AGRICULTURAL BIOLOGY,
2022, V. 57, Iss. 4, pp. 681-693
[SEL'SKOKHOZYAISTVENNAYA BIOLOGIYA]

ISSN 2412-0324 (English ed. Online)
ISSN 0131-6397 (Russian ed. Print)
ISSN 2313-4836 (Russian ed. Online)

UDC 636.2:637.046

doi: 10.15389/agrobiology.2022.4.681eng
doi: 10.15389/agrobiology.2022.4.681rus

MINERAL COMPOSITION OF COW MILK — A MINI REVIEW

O.A. VORONINA✉, N.V. BOGOLYUBOVA, S.Yu. ZAITSEV

Ernst Federal Research Center for Animal Husbandry, 60, pos. Dubrovitsy, Podolsk District, Moscow Province, 142132 Russia, e-mail voroninaok-senia@inbox.ru (✉ corresponding author), 652202@mail.ru, s.y.zaitsev@mail.ru
ORCID:
Voronina O.A. orcid.org/0000-0002-6774-4288
Zaitsev S.Yu. orcid.org/0000-0003-1533-8680
Bogolyubova N.V. orcid.org/0000-0002-0520-7022
The authors declare no conflict of interests
Acknowledgements:
Supported financially by Ministry of Science and Higher Education of the Russian Federation (НИОКТР АААА-А18-118021590136-7). Registration number ЕГИСУ theme НИР ГЗ 2021-2023 121052600314-1
Received June 22, 2021

Abstract

Milk is a secretory product of the mammary glands which synthetic capacity is extremely high at the peak of lactation. Cow's milk is a generally recognized source of Ca, K, Mg, Na, P, Se, and Zn for human nutrition. About 50 mineral elements were found in milk (A.V. Skalny, 2019). Given the fact that the deficiency of micro- and macroelements is becoming global (R.L. Bailey, 2015; A.V. Skalny, 2019), interest in milk to solve this problem is increasing (M.L. Astolfi, 2020). Milk is the only source of nutrients for newborn calves. The composition and proportions of milk components are optimal for their gastrointestinal absorption, which ensures the successful survival of the species. The quantity and structural composition of macro- and microelements of milk are complementary to active anabolism and the development of the musculoskeletal system, in particular the skeleton of young animals. The purpose of our review is to summarize relevant data on micro- and macroelements in milk with regard to their biological role in cows. Comparative analysis shows a wide range of mineral content of milk. The content of Zn can vary from 3.09 to 6.48 mg/kg, Cu from 0.83 to 1.73 mg/kg (S.M. Zain, 2016; S. Kinal, 2007). This may be due to i) alimentary factors (A. Costa, 2021) which are closely related to the natural distribution of micro- and macroelements in the Earth's crust (S.M. Zain, 2016) and ii) synergistic and antagonistic interactions of elements in their assimilation (N. Bortey-Sam, 2015; A.V. Skalny, 2019). For example, an excess of potassium and calcium reduces the absorption of magnesium and phosphorus (A.V. Skalny, 2019), and a deficiency of vitamin D disrupts the absorption of Ca (W.P. Weiss, 2017). We also note the variability of the mineral content depending on the lactation period, season of the year (S.M. O'Kane, 2018; E.S. Kandinskaya, 2019), type of housing and feeding (V.S. Kozyr, 2015; I. Orzhales, 2018). Milk iodine and selenium concentration measured by inductively coupled plasma mass spectrometry were higher than indicated in previously created food composition databases (S.M. O'Kane, 2018). Thus, reliance on previously created databases should be partial when choosing milk as a source of mineral components to compensate for the identified deficiency in the human diet. Newly formed databases should be more accessible to the consumer. In addition, molecular tools should help to identify target genes and proteins as markers for assessing the level of macro- and microelements (W.P. Weiss, 2017; A. Costa, 2021), but so far little progress has been made in this research area. Precise elemental analysis of milk is necessary both to confirm its safety in terms of toxic macro- and microelements, and to solve the mineral deficiency problem.

Keywords: cow milk, mineral composition, microelements, macronutrients, fodder, blood

Milk is a complex biological fluid whose nutritional value cannot be overestimated [1]. The dairy diet plays an important role in preventing the development of chronic diseases [2, 3] such as obesity, diabetes, cancer, and some cardiovascular diseases [2, 3]. The fact of the value of milk for human nutrition (1, 3) is of constant interest in different countries [5, 6] among scientists representing different fields of science [2, 4-6].

An important area of modern milk research [1, 7] is the biochemistry of milk and dairy products [8-12]. In the work of M.L. Astolfi et al. [8] clarifies the well-known notion that cow and goat milk are important sources of macro- and micronutrients (MMEs) [1], in particular Ca, K, Mg, Na, P, Se and Zn [8]. Plant analogues (soybean, rice, oat, almond, coconut milk) lose to animal milk in terms of the content of both MME and other substances [8]. At the same time, soy and coconut milk are good sources of magnesium, while hazelnut milk is rich in sodium ions [8]. In their review, S. Sethi et al. [9], while recognizing the competition of the rapidly developing market for plant-based milk, note that most of the alternatives to cow's milk (type of plant-based milk) lack the nutritional balance of MME required by humans. Vegetable types of milk are inferior to animal milk in a number of parameters, and their use is considered rather as a forced measure (8, 9). At the same time, functionally active components, which the manufacturer focuses on, are the only advantage of vegetable milk types that contribute to the solution of narrow, point problems [9, 10], while about 50 macro- and microelements were found in the composition of cow's milk, which are optimally balanced [1, 11].

