content will be also evaluated.

Keywords: donkey, meat quality, vitamins, minerals, cooking methods

1. Introduction

Donkey's domestication started about 10,000 years ago [1]; this animal has been particularly important for humans, because it shows a great tolerance for hard work, a strong resistance to disease and a little maintenance requirement. Donkey is an animal strictly correlated to human history; it is possible to find texts mentioning donkey in literature, in religious books and in ancient poems. Because he is stoic, slow, and sometimes stubborn, donkey has not been considered a smart animal. Throughout human history, donkey has been sometimes revered, sometimes reviled or ridiculed. Donkey has been a constant presence since the earliest human societies formed. Their greatest use to humans has been as beasts of burden, from Ancient Egypt to present day in many countries both in Africa and/or in Asia, transporting several kinds of goods on their backs or pulling small carts.

The process of donkey's domestication is still not completely known; surely donkeys were first domesticated by ancient cattle herders because of the climatic changes, with lands becoming more arid and rainfall more unpredictable. Probably they have been domesticated several times by different groups of herders, while interbreeding among wild and domestic asses is continued throughout the entire domestication process [2]. Donkeys were bred mainly as working animals; livestock production, such as both meat and milk, were basically considered by-products.

Donkey domestication represents a crucial step in human history, creating a new phase in human populations, moving from a sedentary lifestyle to a new society with an economy based on trade.

2. Donkey breeding today

Actually, the total amount of donkeys all-over the world is about 44 million (**Table 1**), mostly in developing countries [3]. There are over 189 donkey breeds, showing body weights ranging from 80 to 480 kg, and heights at withers ranging between 64.2 cm of the smallest breed (Mediterranean Miniature Donkey) and 170 cm of the tallest breed (American Mammoth Jackstock).

In Europe 60 donkey breeds are actually classified, the most represented are listed in **Table 2**; however, this total amount cannot be considered fully accurate. In fact, among the 60 breeds listed, two of them must be unfortunately considered extinct, while five other breeds are basically synonymous. For six other breeds, only old data about their consistency are shown, while for other five breeds, the actual consistency is reported, but the description of phenotype or photos are not provided. For 14 breeds any values have been reported. Basically, only for 28 breeds morphologic description is really shown and the updated consistency is also reported [5].

2.1 Donkey meat production

Donkeys are normally not considered as meat producing animals. Bovines, buffaloes, and camels are usually bred as working animals, as well as for milk and meat production. On the other hand, among equids horse meat is considered a good alternative red meat, with specific dietary characteristics; its consumption registered in some countries, such as Spain, France, Poland, a significant increase in recent years [6]. Horse meat chemical composition is in fact characterized by low total fat and cholesterol content, a healthy ratio between saturated and unsaturated fatty acids and a good minerals content, especially iron and zinc [7]. Consumers, being more health conscious, actually look for foods with high standard quality, requiring leaner meat, with basically the minimal fat content necessary to maintain adequate sensorial properties, taking also into consideration meat tenderness, juiciness and flavor. The success of any food is directly correlated with consumer's acceptance. Meat quality as perceived by the consumers is strictly associated to its physical and chemical composition, even if quality requirements for meat acceptability by the consumers are not the same all-over the world.

Continent	Donkeys
Asia	15,000,000
Africa	9,700,000
Middle East	9,220,000
South America, Caribbean	8,164,000
Europe	1,500,000
North America	52,000
TOTAL	43,636.000

Table 1.
World donkeys distribution [4].

Country	Breed	Consistency
Croatia	Littoral dinaric	2,150
France	Ane de Provence	271
	Ane Normand	221
Italy	Ragusano	2,481
	Martina Franca	1,086
Portugal	Buro de Miranda	1,400
Spain	Catalana	957
	Zamorano-Leonés	1,338

Table 2.
Main donkey breeds in Europe [5].

Today China is the top producer of donkey meat in the world, followed by Niger (**Table 3**). Considering the well-known good reputation associated to horse meat, the aim of this chapter is to show the recent findings about donkey meat quality, describing its nutritional properties compared to other red meats, evaluating the effects of cooking methods on losses of minerals and vitamins compared to the original amount of these micronutrients in raw donkey meat.

