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REVIEW PAPER

Iodine in cattle – review

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Abstract

Iodine is a trace element responsible for the correct development of the cow's organism, milk production, and reproduction. This microelement ensures the normal function of the thyroid gland, and is indispensable for the synthesis of the thyroid hormones triiodothyronine and thyroxine, which are responsible for healthy metabolism, especially energy metabolism. Iodine exhibits strong disinfecting and bactericidal properties and is a powerful antioxidant. In a feed ration, it may be present as non-organic and organic compounds that are later almost fully absorbed in the rumen and omasum. Non-organic forms are much better absorbed than organic ones. Living organisms do not synthesise iodine, so the main causes of its deficiency are insufficient amounts of iodine in soil and water. Iodine deficiency in ruminants may also be caused by feeding plants with goitrogens and by the excess of calcium in the feed ration. The maximum iodine concentration allowed in feed rations is 5 mg kg^{-1} DM. Iodine deficiency in dairy cattle can lead to hypothyroidism, manifested by the birth of stillborn or weak calves with an overgrowth of the thyroid gland (goiter), reproductive disorders, and an increased incidence of mastitis and hoof diseases. Iodine intoxication in cattle usually occurs as a result of administering too much of a mineral additive containing iodine, using a few different forms of supplements with this element or an uneven mixing of mineral additives with other feed ingredients. The aim of this review is to review the literature and to provide a comprehensive overview of the knowledge concerning the role iodine in cattle.

Keywords: iodine, cattle, metabolism, toxicity, deficiency

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INTRODUCTION

Iodine (I), a non-metal from the group of halogens, is an essential bioactive component of the diet, and participates in the synthesis of thyroid hormones, which determine the correct development and functioning of the body. Generally, more than 95% of total iodine in animals is accumulated in the thyroid gland (Flachowsky 2007). It is estimated that around 2 billion people suffer from iodine deficiency (Biban, Lichiardopol 2017). This element was discovered in 1811 by Bernard Courtois during his works on the saltpeter used for gunpowder production (Wisniak 2002). Ten years later, the Swiss physician Jean-François Coindet used iodine tincture to treat goiter in his patients. In 1895, it was discovered that iodine was essential for the correct functioning of the thyroid gland (Markel 2014). Initially, the newly discovered substance was given the name *substantia x*, then *gas violaceus* – violet gas in Latin, and finally *iodum* (gr. *ion* – violet – flower or gr. *iodes* - violet - color). Iodine is solid at room temperature, when it occurs in the form of black and blue crystals, and has a characteristic pungent odor. Its solutions and vapors are violet (Makhayeva et al. 2020). Iodine does not have such strong oxidizing properties as other halogens, especially bromine, chlorine and fluorine. On an industrial scale, iodine is extracted from iodates from post-crystalline brines obtained during the production of Chilean saltpeter or by the action of chlorine on iodides. This element is used in the food industry (salt iodization), photography, printing and production of dyes, pharmaceuticals, and in production of disinfectants.

OCCURRENCE OF IODINE IN NATURE

Iodine is abundant in the natural environment (air, water, soil, living organisms), although its distribution on Earth is uneven. Approximately a million years ago, the distribution of this element was fairly homogeneous, but glacial periods led to the formation of soils which can be rich or poor in this element (Kurosad et al. 2005). Seas and seaside areas are rich in iodine. Areas deficient in this element include the northern part of North America, most of South America, Africa, Asia and Europe (Niwattisaiwong et al. 2017) – Figure 1.