Milk feeding is a certain strategy of evolutionary development in mammals, their care for offspring and, as a result, the survival of the species. Milk production involves not only the mammary gland, but also various organs and systems, carrier molecules [12]. As a result of the enzymatic transformation of macro- and microelements of feed [13], a composition [1, 14] is formed with the ratio and balance of milk components [15], contributing to their better intestinal absorption and utilization [13, 14]. This is important, since the nature of all interelement relationships changes from an excess or deficiency of only one micro or macro element [15, 16], which affects and disrupts the work of a number of organs and systems [17-19]. In addition, the interaction of MMEs with each other during digestion and absorption may be accompanied by synergistic and antagonistic effects [15, 16]. So, the presence of mercury and arsenic leads to a deficiency of selenium, cadmium to a deficiency of selenium and zinc, calcium to a deficiency of zinc and phosphorus, iron to a deficiency of copper and zinc, manganese to a deficiency of copper and magnesium, molybdenum to a deficiency of copper, zinc to a deficiency of copper and iron [15]. In addition, soil-forming rocks, the composition of water and air [20] in different parts of the earth's surface are often characterized by an uneven distribution of MMEs [21], which largely determines the composition of microorganisms, plants and animals [21]. Environmental dispersion of MMEs (mainly metals) during mining and use leads to serious anthropogenic pollution [17]. This affects both the health of lactating cows and the quality of milk, the composition of which is directly affected by processes occurring in the environment [17, 19, 22].

In a number of comprehensive studies [12, 13] to elucidate the metabolic mechanisms of milk production [18], for example, in the work of H. Sun et al. [23], simultaneously assessed ruminal fluid, milk, blood serum and urine. It is noted that, compared with a biochemical blood test [15, 24, 25], the analysis of the composition of milk is more indicative in assessing the mineral status of an animal [15, 23]. In addition, information on the composition of milk by MME can be used both to assess the balance of MME in the diet of dairy cows, and to inform the end consumer about the level of MME in the product.

Although many researchers [10, 15, 26] have focused on global micronutrient deficiencies [15, 26] and how to improve the efficacy and safety of providing human MME through food [15, 26, 27], little attention has been paid to informing the final consumer about the composition of food products, in particular milk, according to MME. In Russia, the amount of information provided to the consumer on the packaging of milk is strictly regulated [27] by the Federal Law of the Russian Federation No. 88, the technical regulation for milk and dairy products dated 06/13/2008, as amended on 03/22/2014 and the technical regulation of the Customs Union 033/2013 “On the safety of milk and dairy products” from 09.05.2014. The documents prescribe the rules for labeling milk and dairy products (the content of fat, proteins, carbohydrates in the finished product as a percentage or in grams per 100 g of the product, energy value in calories or kilocalories is indicated), but it does not regulate the procedure for informing consumers about the content of MME. However, the content of MME and vitamins in the finished product is indicated only in case of enrichment, that is, their additional introduction into the finished product.

The purpose of the presented mini-review is a comprehensive analysis of data on the content of micro- and macroelements (MME) in cow's milk, taking into account the biological role of MME in the animal's body.

Under industrial conditions, the composition of MME milk [28, 29] is influenced by the main diets and feed additives used [16], the characteristics of animal metabolism [30, 31], the technology of their maintenance [32] and milking [33], productivity [34], genetic characteristics [35], season [36], age at first calving [37] and other factors [38, 39]. During the lactation dominant period, the intake of metabolites, in particular MME, into the mammary gland is a priority [12]. In case of MME deficiency, the reserves of these metabolites are mobilized from their depots in the blood, bones, muscles, liver, skin, and adipose tissue [24, 25, 40].

Calcium and phosphorus (Ca, P). These elements are necessary for the formation of calf bone tissue, since the processes of their absorption from the intestine and participation in the process of ossification proceed simultaneously [15]. Calcium is essential for transmission of nerve impulses and muscle contraction, blood clot reaction and many other procssess [24, 25]. E.S. Kandinsky et al. [41] found that the average content of Ca in raw milk of Holstein and Black-and-White cows ranged from 0.7 to 1.1 g/l. In the same study [41] a trend towards an increase in the amount of Ca in milk obtained in the autumn period was noted. It is known [12, 41] that whatever the content of Ca and P in cow's milk, their ratio tends to a ratio of 1:1-1.4:1. It is worth noting the role of phosphorus in maintaining the cellulolytic function of rumen microorganisms [42], as well as in the synthesis of microbial protein, which is extremely important for ruminants [12, 42].

In addition, since Ca and P are important constituents of casein micelles [14, 43], these chemical elements also influence the rennet coagulation ability of milk. M. Malacarne et al. [43] found that milk with the highest content of protein fractions and minerals, low concentration of chlorides and high values of titratable acidity is most suitable for cheese production [1, 11, 43]. Non-curdling milk had high pH values and low titratable acidity [43]. For the formation of casein micelles, the highest values of colloidal Ca associated with P caseins are optimal. However, excessive mineralization can lead to a decrease in the amount of casein phosphate groups available for curd formation [43].

Sodium and potassium (Na, K). Sodium [24, 25] plays an important role in maintaining the buffer capacity of the blood, activating digestive enzymes [12], regulating nerve and muscle conduction, and water-salt metabolism. Potassium maintains osmotic pressure [24, 25], regulates acid-base balance, participates in the transmission of nerve impulses, muscle contraction, transport of oxygen and carbon dioxide, in phosphorylation of creatinine, acts as an activator or cofactor of enzymatic reactions [12, 24, 25]. Using the atomic emission method, it was found that milk is 350.3-427.2 mg/kg sodium and 1159.8-1337.9 mg/kg potassium [44]. The amount of Na in milk increases during lactation, while the amount of K decreases. Subclinical mastitis and intrauterine infection increase Na concentration and decrease K concentration in milk [45].

Magnesium (Mg). This chemical element is part of and affects the activity of more than 300 enzymes [24, 25] that regulate bioenergetic processes in the body [15], the activity of the cardiovascular system and the level of fats in the blood [25]. Extracellular magnesium is necessary for the functioning of the nervous system, the functioning of muscle tissue, and the formation of bone tissue. Hypomagnesemia is the main cause of herbal tetany.