2.2 Donkey meat quality

Donkeys can be considered an important meat producing animal in arid and semi-arid areas, but donkey breeding for meat production does not represent an important activity for farmers, because donkey meat has a bad reputation. In fact, in the countries in which donkeys are still used as working animals in agriculture, they are normally slaughtered at an advanced age, producing a meat unacceptably tough [9]. However, not all male donkeys can be used as stallion for reproduction, while breeding young males for meat production is an easy way to produce a cheap food, helping local farmers in increasing their own income. In fact, donkey is an animal with a great ability in surviving in extreme weather and environmental conditions, such as high temperatures, low rainfall and poor feed availability. So, donkey can be bred as a meat producing animal in regions where the weather conditions and the feed availability negatively affect other animal's production efficiency.

The term 'meat' is normally associated only to meat flesh, basically skeletal muscle plus the possible attached connective tissue or fat; the term offal describes

Country	Number of donkeys	Meat production (tons/year)
China	2,249,807	183,755
Niger	124,319	9,946
Burkina Faso	72,372	4,342
Senegal	52,581	3,155
Mali	50,598	3,036
Mauritania	22,920	2,521
WORLD	2,569,520	207,172

Table 3.
Donkey meat production in the world [8].

	Beef [11]	Lamb [11]	Pork [11]	Horse [11]	Donkey [12]
Water	71.6	70.2	66.0	75.2	73.7
Protein	20.3	19.8	20.8	21.1	22.8
Fat	8.1	9.9	13.2	3.7	3.5

Table 4.
Chemical composition (g/100 g) of muscle Longissimus thoracis *taken from domestic mammals.*

meat products different than meat flesh, such as brain, heart, kidney, liver, pancreas, spleen, thymus, tongue and tripe [10]. The term 'red meat' is traditionally associated to meat from beef, lamb and goat, even if equid meat can also be considered another kind of red meat [8]. In **Table 4** is shown the chemical composition determined in meat samples taken from beef, lamb, pork, horse and donkey; protein content is very similar in all the meats, while fat content is significantly lower in horse and donkey meat.

3. Meat as a source of vitamins

Meat shows an interesting content of all the B-complex vitamins, such as thiamine (vitamin B_1), riboflavin (vitamin B_2), niacin (vitamin B_3), biotin (vitamin B_8), pyridoxine (vitamin B_6), cobalamin (vitamin B_{12}), pantothenic acid (vitamin B_5) and folic acid (vitamin B_9). The last two show higher contents particularly in liver, which is rich in vitamin A and provides interesting amounts of the other fat-soluble vitamins D, E and K.

Red meat provides about 25% of the recommended dietary intakes for riboflavin, niacin, vitamin B_6, pantothenic acid and almost 70% of the daily requirement of vitamin B_{12} in 100 g of serving [10]. Lack of vitamin B_{12}, together with iron deficiency, is the main cause of anemia in human population.

Vitamins are chemically reactive molecules. Cooking methods affects the stability of several vitamins, causing significant losses in cooked meat. Other foods show significant decrease in vitamins content caused by thermal treatments. In vegetables, vitamin C and thiamine are the most susceptible to cooking degradation, while in fresh milk pasteurization caused a 25% loss of Vitamin C, which increased up to 60% after UHT treatment [13].

Vitamins B-complex is well represented in equid meat, too (**Table 5**). Horse and donkey meat have been recently investigated, showing nutritional properties remarkably similar to the most common red meats, such as beef, lamb and buffalo [14].

Vitamin	Horse meat	Donkey meat
Thiamine (mg/100 g)	0.04	0.02
Riboflavin (mg/100 g)	0.18	0.11
Niacin (mg/100 g)	5.54	4.03
Vitamin B_6 (mg/100 g)	0.64	0.48
Vitamin B_{12} (μg/100 g)	2.08	1.90

Table 5.
B-vitamins in equid meat [8].