Iodine ranks 68th (weight percent-wt%) in terms of its distribution in the Earth's crust. The primary source of iodine is bituminous shale, which releases it into the seas and oceans during erosion, and therefore both sea water and the organisms living in it (algae, crustaceans and fishes) constitute its largest reservoir. The concentration of iodine in seawater is 10 times higher than the concentration of this micronutrient in fresh water, and reaches approximately 50 $\mu g\ l^{-1}$ (Ghirri et al. 2014). Iodine in seawater occurs mainly in the form of iodides, which are released into the atmosphere after oxidation. Then, in the form of rainfall, they return to water bodies and surface layers of soil, where they are available to plants, also used as fodder for animals (Duborská et al. 2021). Unpolluted surface waters contain less than 3 μg l^{-1} iodine, while drinking water has less than 15 μg l^{-1}. The average concentration of iodine in the air is 10-20 ng m^{-3}, while in terrestrial plants it is about 1000 μg kg^{-1} dry weight and depends on the geographical location, plant absorption capacity, selenium concentration in soil and the use of nitrogen fertilizers (Hatch-McChesney, Lieberman 2022). Observations of many authors demonstrate that animals grazed on pastures show a lower concentration of iodine in the blood compared to cattle from intensive production based on total mixed ration or partial mixed ration, which is related to the fact that these types of nutrition are usually supplemented with micronutrients, including iodine (Randhawa, Randhawa 2001, Lejeune et al. 2010). Inorganic salts (NaI, KIO_3, $NaIO_3$, CaI_2, CuI_2, diiodosalicylic acid), elemental iodine, and organic iodine compounds such as methyl iodide and ethylenediamine dihydroiodide (EDDI) are used in bovine nutrition. The latter contains 82% iodine and is more stable than the commonly used potassium or sodium iodides (Goff 2018).

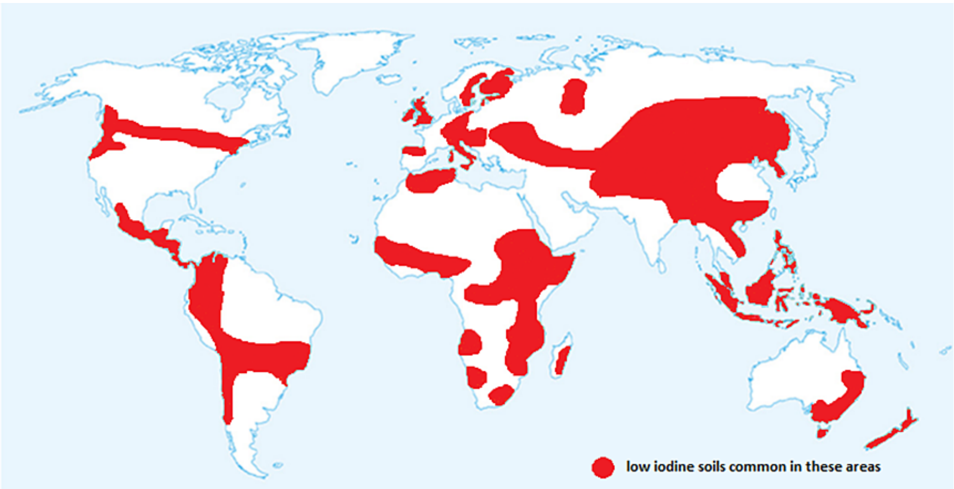

Fig. 1. Global distribution of soils low in iodine. Adapted from Lyons (2018)

IODINE METABOLISM IN CATTLE

Absorption

Iodine in cattle is primarily absorbed in the rumen (70-80% of the daily intake), omasum (10%), and in a small amount in the abomasum (Miller et al. 1975), and then transported by plasma proteins to target organs, mainly the thyroid gland (Schöne et al. 2017). This element is also well absorbed by the mucous membranes of the respiratory system, skin, body cavities and wounds (Figure 2).

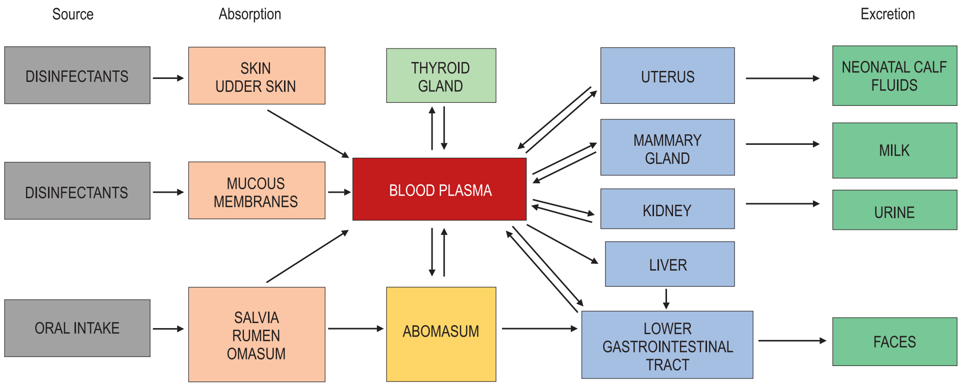

Fig. 2. Schematic diagram of the iodine cycle in cattle (arrows indicate the flow of iodine)