Copper (Cu). Copper affects the activity of enzymes responsible for the oxidation of metabolites and cellular respiration [12, 15, 25]. Cu stimulates the production of sex hormones, thyroxine and neurotransmitters [24, 25], is necessary for heme synthesis, mobilization and transport of iron from the liver to the bone marrow [46] and maintenance of erythropoiesis [24, 46]. Cu ions facilitate the process of excitation transmission in the brain [15]. The role of copper is extremely important for the formation of connective tissue (cartilage, ligaments, vessel walls), since it is copper that catalyzes the formation of desmosine cross-links in collagen and elastin [12]. Cu is a component of superoxide dismutase (EC 1.15.1.1) [24], which protects cells from oxidative metabolites and is important for maintaining active phagocytosis [15]. It is known [1] that elevated concentrations of Cu in milk lead to the risk of developing oxidative processes and the appearance of a specific taste [11]. Cu deficiency leads to a decrease in the bioavailability of iron deposited in the liver [15, 46]. Over time, this causes changes in hematological parameters, which manifests itself in the form of normocytic normochromic or hypochromic microcytic anemia [46]. Primary copper deficiency in dairy cows is associated with biogeochemical provinces in which copper is less abundant, secondary is caused by excessive intake of antagonists [15], the molybdenum, sulfur, iron and zinc, which reduces the absorption of copper from the gastrointestinal tract [46].

Cobalt (Co). Co is a component of vitamin B_{12} (cobalamin), which is synthesized by rumen microorganisms [12]. The lack of Co and, as a result, vitamin B_{12}, is especially acute during active cell proliferation, in particular in the hematopoietic system [15]. Young animals are most susceptible to Co deficiency [12] because their liver reserves of vitamin B_{12} are still low, while adults may have enough vitamin B_{12} for several months.

Iron (Fe^{2+}). Ferrous iron is a vital element [15, 24], which is involved in metabolism in the form of Fe^{2+} (in the composition of hemoglobin, myoglobin) or in the form of the Fe^{2+}/Fe^{3+} redox pair (for example, in respiratory chain enzymes). Its main function is associated with the transport of oxygen and carbon dioxide in the composition of hemoglobin [25], participation as a cofactor for the implementation of the function of electron transport chain enzymes and a number of other enzymes [25]. It should be noted that iron deficiency is rare in adult animals [46], which is associated with a significant prevalence of iron in the environment, as well as contamination of roughage with soil [12, 15], but often manifests itself in calves before weaning [46, 47] . The bioavailability of Fe from mammalian milk does not always fully satisfy the needs of offspring [12, 47]. Perhaps this is the exceptional case when, with the problem of Fe deficiency, milk should be excluded from the diet. In our opinion, this is due to the presence in milk of a large number of Fe antagonists - phosphates, manganese, nickel and selenium, since they prevent the absorption of Fe in the proximal small intestine [15, 47]. In turn, J. Joerling and K. Doll [47] attribute the low level of Fe and the development of anemia in calves mainly to their feeding with whole milk without food additives. Of course, this fact should also be taken into account when prescribing a diet for patients with anemia and using milk substitutes prepared from plant materials, as demonstrated in the work of M.L. Astolfi et al. [8]. In this case, soy milk and coconut milk will better provide the need for Fe, in addition, these products do not contain such an amount of Fe antagonists that prevent its absorption.

Iodine (I). Iodine is an essential trace mineral [15, 25] that comes from the oceans [15]. It is necessary for the synthesis of thyroid hormones that regulate energy metabolism [24], growth and development [25], and to some extent the transmission of nerve stimuli and brain development [48, 49]. During lactation, active synthesis of thyroid hormones occurs [12], which requires a large supply of iodine to the thyroid gland [12, 48]. In addition, most dietary iodine is excreted in milk and urine [12, 15]. Milk can contain between 530.40 and 588.85 micrograms of iodine per liter [50]. It depends on the source of iodine and its content in the feed, the presence of antagonists, the choice in favor of iodine-containing preparations for the disinfection of udder teats [48, 49]. Milk and dairy products are considered important sources of iodine [48, 49], which is especially important for areas with severe iodine deficiency, the Western (Tyumen region, Bashkiria) and Eastern (Krasnoyarsk Territory, Yakutia, Tyva) Siberia, as well as in regions of Russia affected by the accident at the Chernobyl nuclear power plant, which are endemic for goiter [15, 26].

In the work of A. Costa et al. [49] on a sample of 4072 cows found that the iodine content in cow's milk is a trait that is inherited with a low frequency. Thus, breeding strategies are significantly inferior to feeding strategies in terms of the effectiveness of increasing the level of iodine in milk.

Manganese (Mn). The greatest accumulation of manganese is characteristic of the pituitary gland, liver, inorganic matrix of bone tissue, thyroid and pancreas, as well as the mammary gland during lactation [12]. Mn-superoxide dismutase (EC 1.15.1.1) [51] together with other antioxidants limits the accumulation of reactive oxygen species [3, 51]. The lack of manganese intake in the body of calves leads to slow growth, abnormalities in the development of the skeleton, which is associated with a lack of enzymes galactotransferase and glycosyltransferases (EC 2.4) [12]. The content of manganese in milk can vary from 51.24 to 101.84 μg/l [50].

Zinc (Zn). Zinc is a component of many metal-containing enzymes [24, 25] that are directly involved in the metabolism of carbohydrates, proteins, lipids, and nucleic acids [12, 15]. Examples are Zn- and Cu-containing superoxide dismutase (EC 1.15.1.1) [3, 51], carbonic anhydrase (EC 4.2.1.1), alcohol dehydrogenase (EC 1.1.1.1), RNA polymerase (EC 2.7.7) [12, 15]. Zn is involved in the regulation of cell division, reproduction of offspring, production of proteins and digestive enzymes [15, 25]. The content of zinc in milk, according to various sources, varies greatly, from 3.09 to 6.48 mg/kg [22]. The introduction of chelate forms of Zn, Cu, Mn into the diet of highly productive cows increases milk yield by 6.5% for 305 days of lactation, positively affects the level of MME and immunoglobulins in colostrum [52, 53].