4. Meat as a source of minerals

Living organisms need minerals to maintain a healthy condition. In fact, lack or deficiency of trace elements can produce diseases that are reversed once incorporated [15]. Several of the essential trace elements are metals: copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn), all of them involved in different metabolic reactions. Iron is also involved in the metabolism of the oxygen carrier hemoproteins, namely hemoglobin and myoglobin [16]. Humans obtain the recommended micronutrients intakes through diet [17].

Meat is the richest source of zinc in the diet and supplies one third to one half of the total zinc recommended daily intake. A zinc dietary deficiency has been detected in teenagers in the Middle East eating a poor diet mainly based on unleavened bread. Red meats such as beef and lamb are the richest sources of the minerals iron and zinc; a serving size of 100 g of red meat provides about 25% of daily adult requirements [10]. The iron in meat is mostly heme iron, which is well absorbed. Also zinc absorption is higher in animal source foods compared to plant foods; zinc requirements may be 50% higher for vegetarians. Red meats are also good sources of selenium, providing more than 20% of daily intake requirement. Lean meat is low in sodium, with a ratio potassium/sodium >5. The copper content in raw lean meat is in the range 0.055–0.190 mg/100 g in beef and veal, 0.090–0.140 mg/100 g in lamb, and 0.190–0.240 mg/100 g in mutton [10].

Minerals content has also been determined in both horse and donkey meat (**Table 6**); values obtained confirm the interesting nutritional properties of equid meat [19] compared to other traditional red meats.

5. Cooking meat

Cooking meat can guarantee food safety to the consumer. Meat can be cooked at high temperatures for long time, but this cooking method can affect meat nutritional and sensorial quality, with loss of water-soluble vitamins and thermolabile minerals [20].

Minerals	Horse [8]	Donkey [18]	Beef [10]	Lamb [10]	Veal [10]
Macroelements					
Potassium	191–203	312–438	363	344	362
Phosphorus	186–198	185–335	215	194	260
Sodium	52.6–68.1	36.8–83.6	51	69	51
Magnesium	18.5–33.6	38.7–43.3	25	28	26
Calcium	4.11–4.51	6.12–11.5	4.5	7.2	6.5
Microelements					
Iron	2.56–4.04	2.86–4.77	1.8	2.0	1.1
Zinc	2.07–2.66	2.99–4.71	4.6	4.5	4.2
Copper	0.13–0.21	N.D.	0.12	0.12	0.08
Manganese	0.01–0.002	N.D.	N.D.	N.D.	N.D.

Table 6.
Mineral content (mg/100 g) in different meats.

Meat proteins are differently affected by cooking temperatures. In the case of boiling or microwave cooking, temperature gets over 100 °C, causing proteins denaturation due to an enzymatic inactivation of lipases, proteases, etc. When cooking temperature ranges between 100 and 140 °C, that is the situation related to pressure cooking and baking, meat digestibility is reduced because of the formation of intramolecular and intermolecular covalent bonds [21]. In fried and roasted meat, when cooking temperatures are above 140 °C, amino acid destruction occurs, particularly cysteine or tryptophan, followed by an isomerization to D-configuration and a consequent reduction of the nutritional value [22].

Meat fat can undergo toward a fusion process after heat treatment, but it is hard to determine the exact melting point, because of the different triglyceride mixtures; depending on the type of fat, in fact, triglycerides decompose at a different temperature [23]. High cooking temperatures can sometimes form toxic cyclic monomers, dimers and polymers; this is the typical situation that occurs when acrolein is formed after high thermal treatments [24].

Purchased meat may include bone, external fat, gristle and tendons which are often removed before cooking, so that the meat composition “on the plate” can be quite different. Meat and meat products are considered cooked when the internal temperature is maintained at 65–70 °C for 10 minutes, with a consequent coagulation of the proteins and a meat tenderizing effect due to the partial hydrolysis of the collagen [25]. Most of meat bacteria will be destroyed during cooking, only thermoresistant spores can survive above 100 °C [26]. The end of the cooking process can be normally detected by a change of color from red to brown with an associated flavors development [27]. In fact, cooked flavor can be considered the result of several reactions affecting changes in fat and proteins, with heat breakdown of peptides and amino acids [28].