From the gastrointestinal tract it is absorbed primarily as iodide, and its elemental form and most of the organic forms (iodine bound to protein, iodinated amino acids, thyroxine) are reduced to iodides before absorption (Flachowsky et al. 2014). Absorption of organic forms of iodine in the gastrointestinal tract is possible, but their bioavailability is much lower and amounts to only 40-70%. In cattle, unlike in other animal species, there also occurs iodine retention, which consists of endogenous secretion of iodine back into the digestive tract, in particular to the abomasum, which in turn contributes to its absorption in further parts of the digestive tract (Goff 2018). Studies on cows have shown that after intravenous administration of radioactive iodine (^{131}) to animals, more than 65% of the injected dose of this element was found in the contents of the abomasum in the first 6 hours (Swanson, Miller 1973). Absorption from the skin is of particular importance in cows due to the use of preparations containing iodine for post-milking teats disinfection, with studies showing a much higher concentration of iodine in the milk when using an iodine solution in the form of a spray on the teat skin than by dipping only (Flachowsky et al. 2007). According to the available literature data, the increase of iodine concentration in milk after disinfection by dipping is from 32 µg l^{-1} to 184 µg l^{-1} (Flachowsky et al. 2007, Cabral et al. 2022).

The absorption of iodine may be hampered by the presence of certain substances in the feed, as well as the deficiency of some compounds, especially micronutrients such as iron or selenium, which contribute to the lowered absorption of this element (Arthur 1999). Some plant species (white clover, rape), containing variable amounts of goitrogens, increase the demand for iodine in ruminants by up to 4 times (Schöne et al. 2017, Franke et al. 2009). This is due to the fact that these compounds disturb the synthesis and/or secretion of thyroid hormones. Goitrogens can be classified into two categories. The most common type are cyanogenic goitrogens which interfere with iodine intake by the thyroid gland (Pesce, Kopp 2014). The second and more harmful type are goitrogens found in cruciferous plants (rape). These compounds inhibit the enzyme thyroperoxidase, which in turn blocks the production of thyroxine (T4) – Goff (2018). Studies carried out on dairy cows that received an average of 1.2 mg iodine kg^{-1} DM diets via premixes showed that despite supplementation the concentration of iodine was twofold lower than expected in the milk of the animals. This was due to the presence of the rapeseed meal (RSM) commonly used in cattle nutrition (Schöne et al. 2017). Currently, attention is paid to other factors that may permanently interfere with the effects of the applied iodine prophylaxis. They include, among others, the presence of a significant amount of calcium ions in the feed and/or water (van Wuijckhuise et al. 2003), and an excess of nitrate anion (NO_3), which comes from intensive fertilization of meadows and pastures with nitrogen fertilizers (Espino-Vázquez et al. 2022, Serrano-Nascimento, Nunes 2022). Increasing iodide supply seems to be the most effective way of eliminating the effects of nitric anions because they compete with the iodide anion during the process of intake into the thyroid (Craps et al. 2015).

The developing foetus demonstrates a very high demand for this micronutrient, especially in the last stage of pregnancy, because thyroxine is essential for organogenesis and growth. Iodine is actively transported through the placenta to the foetus, which maintains the concentration of this element in the foetus eight-fold higher than in the mother's body (Richard et al. 2017).

Excretion

Iodine is excreted from the organism in the form of iodide, and elimination is primarily through the kidneys. Smaller amounts of iodine are eliminated in the faeces, milk and bile (Śliwiński et al. 2015) – Figure 2. Urine iodine concentrations in cows that receive sufficient amounts of iodine in a feed ration exceed 100 μg l^{-1} (Herzig et al. 1996). The amount of iodine excreted in the urine is a very good indicator of the body's supply of this element. Iodine retention in the body is reduced with high dietary chloride and potassium, presumably due to increased urinary excretion (Miller et al. 1975).