Selenium (Se). Se acts as a powerful immunostimulant, participating in the regulation of the formation and activity of T-helpers, natural killers, and the phagocytic activity of neutrophils [54, 55]. Its antioxidant properties are realized through the action of enzymes containing selenocysteine (eg, the glutathione peroxidase family, EC 1.11.1.9) [29, 55]. Se is found in proteins involved in thyroid hormone metabolism, iodothyronine deiodinases (EC 1.21.99.4 and EC 1.21.99.3), and thus affects metabolism [55]. Se directly in milk prevents the accumulation of lipid peroxidation products [3, 12, 29]. Organic forms of selenium in the diet of dairy cows increased the milk content of Se up to 57.25 rg/l on day 90 of the experiment vs. 21.98-25.25 μg/l in the control [29].

Quantitative composition of macro- and microelements and its formation. In a comparative analysis of the results of studies performed in the period from 2005 to 2018 (Table 1), a strong variation of milk samples in terms of the quantitative composition of MME is obvious [22, 29, 44, 50, 52, 53, 55-58].

1. The reported content of mineral elements in cow milk

Element	Concentration
Ca	1.273-2.156 μg/ml [56], 1.06-1.20 g/kg [53], 0.81-0.85 g/kg [52], 942.2-1009.3 mg/l [57]
P	719.93-1216.55 μg/ml [56], 0.95-1.01 g/kg [53], 0.88-0.93 g/kg [52]
Na	350.3-427.2 mg/kg [44], 0.47-0.49 g/kg [52], 321.3-452.9 ml/l [57], 372-495.1 mg/l [22]
K	1159-1337 mg/kg [44], 1474-1550 mg/kg [22], 764.7-1206.5 mg/l [57]
Mg	119.7-130.9 μg/ml [56], 0.11-0.13 g/kg [53], 0.095-0.097 g/kg [52], 62.8-128.3 ml/l [57]
Fe	0.198-0.258 μg/ml [56], 1.33-4.58 mg/kg [22], 0.16-0.63 mg/l [57], 1.01-3.48 mg/kg [22]
Cu	1.49-1.73 mg/kg [53], 65.37-89.85 μg/l [50], 0.83-1.30 mg/kg [22], 0.01471-0.1420 μg/ml [56]
Zn	3.69-4.98 mg/kg [53], 3085.42-3163.68 μg/l [50], 3.09-6.48 mg/kg [22], 2.026-4.800 μg/ml [56]
Mn	0.02 μg/ml [55], 51.24-101.84 μg/l [50], 0.08 mg/kg [22], 0.0116-0.0407 μg/ml [56]
Mo	10.39-10.65 μg/l [50], 0.05-0.098 mg/kg [22]
Co	5.16-8.34 μg/l [50]
I	530.4-588.9 μg/l [50], 423.1-534.3 μg/kg [58]
Se	0.0100-0.0209 μg/ml [56], 22.44-39.20 μg/l [50], 21.98-57.25 μg/l [29]

N o t e. Reference [55] gives data for the Simmental and Holstein-Friesian breeds.

For example, Zn in milk has been reported to range from 3.09 to 6.48 mg/kg [22], Cu from 0.83 mg/kg [22] to 1.73 mg/kg [53], Ca from 0.81 g/kg [52] to 1.20 g/kg [53]. A comparative study of the MME composition in the Simmental and Holstein-Friesian rocks, carried out by R. Pilarczyk et al. [56] showed the best combination of MME in Simmental milk. It contains more Fe, Mg and less Pb and Cd [56]. In the work performed in 2016 by S.M. Zain et al. [22] Ca, Na, Fe, Zn, Mn, K, Ba and Mg have been identified as key mineral elements in a comparative study of Malaysian milk and milk from other regions of the world [22]. Such a difference is obviously related to the composition of the MMEs of soils characteristic of specific geographic zones [17].

In turn, the widespread use of MME additives in the feeding of dairy cattle [29, 52, 57-59] and anthropogenic impact [20, 21] make their own adjustments to milk autoinfection by MME composition [22], which requires regular analysis and timely introduction of the obtained results. results into current databases. S.M. O'Kane et al. [58] showed that in 2018 iodine and selenium concentrations were higher vs. current UK food composition databases.

Undoubtedly, methods of analysis play their role in determining the amount of MME in milk. W.P. Weiss [59] reports this in sufficient detail.. The development of flame spectroscopy has greatly simplified elemental analysis [59] and increased the analytical sensitivity. The late 1960s saw a boom in research on Co, Cu, Fe, Mn, Se, J, Zn, and many other elements [15, 59]. Currently, 22 MMEs are classified as subject to rationing in the preparation of the diet of dairy cattle [59]. Š. Zamberlin et al. [10] identify 20 MMEs as essential in human nutrition, and again, all of these are found in milk. The elemental composition of milk is directly related to the quality of the elemental nutrition of dairy cows. Modern methods of analysis available for monitoring MME in feed, biological fluids and tissues are atomic absorption spectrometry [52, 57], inductively coupled plasma atomic emission spectroscopy [56], inductively coupled plasma mass spectrometry [50, 60], atomic fluorescence spectrometry [29]. Their use makes it possible to multiply the speed and accuracy of studies performed simultaneously on several MMEs when monitoring diets, the elemental status of animals, and the quality of dairy products.

At present, attempts are being made to apply molecular methods to elemental analysis [59]. For example, the possibility of identifying specific genes and proteins as markers for assessing the level of MME is being considered. L.A. Sinclair et al. [60] tested the effect of Cu source on mRNA expression in the liver. However, the authors did not observe an effect ($p > 0.05$) both in the presence of copper antagonists (S and Mo) and without them.

The study of breed characteristics as a factor influencing the quantitative composition of MME in milk [56, 57] showed that Simmental cows, in comparison with Holstein cows, had more Ca, Mn, Se and significantly more Fe and Mg ($p < 0.05$) [56]. An assessment of the content of mineral elements in the milk of six different breeds (Simmental, Holstein-Friesian, Black-and-White and Red-White, Polish Red, White-tailed) showed that the milk of Simmental cows and native breeds contained more K, Ca, Na, Mg, Zn, Fe [57]. The authors emphasize that aboriginal and Simmental breeds of cows received more green fodder in comparison with Holstein-Friesian, Black-and-White and Red-White cows [57].