Meat obtained from animals slaughtered at older ages, as normally occurs in donkey breeding, is richer in connective tissue, therefore longer cooking times at 50–60 °C are necessary, because at this temperature collagen can be hydrolyzed [29]. If heated for long times at temperature above 80 °C, unpleasant flavors can be produced because amino acids begin to decompose; hydrolysis of collagen, in fact, is fast when high temperatures are used for only a short time [30]. Finally, water is lost during cooking, too. The loss of water is strictly correlated with cooking time, cooking temperature, cooling method, serving size, heat penetration and original meat chemical composition. Loss of water causes an increase in fat and protein concentration in cooked meat [27].

6. Effects of cooking methods on meat vitamins content

Meat cooking techniques show significant effects on vitamins content, especially considering the important losses of B vitamins complex [31]. Vitamin B_{12} and thiamine are the most affected B vitamins, while riboflavin and niacin show lower decreases [32]. B vitamins are water soluble and thermally instable, therefore some cooking methods, such as boiling, may provoke high vitamin losses, while shorter cooking time may reduce these losses [33].

In the juices exuded from meat during cooking are contained small amount of all the water-soluble constituents, minerals, proteins and vitamins. Losses of thiamine are normally in the range 15–40% in boiled meat, 40–50% in fried meat, 30–60% in roasted meat and 50–70% in canned meat. Average cooking losses of riboflavin are close to 10%. Riboflavin is relatively stable to most cooking methods, excluding the high temperature necessary for roasted meat. Canning and dehydration do not significantly affect riboflavin content, either. Niacin is quite stable to several thermal treatments: losses normally average about 10% in cooked meat [33].

There are not many data available about other B vitamins: according to a recent report, about 30% of the vitamin B_6 and pantothenate are lost in cooked meat [34].

7. Effects of cooking methods on meat minerals content

Minerals loss during meat cooking occurs, too; the amounts of these nutrients ingested with cooked meat could show great variations compared with their content in raw meat. For example, heme iron is converted after different thermal treatments in non-heme iron, the less available form of this mineral [35].

The most common methods normally used in order to determine trace elements content in foods are based on microwave-assisted digestion with mineral acids followed by a measurement using atomic spectrometry techniques [15].

Cooking process reduces the meat content of the trace elements like zinc, magnesium, iron, phosphorous; some of these nutrients can be completely lost after thermal treatments [36]. A study performed by Kimura & Itokawa [37] determined in home cooked hamburger an average loss of 56% of total minerals content, with the following values for each macro and micronutrients:

- Sodium (Na): - 54%
- Potassium (K): - 67%
- Phosphorus (P): - 66%
- Calcium (Ca): - 47%
- Magnesium (Mg): - 59%
- Iron (Fe): - 46%
- Zinc (Zn): - 71%
- Copper (Cu): - 41%

In the same study [37] cooking loss of minerals in pork was largest in zinc, followed by sodium, potassium, calcium, iron, magnesium and phosphorus. In these samples, cooking loss was correlated with the different cooking method, not on the type of mineral. A recent study [15] was performed with the aim of determining minerals content in beef cooked using two levels of doneness, respectively medium and well done. The results obtained for medium cooking level showed this range of minerals content (μg/100 g serving size):

- Cu (84.9–117.4);
- Fe (2288–2689);
- Mn (11.6–20.7);
- Ni (12.4–19.8);
- Zn (4100–7471);

For well-done cooking level the results obtained were in the following ranges:

- Cu (76.3–97.0);
- Fe (1886–2689);
- Mn (9.7–15.4);
- Ni (12.7–26.8);
- Zn (3187–6204).

No significant minerals loss was detected in meat when medium cooking level was applied and total amount of exuded juices caused a weight loss of 16%, but when the weight loss was 28–35%, following the well-done cooking level, minerals content significantly decreased in cooked meat.