About 8% of iodine enters the milk of dairy cattle (regardless of the milking process), hence, in some European countries milk is considered the most important natural source of this element in the human diet (Brantsaeter et al. 2013). The iodine content in milk depends mainly on the cows' breed, lactation period and the time of year. Larger amounts of iodine were found in the milk of Holstein-Friesian cattle than in the milk of Guernsey cattle. As lactation progresses, milk production decreases and the iodine content increases (Iannaccone et al. 2019). This microelement can be reabsorbed from milk by up to 94% of its content after the secretion to the mammary gland in the form of an iodide (Figure 2). Data from the published literature shows that only free iodine becomes absorbed from milk. Iodine in combination with proteins has no ability to move between blood and milk in either direction (Miller et al. 1975).

INFLUENCE OF IODINE ON THE CATTLE

Iodine is an important micronutrient and plays a fundamental role in the proper functioning of the bovine organism. It is necessary for the synthesis of the thyroid hormones: triiodothyronine (T3) and thyroxine (T4), which are responsible for metabolism, thermoregulatory processes, reproduction, growth and development of the body, muscle function and oxidation control of all cells (Witard et al. 2022).

This element also shows strong antimicrobial properties. As a small particle, iodine quickly penetrates microorganisms and oxidizes key proteins, nucleotides and fatty acids, ultimately leading to the death of the pathogen cell (Lepelletier et al. 2020). Research has proven that supplementing daily rations with iodine strengthens the immune system's response towards the infectious agents (Iannaccone et al. 2019). This occurs due to an increased production of antibodies by stimulated B lymphocytes, and an increase in phagocytosis. Moreover, iodide also influences myeloperoxidase and hydrogen peroxide, thereby strengthening their bactericidal properties (Klebanoff et al. 2013). In consequence, the milk from cows that received iodine supplementation had fewer somatic cells (Iannaccone et al. 2019). However, iodine supplementation of cows before calving does not influence the increase of the IgG antibodies in their offspring on their third day of life (Conneely et al. 2014).

There are innate defence mechanisms in the upper respiratory tract that are used to protect the respiratory system from microorganisms. One of them is the lactoperoxidase/hydrogen peroxide/iodide (LPO/H_2O_2/I) system, which was proven in *in vitro* trials to inactivate bovine herpesvirus-1, parainfluenza-3 virus and inhibit the growth of *Mannheimia haemolytica* and *Bibersteinia trehalose* – with some of these pathogens responsible for Bovine Respiratory Disease (BRD) in calves (Fischer et al. 2011). Research conducted on beef calves has proven that after a single oral dose of NaI (70 mg kg^{-1} of body weight) there was an increase in the amount of iodine in the upper respiratory tract, which suggests that this form of supplementation can prevent the occurrence of BRD or mitigate its course (Shoemake et al. 2018).

In the salivary glands, stomach, and intestine, iodide is thought to play a role in the innate immune defense. In these sites, it is possible to oxidize iodide to hypoiodite (IO−), which is endowed with fungicidal and bactericidal activity (Sorrenti et al. 2021). It has also been proven that iodide oxidation has been shown to possess a strong anti-viral action against lung adenoviruses (De la Vieja, Santisteban 2018)

In addition, *in vitro* studies have shown that the newly discovered substance (iodine-containing nano-molecular complex FS-1), the main component of which is iodine, significantly improves the susceptibility to antibiotics of various pathogens, including the MRSA strain *Staphylococcus aureus* (Korotetskiy et al. 2017, Reva et al. 2020).

CONSEQUENCES OF IODINE DEFICIENCY IN CATTLE

According to NRC (2021), there should be 0.5 mg of iodine in the dry weight of a feed ration for lactating dairy cows, which corresponds to about 12 mg of iodine per day per animal and 6 g per animal per day for dry cows. The daily requirement for calves is 0.02 mg/kg of body weight (Paulíková et al. 2002). It is assumed that the physiological serum iodine concentration in cows varies from 40 to 200 μg l^{-1} (Launer, Richter 2005).