Productive longevity of dairy cows and mineral metabolism. Lactation as a physiological process is associated with increased metabolic load [61-63]. Different stages of lactation are accompanied by characteristic hormonal, hematological, biochemical and immunological changes [61, 62]. According to A. Sundrum [64], the functional adaptations that occur in a lactating cow affect the entire body. So, at the peak of lactation, S.B. Kim et al. [61] observed a decrease in hemoglobin and hematocrit, an increase in the concentration of urea nitrogen and total cholesterol, an increase in the activity of alanine aminotransferase (EC 2.6.1.2) [61]. High milk productivity inevitably affects mineral metabolism [61, 62]. The most striking example of this is paresis of smooth and striated muscles caused by active excretion of Ca with milk [59, 61] in the first days and even hours [64] after calving. The early lactation period is characterized by an increased need not only for Ca (6.8-fold), but also for glucose (2.7-fold), amino acids (2-fold), fatty acids (6.8-fold) [64]. Purposeful selection to increase milk production has significantly increased the gap between the consumption of resources in the body and the ability to consume them [64, 65]. This also applies to MME. The energy expended to ensure high milk production, the animal replenishes at the expense of its own tissues [65], which leads to chronic metabolic acidosis [64, 65]. Under such conditions, even increased absorption of Ca from the intestine and mobilization of this element from the bone tissue depot does not maintain a normal level of electrolyte in the blood [64].

Therefore, it is necessary to regularly monitor the condition of lactating animals. In Table 2 we present some data on the blood MME in the of dairy cows [12, 66].

2. The reported content of mineral elements in cow blood

Element	Concentration
Ca	2.50-3.11 mmol/l [25], 1.90-2.33 g/kg [53], 2.53±0.25 mmol/l [61]
P	1.45-2.10 mmol/l [25], 1.94±0.06 mmol/l [61], 1.57-2.42 g/kg [53]
Na	139-148 mmol/l [25]
K	4.1-4.9 mmol/l [25]
Mg	0.5-1.5 mmol/l [25], 1.14-1.30 g/kg [53], 1.08±0.08 mmol/l [61]
Fe	17.9-29.0 mmol/l [25], 29.7-39.7 mmol/l [24], 26.5-29.2 μmol/l [60]
Cu	0.593-0.776 mg/l [63], 5.14-5.54 mmol/l [24], 12.8-13.5 μmol/l [60]
Zn	0.851-0.87 mg/l [63], 16.54-18.83 μmol/l [53], 10.2-10.6 μmol/l [60]
Mn	2.72-4.48 μg/l [63]
Mo	13.1-36.2 μg/l [63], 0.16-0.36 μmol/l [60]
Co	0,.884-1.111 μg/l [63]
I	48.4-83.6 μg/l [63]
Se	33.9-59.8 μg/l [63], 118.19-125.08 μg/l [29], 0.08-0.16 mg/l [55]

Obviously, blood MME composition is less variable due to homeostatic regulation [67, 68]. The determining factor in maintaining productive longevity will be how well the body copes with metabolic stress in both the short and long term [64, 65].

Should not lose sight of the fact that that in large livestock complexes with a strictly regulated type of feeding and composition of the diet, the influence of geographical location (including geochemical provinces) on the mineral status of the animal and the quality of dairy products is either minimal or completely leveled by the introduction of appropriate mineral additives into the diet. In organic production, both the mineral metabolism of animals and the quality of the products obtained from them depend to a greater extent on local conditions (66). So, with free grazing and feeding with silage, the content of As, Cr, Fe, Pb increased in milk. Undoubtedly, in such cases, it is also possible to normalize MMEs and introduce them additionally into the diet; however, it will be more difficult to exclude and/or take into account the influence of MMEs that are characteristic of the area and supplied with feed. Alternatively, one can take into account the presence, for example, of an excess amount of iron in water, soil, feed, and introduce iron antagonists into the diet or water, preventing its excessive intake into the body. The concentrated type of feeding enriches milk with Co, Cu, I, Se, Zn [66], however, it has its own peculiarities of influencing the health of productive animals (we do not touch on these issues in this publication).

Summing up the discussion of the macro- and microelement composition of cow milk, and the factors determining its formation, we note that, in our opinion, a system of measures is needed to ensure the possibility of using milk as a product that compensates for the deficiency of human elemental nutrition. Firstly, it is necessary to form a sufficient number of healthy livestock with milk productivity corresponding to the physiological capabilities of the animal organism. Secondly, the feeding of dairy cows should be balanced according to MME, taking into account local characteristics (in particular, data on the composition of MME in soil and water, distance from enterprises that are potentially dangerous and pollute the environment with toxic MME, seasonality of conditions, macro - and the microelement composition of feed, especially imported ones). Thirdly, it is important to regularly monitor the MME in milk, indicating reliable and accurate information about the finished product.

It may also be worth paying more attention to the use of local native breeds in dairy cattle breeding, focusing on their adaptive potential for the use of MMEs.

So, cow milk is considered a generally recognized source of macro- and microelements (MME), in particular Ca, K, Mg, Na, P, Se, Zn, in human nutrition. The content of MME in milk is determined by the geochemical conditions of the region (mainly with loose housing) and feeding (taking into account the addition of MME in one form or another). The quantitative composition of milk MME is indicative in assessing the mineral status of dairy cows and the balance of MME in their diet, which is important for normalizing metabolism, ensuring productive longevity of the animal, growth and development of young animals. When choosing milk as a source of mineral elements to compensate for their deficiency in the human diet, it is possible to use previously created databases only in part of the information confirmed by modern methods of qualitative and quantitative analysis. To use cow's milk as a product of functional (elemental) human nutrition, a system of measures is needed, including the formation of an appropriate livestock, control of feeding according to the balance and composition of MME, and monitoring of MME in milk. Reliable and accurate information about the quality of the finished product, in particular, its mineral composition should be available to the consumer.