8. Effects of cooking methods on donkey meat

A study has been performed at the University of Camerino, Italy, in order to detect minerals and vitamins B complex content in raw meat obtained slaughtering donkey males 20 months old. The influence of donkey meat cooking process on the retention of these micronutrients was also evaluated.

Twelve male entire crossbred (Romagnolo x Amiata) donkeys born and reared in the same farm in extensive conditions based on pasture were slaughtered at 20 months of age, with an average final body weight of 246 ± 20 kg. After slaughtering, all the carcasses were transferred to a cold room at a temperature of 4 °C; after 24 h, four samples of 600 g were taken from the muscle Longissimus thoracis (LT) at the height of the 12-14th thoracic vertebra.

From each carcass, two samples (300 g) of muscle LT were used for raw meat chemical analysis, the other two LT samples (300 g) were cooked in an oven at 170 °C for 45 min, following a common type of home cooking. Both raw and cooked meats were freeze-dried and then ground in a food blender to ensure homogeneity and representative samples for analysis [38]. B complex vitamins were quantified by HPLC after acidic and enzymatic hydrolysis of the samples [39].

To assess the minerals content in raw and cooked donkey meat was used a published guide [40] for calculating the mineral retention percentages in foods prepared using different cooking methods, normalizing a serving size portion of 100 g to the weight loss during cooking [31]. Macro (Ca, K, Mg, Na, P) and micro-elements (Cu, Mn, Fe, Zn) were mineralized using the Mileston Ethos 900 microwave; samples were analyzed by means of atomic absorption spectroscopy (AAS) equipped with a low-flow Gem Cone ultrasonic nebulizer for the detection of very low concentrations [41].

8.1 Vitamins and minerals losses in cooked donkey meat

Vitamins content in raw and cooked donkey meat is shown in **Table 7**. Niacin content was the most abundant vitamin determined in raw meat, followed by pantothenic acid, vitamin B_5, then pyridoxine, vitamin B_6. Thiamine content was higher compared to the same vitamin level determined in beef (0.04 mg/100 g), but lower compared to the content (0.12 mg/100 g) detected in lamb [10]. Higher contents of niacin (7.3 mg/100 g) and thiamine (0.16 mg/100 g) were found in horse fillet,

	Raw Donkey Meat	Cooked Donkey Meat
Thiamine – Vitamin B_1 (mg/100 g)	0.09 ± 0.01	Trace
Riboflavin – Vitamin B_2 (mg/100 g)	0.22 ± 0.07	0.18 ± 0.05
Niacin -Vitamin B_3 (mg/100 g)	6.09 ± 0.27	5,22 ± 0.16
Pantothenic acid – Vitamin B_5 (mg/100 g)	1.13 ± 0.23	0.99 ± 0.06
Piridoxine – Vitamin B_6 (mg/100 g)	0.61 ± 0.12	0.49 ± 0.08
Cobalamine – Vitamin B_{12} (μg/100 g)	1.80 ± 0.15	1.10 ± 0.04

Table 7.
Vitamin B complex content in raw and cooked donkey meat.

while riboflavin content was lower (0.20 mg/100 g) in this kind of meat, confirming the great variability in meat vitamins content among species [31]. Vitamin B_{12} level in raw donkey meat is close to the contents of this vitamin determined in different beef cuts [42].

Cooking procedure decreased B vitamins complex content, mainly thiamine, that resulted significantly reduced by thermal degradation, becoming hard to detect in the cooked meat analyzed. Niacin content showed a significant decrease after cooking, too: its retention was about 35%. Riboflavin resulted more stable to heat, showing a retention value close to 70%; these results confirmed the findings of Lombardi-Boccia et al. [31], who found in roast beef a complete riboflavin retention, a severe loss in niacin, while thiamine was basically undetectable. Vitamin B_{12} showed a significant decrease in cooked donkey meat, confirming the results obtained in cooked beef [43] and in grilled fish [44]; the Authors in both the cited studies attributed the loss of vitamin B_{12} to the destruction of this vitamin caused by the heating.