Living organisms do not have the capacity to synthetize iodine and therefore it has to be administered externally, mainly with feeds. The cause of iodine deficiency in cattle is an insufficient iodine content in feed or the supply of goitrogenic substances in feed rations. Iodine deficiency in cattle is considered to be a very common phenomenon that influences many health and production aspects, and mainly concerns animals that are grazed on pastures. High-yielding dairy cows are especially vulnerable to iodine deficiency, given that this element is intensively excreted with milk. An insufficient amount of iodine in an organism can lead to thyroid insufficiency, which manifests in the overgrowth of this gland and in the appearance of goiters.

Iodine deficiency in cattle can occur in a clinical and subclinical form or in a form referred to as "nonclinical". Those forms can be differentiated on the basis of the presence or absence of clinical symptoms in two groups, blood iodine concentration, and the response to iodine supplementation. All or some of the symptoms occur in the clinical form of deficiency, meanwhile, in the subclinical form there can be only few or no symptoms. In both cases, iodine supplementation leads to the disappearance of these symptoms. On the other hand, in the third form deficiency form mentioned, the blood iodine concentration is observed to fall below the reference values, although the affected animals do not manifest typical clinical symptoms of deficiency or responses to iodine supplementation (Randhawa, Randhawa 2001). The clinical image of iodine deficiency varies depending on the age of the animals (Randhawa, Randhawa 2001, McCoy et al. 1997, Takahashi et al. 2001, Anderson et al. 2007, Bindari et al. 2013) (Table 1). Another disorder caused by a low iodine concentration is a decline in metabolism: decrease in concentrations of carbohydrates, fats and proteins in blood, with an increase in concentrations of indirect metabolism products, such as acetone (Nikulin, Kalyuzhny 2021).

In a study conducted on pregnant heifers that were fed a low iodine diet during the last five months of pregnancy (medium iodine concentration 0.06 mg kg^{-1} of body weight), it was proven that pathological changes in the thyroid occurred in mothers as well as in their calves. However, cases of stillbirths or weak calves were not noted (McCoy et al. 1997). A decrease in the iodine concentration in the thyroid is observed along with iodine deficiency in calves. A study conducted on stillborn calves has proven that hypertrophic changes in a histological image of thyroid samples occurred in animals with the thyroid iodine concentration lower than 1000 mg kg^{-1}

Table 1

Iodine deficiency disorders at different ages

Age	Iodine deficiency disorders
Foetus	abortions, stillbirths or weak calves increased perinatal mortality
Neonate/calves	goiter changes in hair coat – partial or complete hair loss increased dryness and skin wrinkling
Adult	silent heats, irregular cycles, prolonged calving intervals, lowered libido and sperm quality, retained placenta reduced milk production, mastitis and an increase in the somatic cell count hoof diseases, hoof rotting and hair loss

of dry weight. No such changes were detected in calves with the iodine concentration higher than 1000 mg/kg of dry weight (Anderson et al. 2007).