REFERENCES

1. Gorbatova K.K., Gun'kova P.I. *Biokhimiya moloka i molochnykh produktov* [Biochemistry of milk and dairy products]. St. Petersburg, 2010 (in Russ.).
2. Komine-Aizawa S., Ito S., Aizawa S., Namiki T., Hayakawa S. Cow milk exosomes activate NK cells and γδT cells in human PBMCs in vitro. *Immunol. Med.*, 2020, 43(4): 161-170 (doi: 10.1080/25785826.2020.1791400).

3. Khan I.T., Nadeem M., Imran M., Ullah R., Ajmal M., Jaspal M.H. Antioxidant properties of Milk and dairy products: a comprehensive review of the current knowledge. *Lipids Health Dis.*, 2019, 18(1): 1-14 (doi: 10.1186/s12944-019-0969-8).
4. Pipino C., Mandatori D., Buccella F., Lanuti P., Preziuso A., Castellani F., Grotta L., Tomo P., Marchetti S., Pietro N., Cichelli A., Pandolfi A., Martino G. Identification and characterization of a stem cell-like population in bovine milk: a potential new source for regenerative medicine in veterinary. *Stem Cells and Development*, 2018, 27(7): 1587-1597 (doi: 10.1089/scd.2018.0114).
5. Rahman M.M., Gofur M.R., Rahman M.S., Bari F.Y., Juyena N.S. Effect of genotype on reproductive and productive performances of dairy cows under rural context in Bangladesh. *International Journal of Livestock Research*, 2016, 6(6): 9-24 (doi: 10.5455/ijlr.20160412082206).
6. Dufrasne I., Istasse L., Lambert R., Robaye V., Hornick J.L. Study on environmental factors influencing the urea content of cow milk in Wallonia (Belgium). *Biotechnologie, Agronomie, Sociйtй et Environnement*, 2010, 14: 59-66.
7. Shuvarikov A.S. *Izvestiya TSKhA*, 2012, 6: 186-193 (in Russ.).
8. Astolfi M.L., Marconi E., Protano C., Canepari S. Comparative elemental analysis of dairy milk and plant-based milk alternatives. *Food Control*, 2020, 116: 107327 (doi: 10.1016/j.foodcont.2020.107327).
9. Sethi S., Tyagi S.K., Anurag R.K. Plant-based milk alternatives an emerging segment of functional beverages: a review. *J. Food Sci. Technol.*, 2016, 53: 3408-3423 (doi: 10.1007/s13197-016-2328-3).
10. Zamberlin Š., Neven A., Havranek J., Samaržija D. Mineral elements in milk and dairy products. *Mljekarstvo*, 2012, 62: 111-125.
11. Zabodalova L.A., Evstigneeva T.N. *Tekhnologiya tsel'nomolochnykh produktov i morozhennogo* [Technology of whole milk products and ice cream]. St. Petersburg, 2013 (in Russ.).
12. Kharitonov E.L. *Fiziologiya i biokhimiya pitaniya molochnogo skota* [Physiology and biochemistry of dairy cattle nutrition]. Borovsk, 2011 (in Russ.).
13. Kharitonov E.L., Panyushkin D.E., Makar Z.N. *Niva Povolzh'ya*, 2019, 1(50): 79-86 (doi: 10.26177/VRF.2019.1.1.010) (in Russ.).
14. Zaitsev S.Yu., Voronina O.A., Dovzhenko N.A., Milaeva I.V., Tsarkova M.S. Comprehensive analysis of the colloid biochemical properties of animal milk as complex multicomponent system. *BioNanoScience*, 2016, 4(6): 1-8 (doi: 10.1007/s12668-016-0389-4).
15. Skal'nyy A.V. *Mikroelementy: bodrost', zdorov'e, dolgoletie* [Trace elements: vitality, health, longevity]. Moscow, 2019 (in Russ.).
16. Kryukov V.S., Kuznetsov S.G., Nekrasov R.V., Zinov'ev S.V. *Problemy biologii produktivnykh zhivotnykh*, 2020, 3: 27-54 (doi: 10.25687/1996-6733.prodanimbiol.2020.3.27-54) (in Russ.).
17. Beznosova E.A., Beznosov G.A., Ustyugov A.D., Flefel' Kh.E. *Agrarnyy vestnik Urala*, 2019, 5(184): 28-32 (doi: 10.32417/article_5d5157e47a3e85.50147466). (in Russ.)
18. Baumgard L.H., Collier R.J., Bauman D.E. *A* 100-year review: regulation of nutrient partitioning to support lactation. *Journal of Dairy Science*, 2017, 100(12): 10353-10366 (doi: 10.3168/jds.2017-13242).
19. Bortey-Sam N., Nakayama S.M.M., Ikenaka Y., Akoto O., Baidoo E., Yohannes Y.B., Mizukawa H., Ishizuka M. Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa, Ghana: estimation of the daily intakes and target hazard quotients (THQs). *Ecotoxicology and Environmental Safety*, 2015, 111: 160-167 (doi: 10.1016/j.ecoenv.2014.09.008).
20. Skalny A.V., Salnikova E.V., Burtseva T.I., Skalnaya M.G., Tinkov A.A. Zinc, copper, cadmium, and lead levels in cattle tissues in relation to different metal levels in ground water and soil. *Environmental Science and Pollution Research*, 2019, 26(1): 559-569 (doi: 10.1007/s11356-018-3654-y).
21. Liseev I.K. *Problemy tsivilizatsionnogo razvitiya*, 2020, 2(1): 20-34 (doi: 10.21146/2713-1483-2020-2-1-20-34) (in Russ.).
22. Zain S.M., Behkami S., Bakirdere S., Koki I.B. Milk authentication and discrimination via metal content clustering — a case of comparing milk from Malaysia and selected countries of the world. *Food Control*, 2016, 66: 306-314 (doi: 10.1016/j.foodcont.2016.02.015).
23. Sun H., Wang D., Wang B., Wang J., Liu H., Guan L.L., Liu J. Metabolomics of four biofluids from dairy cows: potential biomarkers for milk production and quality. *Journal of Proteome Research*, 2015, 14(2): 1287-1298 (doi: 10.1021/pr501305g).
24. Kaneko J.J., Harvey J.W., Bruss M.L. *Clinical Biochemistry of Domestic Animals*. Amsterdam, 2008.
25. Zaytsev S.Yu. *Biologicheskaya khimiya: ot biologicheski aktivnykh veshchestv do organov i tkaney zhivotnykh* [Biochemistry: from bioactive substances to animal organs and tissues]. Moscow, 2017 (in Russ.).
26. Bailey R.L., West K.P., Black R.E. The epidemiology of global micronutrient deficiencies. *Annals of Nutrition and Metabolism*, 2015, *66(9)*: 22-33 (doi: 10.1159/000371618).
27. Smirnov A.V. *Voprosy normativno-pravovogo regulirovaniya v veterinarii*, 2014, 2: 19-22 (in Russ.).
28. Strusiska D., Mierzejewska J., Skok A. Concentration of mineral components, β-carotene, vitamins A and E in cow colostrum and milk when using mineral-vitamin supplements. *Medycyna*