The effect of cooking procedure on minerals content in donkey meat is pointed out in **Table 8**. Cooked donkey meat did not show significant decrease in the iron content compared to raw meat; in a study performed on horse fillet [38], a significant loss in total iron content after cooking the horse meat 180 °C for 50 min was reported, confirming the effect of cooking time and temperature on minerals content. Previous studies [38, 45] demonstrated that in cooked meat total iron

	Raw Donkey Meat	Cooked Donkey Meat
Macroelements		
Calcium (Ca)	3.46 ± 0.64	3.15 ± 0.53
Potassium (K)	285.60 ± 26.8	228.17 ± 13.8
Magnesium (Mg)	24.36 ± 1.12	22.12 ± 1.23
Sodium (Na)	67.25 ± 3.31	72.84 ± 3.42
Phosphorus (P)	213.35 ± 11.4	204.43 ± 10.6
Microelements		
Copper (Cu)	0.21 ± 0.03	0,19 ± 0.05
Manganese (Mn)	0.03 ± 0.005	0.01 ± 0.004
Iron (Fe)	2.81 ± 0.38	2.39 ± 0.41
Zinc (Zn)	4.35 ± 0.13	3.90 ± 0.12

Table 8.
Mineral content (mg/100 g) determined in raw and cooked donkey meat.

content did not decrease compared to raw meat, but the heme/non-heme iron ratio was modified; the heme iron content decreased according to the different heat treatment utilized. Zinc content in donkey meat was not significantly affected by the cooking method (**Table 8**); this insoluble mineral is linked to proteins and tend to remain in the meat during cooking [27]. Among the other minerals, copper remained quite stable after cooking process, and the other minerals did not show significant differences, confirming the results obtained in a previous study [46].

9. Conclusions

Vitamins and minerals have been recognized to be particularly important in human nutrition. Meat provides significant amounts of nutrients, including thiamine, vitamin B_{12}, available iron and zinc. Physical and chemical changes in meat can be caused by different cooking methods. Meat tissue structure is affected by physical changes, regarding in particular meat sensorial characteristics such as color, texture, aroma, and taste.

The remarkable nutritional value of donkey meat is summarized in its low fat content, an interesting protein concentration together with a valid heme iron content showing that their consumption may be favorable for human health. The nutritional characteristics of donkey meat show interesting aspects in comparison to the usual red meat; when related to the human health parameters, this kind of meat can be favourably accepted by the consumers.

Production of donkey meat shows a very important potential to be considered in the economic development of many countries; there is a big challenge for the farmers to use donkeys as meat animals. Donkey, especially young males, can be used as cheap meat animals, and donkey meat can easily have a market in the western countries, considering the high quality level shown by this kind of red meat.

The loss of vitamins and minerals in cooked meat are due to the molecular interactions that occur when thermal treatment is applied. Cooking methods strongly affect trace elements and B vitamins content in meat, causing losses during cooking processes. The amount of these nutrients ingested with cooked meat could be hugely different compared to raw food, according to the different cooking methods. Cooked donkey meat showed lower values of thiamine and niacin compared to raw muscle, while riboflavin content was not significantly affected by cooking. Minerals retention in cooked donkey meat showed that zinc, copper and iron contents did not significantly decrease after thermal treatments. Donkey meat, rediscovering the local culinary tradition, can represent a valuable niche quality food in human diet.

Donkey meat production could help in taking care of many marginal lands of the world, where soil stability and animal biodiversity preservation represent hard worries. Donkeys possess a peculiar digestive physiology, being hindgut fermenter herbivores: for this reason, they can advantageously compete with big and/or small ruminants for pastures utilization. In order to fulfill this target, use of indigenous donkey breeds can help in preserving local animal biodiversity. Further studies must be performed to investigate on the effects of feeding on donkey meat quality. Moreover, no data are actually available about the presence in donkey meat of specific nutraceutical molecules, such as carnosine, carnitine and taurine.

Conflict of interest

"The authors declare no conflict of interest."

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