DIAGNOSING THE DEFICIENCIES OF IODINE IN CATTLE

The appearance of a goiter in newborn calves is considered to be a primary symptom of iodine deficiency in adult cattle (Homerosky et al. 2019). When clinical symptoms indicate iodine deficiency in a herd, it is recommended to perform an autopsy of stillborn calves in order to confirm the diagnosis. It is recommended to assess calves' body weight, weight or size of their thyroid glands, perform a histopathological exam of thyroid samples and determine the concentration of iodine and T4 in blood (for example from a foetus' heart) (Anderson et al. 2007). One of the earliest tests to assess iodine status in cattle was the protein-bound iodine (PBI) test, where the thyroid's activity was assessed through measuring the concentration of iodine bound with proteins present in the bloodstream. However, this test was not very sensitive and did not provide sufficient information regarding T4 function. Nowadays, a PBI test has been replaced by a test that enables direct measurement of hormone levels in the thyroid (Nikulin, Kalyuzhny 2021). The thyroxine concentration is often used as an indirect indicator of iodine supply of an organism. But some authors are of the opinion that assessing the thyroxin concentration is unreliable due to the fact that thyroxin production is regulated by a haemostatic regulator that is based on a negative feedback loop, and given the physiological re-administration of iodine and storing it in the thyroid (Grace, Waghorn 2005). Moreover, the T4 concentration demonstrates temporary variations: it is higher in winter than in autumn or summer. A decrease in this hormone's concentration is observed in cattle in early lactation or during invasions of intestinal parasites. Changes in its concentration also depend on the age of an animal. In newborn calves, the thyroxin concentration significantly surpasses levels observed in adult animals. According to Takahashi et al. (2001), the maximum serum level of this hormone in healthy calves is observed on the second day of life, then decreases to reach an adult animal's level approximately during the 2nd month. The authors have also observed that serum T4 level in calves with the endemic goiter was lower than in healthy calves, but close to the levels in adult cows. The triiodothyronine concentration in calves with a goiter was similar to the one in healthy calves, but proved to be more variable. On the other hand, the T4/T3 ratio in calves with a goiter was significantly lower than in healthy calves and adult cattle, which suggests that it can be accepted as a diagnostic indicator of an endemic goiter. Lack of reference values for T3 and T4 is a major difficulty given that the concentration of these hormones in blood varies dramatically (Anderson et al. 2007). Moreover, the data presented by various authors is obtained under different conditions and by using different analytical methods. Written sources indicate that the plasma concentration of thyrotropin hormone (TSH) can be the most sensitive indicator of the iodine status in adult animals. TSH level increases, aiming to maintain proper thyroxin and triiodothyronine concentrations, when a diet is low in iodine (Arthur 1999). In a study conducted on cows that were administered goitrogen in the form of 6-*n*-propyl-2-thiouracil for two months, the TSH level was five times higher in comparison to cows that did not receive it (Moraes et al. 1997). According to Guyot et al. (2007) TSH reference values in cattle range between 1.3 and 13.0 μU ml^{-1} in beef and dairy breeds respectively. The authors also state that the TSH threshold enabling the detection of newborn calves with iodine deficiency is 35 μU ml^{-1}.

Due to a significant correlation between iodine intake and excretion, its concentration in urine is the most precise indicator of biological availability of this element in diet and of iodine status of an organism (Herzig et al. 1996, Ingenbleek et al. 1997). Urine analysis of almost 700 dairy cows has proven that the average iodine concentration at the peak of lactation was 94.8 μg l^{-1}, and 82.3 μg l^{-1} prior to the dry period (Herzig et al. 1996). In the same study iodine concentration in cattle with and without supplementation was compared and it turned out to be 316.2 μg l^{-1} and 52.3 μg l^{-1} respectively. It is assumed that the concentration of iodine from 100 to 250 μg l^{-1} indicates a deficiency, and the concentration above 500 μg l^{-1} indicates an excessive intake (Puls 1994). However, as Arthur (1999) states, when goitrogens causing the inhibition of iodine uptake to the thyroid gland are present in the feed ration, urine excretion of this element can be correct or even higher, and in consequence its assessment in these cases can be unreliable.

Similarly, an assay of the iodine concentration in milk can serve to determine the iodine status of a cow's organism. According to Puls (1994), values below 25 μg kg^{-1} indicate a deficiency, meanwhile values of 30-300 μg kg^{-1} indicate a sufficient iodine supply. However, due to the fact that iodine can be accumulated in milk via active transport to the udder, assessing the concentration of this element in milk only permits the determining of deficiency.