Weterynaryjna, 2004, 60(2): 202-206.
29. Ran L., Wu X., Shen X., Zhang K., Ren F., Huang K. Effects of selenium form on blood and milk selenium concentrations, milk component and milk fatty acid composition in dairy cows. *Journal of the Science of Food and Agriculture*, 2010, 90(13): 2214-2219 (doi: 10.1002/jsfa.4073).
30. Rius A.G, Appuhamy J., Cyriac J., Kirovski D., Becvar O., Escobar J., McGilliard M.L., Bequette B.J., Akers R.M., Hanigan M.D., Regulation of protein synthesis in mammary glands of lactating dairy cows by starch and amino acids. *Journal of Dairy Science*, 2010, 93: 3114-3127 (doi: 10.3168/jds.2009-2743).
31. Kharitonov E.L., Panyushkin D.E. *Problemy biologii produktivnykh zhivotnykh*, 2016, 2: 76-106 (in Russ.).
32. Colditz I.G., Hine B.C. Resilience in farm animals: biology, management, breeding and implications for animal welfare. *Animal Production Science,* 2016, 56(12): 1961-1983 (doi: 10.1071/AN15297).
33. Rodenburg J. Robotic milking: technology, farm design, and effects on work flow. *Journal of Dairy Science*, 2017, 9(100): 7729-7738 (doi: 10.3168/jds.2016-11715).
34. Nogalska A., Momot M., Sobczuk-Szul M., Pogorzelska-Przybyłek P., Nogalski Z. Calcium and magnesium contents in the milk of high-yielding cows. *Journal of Elementology*, 2017, 22(3): 809-815 (doi: 10.5601/jelem.2016.21.4.1365).
35. Canario L., Mignon-Grasteau S., Dupont-Nivet M., Phocas F. Genetics of behavioural adaptation of livestock to farming conditions. *Animal*, 2013, 7(3): 357-377 (doi: 10.1017/S1751731112001978).
36. Kapsamun A.D., Ivanova N.N., Pavlyuchik E.N., Pushkina L.V. *Mezhdunarodnyy nauchno-issledovatel'skiy zhurnal*, 2019, 6-1(84): 107-110 (doi: 10.23670/IRJ.2019.84.6.023) (in Russ.).
37. Sawa A., Siatka K., Krężel-Czopek S. Effect of age at first calving on first lactation milk yield, lifetime milk production and longevity of cows. *Annals of Animal Science*, 2019, 19(1): 189-200 (doi: 10.2478/aoas-2018-0044).
38. Li S., Wang Q., Lin X., Jin X., Liu L., Wang C., Chen Q., Liu J., Liu H. The use of "omics" in lactation research in dairy cows. *International Journal of Molecular Sciences,* 2017, *18*(5): 983 (doi: 10.3390/ijms18050983).
39. Vailati-Riboni M., Elolimy A., Loor J.J. Nutritional systems biology to elucidate adaptations in lactation physiology of dairy cows. *Systems Biology in Animal Production and Health*, 2016, 2: 97-125 (doi: 10.1007/978-3-319-43332-5_5).
40. Connor E.E. Invited review: Improving feed efficiency in dairy production: challenges and possibilities. *Animal*, 2015, 9(3): 395-408 (doi: 10.1017/S1751731114002997).
41. Kandinskaya E.S., Red'kin S.V., Chebakova, G.V. *Veterinariya segodnya*, 2019, 1: 29-33 (doi: 10.29326/2304-196X-2019-1-28-29-33) (in Russ.).
42. Durand M., Komisarczuk S. Influence of major minerals on rumen microbiota. *The Journal of nutrition*, 1988, 118(2): 249-260 (doi: 10.1093/jn/118.2.249).
43. Malacarne M., Franceschi P., Formaggioni P., Sandri S., Mariani P., Summer A. Influence of micellar calcium and phosphorus onrennet coagulation properties of cows milk. *Journal of Dairy Research*, 2014, 81: 129-136 (doi: 10.1017/S0022029913000630).
44. Ivashkevich L.S., Velentey Yu.N., Gonta P.P. *Zdorov'e i okruzhayushchaya sreda*, 2009, 14: 104-107 (in Russ.).
45. Kandeel S.A., Megahed A.A., Constable P.D. Evaluation of hand-held sodium, potassium, calcium, and electrical conductivity meters for diagnosing subclinical mastitis and intramammary infection in dairy cattle. *Journal of Veterinary Internal Medicine*, 2019, 33(5): 2343-2353 (doi: 10.1111/jvim.15550).
46. Abramowicz B., Kurek Ł., Chałabis-Mazurek A., Lutnicki K. Copper and iron deficiency in dairy cattle. *Journal of Elementology*, 2021, 26(1): 241-248 (doi: 10.5601/jelem.2020.25.4.2093).
47. Joerling J., Doll K. Monitoring of iron deficiency in calves by determination of serum ferritin in comparison with serum iron: a preliminary study. *Open Veterinary Journal*, 2019, 9(2): 177-184 (doi: 10.4314/ovj.v9i2.14).
48. Flachowsky G., Franke K., Meyer U., Leiterer M., Schöne F. Influencing factors on iodine content of cow milk. *European Journal of Nutrition*, 2014, 53(2): 351-365 (doi: 10.1007/s00394-013-0597-4).
49. Costa A., Niero G., Franzoi M., Cassandro M., De Marchi M., Penasa M. Iodine content in bovine milk is lowly heritable and shows limited genetic variation. *Journal of Dairy Science*, 2021, 104(3): 3292-3297 (doi: 10.3168/jds.2020-19486).
50. Dobrzanski Z., Kołacz R., Gorecka H., Chojnacka K., Bartkowiak A. The content of microelements and trace elements in raw milk from cows in the Silesian Region. *Polish Journal of Environmental Studies*, 2005, 14(5): 685-689.
51. Khan I.T., Nadeem M., Imran M., Ayaz M., Ajmal M., Ellahi M.Y., Khalique A. Antioxidant capacity and fatty acids characterization of heat treated cow and buffalo milk. *Lipids in Health and Disease*, 2017, 16(1): 163 (doi: 10.1186/s12944-017-0553-z).
52. Kinal S., Korniewicz A., Jamroz D., Zieminski R., Slupczynska M. Dietary effects of zinc, copper and manganese chelates and sulphates on dairy cows. *Journal of Food, Agriculture & Environment*, 2005, 3(1): 168-172.

53. Kinal S., Korniewicz A., Słupczyńska M., Bodarski R., Korniewicz D., Čermák B. Effect of the application of bioplexes of zinc, copper and manganese on milk quality and composition of milk and colostrum and some indices of the blood metabolic profile of cows. *Czech Journal of Animal Science*, 2007, 52(12): 423-429 (doi: 10.17221/2338-CJAS).
54. Ferreira G.M., Petzer I.M. Injectable organic and inorganic selenium in dairy cows — effects on milk, blood and somatic cell count levels. *Onderstepoort Journal of Veterinary Research*, 2019, 86(1): a1664 (doi: 10.4102/ojvr.v86i1.1664).
55. Mehdi Y., Dufrasne I. Selenium in cattle: a review. *Molecules*, 2016, 21(4): 545 (doi: 10.3390/molecules21040545).
56. Pilarczyk R., Wojcik J., Czerniak P., Sablik P., Pilarczyk B., Tomza-Marciniak A. Concentrations of toxic heavy metals and trace elements in raw milk of Simmental and Holstein-Friesian cows from organic farm. *Environmental Monitoring and Assessment*, 2013, 185(10): 8383-8392 (doi: 10.1007/s10661-013-3180-9).
57. Barlowska J., Litwinczuk Z., Krol J., Kedzierska-Matysek M. Fatty acid profile and minerals content milk from cows of various breeds over spring-summer feeding period. *Polish Journal of Food and Nutrition Sciences*, 2006, 15(1s): 13-16.
58. O'Kane S.M., Pourshahidi L.K., Mulhern M.S., Weir R.R., Hill S., O'Reilly J., Kmiotek D., Deitrich C., Mackle E.M., Fitzgerald E., Lowis C., Johnston M., Strain J.J., Yeates A.J. The effect of processing and seasonality on the iodine and selenium concentration of cow's milk produced in Northern Ireland (NI): implications for population dietary intake. *Nutrients,* 2018, 10(3): 287 (doi: 10.3390/nu10030287).
59. Weiss W.P. A 100-Year review: from ascorbic acid to zinc — mineral and vitamin nutrition of dairy cows. *Journal of Dairy Science*, 2017, 100(12): 10045-10060 (doi: 10.3168/jds.2017-12935).
60. Sinclair L.A., Hart K.J., Johnson A.M. Effect of inorganic or organic copper fed without or with added sulfur and molybdenum on the performance, indicators of copper status, and hepatic mRNA in dairy cows. *Journal of Dairy Science*, 2013, 96(7): 4355-4367 (doi: 10.3168/jds.2012-6322).
61. Kim S.B., Jung S.H., Do Y.J., Jung Y.H., Choe C., Ha S., Jeong H.Y., Cho A., Oh S.I., Kim E., Yoo J.G., Kim S. Haemato-chemical and immune variations in Holstein cows at different stages of lactation, parity, and age. *Veterinarni Medicina*, 2020, 65(03): 95-103 (doi: 10.17221/110/2019-VETMED).
62. Fadlalla I.M.T., Omer S.A., Atta M. Determination of some serum macroelement minerals levels at different lactation of dairy cows and their correlations. *Scientific African*, 2020, 8: e00351 (doi: 10.1016/j.sciaf.2020.e00351).
63. Aleri J.W., Hine B.C., Pyman M.F., Mansell P.D., Wales W.J., Mallard B., Fisher A.D. An assessment of immune and stress responsiveness in Holstein-Friesian cows selected for high and low feed conversion efficiency. *Animal Production Science*, 2017, 57(2): 244-251 (doi: 10.1071/AN15406).
64. Sundrum A. Metabolic disorders in the transition period indicate that the dairy cows' ability to adapt is overstressed. *Animals*, 2015, 5: 978-1020 (doi: 10.3390/ani5040395).
65. Opsomer G. Interaction between metabolic challenges and productivity in high yielding dairy cows. *Japanese Journal of Veterinary Research*, 2015, 63(1): S1-S14 (doi: 10.14943/jjvr.63.suppl.s1).
66. Orjales I., Herrero-Latorre C., Miranda M., Rey-Crespo F., Rodriguez-Bermudez R., Lopez-Alonso M. Evaluation of trace element status of organic dairy cattle. *Animal*, 2018, 12(6): 1296-1305 (doi: 10.1017/S1751731117002890).
67. Kozyr' V.S. *Vestnik APK Stavropol'ya*, 2015, 2(18): 135-139 (in Russ.).
68. Lane T.W., Morel F.M. A biological function for cadmium in marine diatoms. *Proceedings of the National Academy of Sciences*, 2000, 97(9): 4627-4631 (doi: 10.1073/pnas.090091397).