IODINE TOXICITY IN CATTLE

The effect of iodine on a ruminant organism is mostly assessed in the context of its deficiency. Despite the fact that iodine intoxication in cattle is a less frequent clinical problem due to very high potentially toxic doses, it is advised to pay attention to possible side effects of long-term use of this microelement in the diet. Intoxication in cattle usually occurs as a result of administering too much of a mineral additive containing iodine, using a few different forms of supplements with this element (e.g. mineral feed additives and ruminal bolus), or an uneven mixing of mineral additives with other feed ingredients (Ong 2014). There are described cases of temporary reactions to iodine or its inorganic salts after intravenous or oral administration during the treatment of actinobacillosis, i.e. an infection caused by *Actinobacillus lignieresii*, foot rot, and BRD (Paulíková et al. 2002). Iodine intoxication can also be triggered by applying iodine-based disinfectants on wounds, teats or surfaces in cowsheds. Reaction to excess iodine can vary between species, as well as between individuals within the same species. Adult animals, especially during lactation are more resistant to large amounts of iodine, which is caused by iodine transfer to the milk and lowering its concentration in serum. Research conducted on adult cow herds in field conditions has proven that a daily iodine intake from 68 to 600 mg per animal per day (0.12-1.0 mg kg^{-1} BW per day) was linked to the occurrence of symptoms indicating iodine intoxication (Olson et al. 1984). These doses were from 7.5 to 63 times higher than the daily requirement for animals necessary for the synthesis of thyroid hormones. The symptoms of intoxication reversed the moment the daily iodine intake was reduced to less than 12 mg per animal per day. The serum iodine concentrations of the animals showing symptoms of intoxication were between 2.6 to 6.9 times higher than the iodine concentrations observed in the control group, which was given 12 mg of iodine per day. In turn, milk concentrations of this element were between 3.6 and 13.6 times higher compared to the concentrations in the control group (Olson et al. 1984). A significant increase of the iodine concentration in cows' serum varying between 322 and 913 ng ml^{-1} was observed on a daily iodine intake of between 0.007-0.12 mg kg^{-1} of body weight (Ong et al. 2014). The same research shows that the concentration of this microelement in the blood serum fell to the level of 46-71 ng ml^{-1} after a week from ending iodine supplementation. The following table (Table 2) presents the daily requirement and the consequences of an overdose of iodine in calves.

The mechanism of iodine toxicity is multidirectional. Iodine is a typical protoplasmic poison that contributes to the denaturation of proteins and cellular breakdown. The main symptom of iodine toxicity, when the substance is administered in small doses and at smaller concentrations is the irritation of mucous membranes (Sherer et al. 1991). The time after which the symptoms associated with iodine intoxication appear depends on the dose and the period of administration. The symptoms include a decrease in appetite,

Table 2

Daily requirement and toxic doses of iodine in calves
(Mangkoewidjojo et al. 1980, Paulíková et al. 2002)

Dose (mg kg^{-1} body weight)	Degree of iodine intoxication
0.02 (daily requirement)	no symptoms of intoxication
0.4	mild symptoms of intoxication
2.2	strong symptoms of intoxication
10	severe or lethal iodine intoxication

weight and milk yield, increased or decreased body temperature, tachycardia, mucous or serous nasal discharge, lachrymation, excess drooling, dermatitis, balding, nervousness, and exophthalmos. A persistent dry cough, laryngitis or pneumonia can also occur (Olson et al. 1984, Paulíková et al. 2002, Ong et al. 2014, Şentürk et al. 2018). Iodine toxicity is also connected to a weakened cellular as well as humoral immune response in cattle, and it results in increased susceptibility to infections (Olson et al. 1984). Disturbances in the process of phagocytosis, decreased in T and B lymphocyte production and weakened antibodies response to the bacterial factors have been observed in the calves exposed to high doses of iodine (Haggard et al. 1980). The autopsy images of dead animals show a dominance of changes in the respiratory system that are characteristic for tracheitis, bronchopneumonia and pleurisy (Mangkoewidjojo et al. 1980). Effects of high iodine intake on the thyroid and the adrenal glands up to this point are in doubt. In many cases, the same authors during different studies observed hypertrophy or no changes is these organs after consuming high doses of iodine (Paulíková et al. 2002). Thyroid hypertrophy (that can lead to goiters) is relatively common among newborn calves and rarely occurs in adult cattle. The goiter is usually associated with long-term intoxication with high doses of iodine, and histopathological samples display thyroid gland fibrosis, and variable cystic and hyperplastic glandular architecture distortion (Ong et al. 2014). There are no data from any published literature that would indicate that the excess of iodine is a direct cause of animals' death; however, it can contribute to the development of a disease, including pneumonia, that can lead to the death of an animal.

Treatment of iodine poisoning is mainly based on decreasing the supply of this element in the feed, that leads to a quick decrease in its level in the organism and gradual vanishing of the poisonous symptoms, indicating that the toxic symptoms of iodine surplus are not permanent (Olson et al. 1984, Ong et al. 2014).

SUPPLEMENTATION OF IODINE IN CATTLE

Plant components used in cattle feeding are often iodine deficient – they supply only slightly over twelve percent of the daily requirement for this element, which leads to the need of supplementation (Meyer et al. 2008, Castro et al. 2011). It is necessary for the correct functioning of the ruminants' bodies, as well as in humans, due to the fact, as was mentioned earlier, cows' milk is an important source of iodine in our diet. However, no significant changes in the concentration of iodine in the meat after supplementation were observed (Swanson et al. 1990). Supplements can be generally divided into two types, short lasting with quick absorption and quick usage or long lasting with slower absorption that guarantee extended usage (Grace, Knowles 2012). According to EU Legislation, it is permitted to use iodine in the nutrition of cattle as a feed additive in the form of potassium iodide, calcium iodate anhydrous and coated granulated calcium iodate anhydrous (Commission Implementing Regulation EU 2015).

Products from the first group are sufficient in cases when it is possible to administer a product multiple times during the whole period of deficiency/increased demand. Usually these products are used for oral administration and they include: intraruminal infusion, salt blocks, molasses licks containing trace elements and feed supplements. One of the richest natural iodine sources (but also other minerals i.e. iron, potassium, and selenium) are algae. Studies conducted on Jersey cows during early lactation showed that adding increasing amounts of marine algae to the diet (0, 57, 113 or 170 g per day) caused a linear increase of the amount of iodine in the milk (from 178 to 13 370 μg l^{-1}). The concentration of iodine in these algae exceeded 800 mg kg^{-1} dry weight (Antaya et al. 2015).

The second group of products used in supplementing minerals has long-lasting effectiveness while requiring less amount of work. These products are usually subjected to a proper chemical or thermal treatment which makes them more expensive than the short-lasting versions. This group includes intraruminal boluses and injection products. Intraruminal boluses are heavy capsules, pills or ampules meant for oral administration, that reach the reticulum and remain there until total dissolution. The most basic advantages of boluses are their long-lasting effect (even up to 12 months) and the certainty that the administered product will be completely utilized by the animal (Rogers et al. 1998). Iodine covalently bound to polyunsaturated fatty acids ("iodised oil") is insoluble in water and undergoes slow release when injected subcutaneously or intramuscularly (Grace, Knowles 2012). Studies conducted on nearly 300 dairy cows that were given iodised oil three times (on the first, 100^{th} and 200^{th} day of lactation) in a dose of 2.370 mg per animal showed an increase of the iodine concentration in milk up to 160 μg l^{-1} on the 55^{th} day following the injection and up to about 60 μg l^{-1} on the 98^{th} day following the injection. In comparison, in the group of cows that were not given such supplementation the iodine concentration in milk was below 20 µg l^{-1} (Grace, Waghorn 2004). There are reports of the possibility of preventing iodine deficiency in cows for a period of over 70 days after a single subcutaneous administration of 1 ml 78% ethiodised oil (Randhawa, Randhawa 2001). The possibility of securing animals for such a long period of time is of great importance in the case of pasture feeding and when it is difficult to administer feed additives.

Bearing in mind that iodine is actively transported by the placenta from the mother's vascular system to the foetus, enriching a pregnant cow's diet is an effective way to improve the level of the supply of this element in newborn calves. The relevant observations show that iodine supplementation (15 mg kg^{-1} dry weight) in pregnant cows during the last weeks of pregnancy has led to increased iodine concentrations in the plasma of their calves even up to 990 µg l^{-1}. Meanwhile, the iodine concentration in calves born from cows that did not receive supplementation was almost twofold lower (Klebanoff et al. 2013).

CONCLUSIONS

The optimal supply of dairy cows with iodine contributes to the correct functioning of the body of a cow or calf. Moreover, milk it can be an excellent, natural source of this element for humans. For this reason, detailed analysis should be carried out on both the feed components used on the farm (the presence of goitrogens), as well as other elements that may affect the effectiveness of supplementation (excess calcium, nitrogen fertilization). It should also be borne in mind that supplementing the diet with iodine strengthens the response of the cattle's immune system against infectious agents, and thus may contribute to reducing the use of antibiotics in these animals and improving the condition related to the build-up of drug resistance.

AUTHOR CONTRIBUTIONS

K.Ż., G.Ś – conceptualization, K.Ż., G.Ś. – methodology, K.Ż – writing-original draft preparation, G.Ś – writing-review and editing, K.Ż., G.Ś – visualization, K.Ż. – funding acquisition. All authors have read and agreed to the published version of the manuscript. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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