DOI 10.20544/HORIZONS.B.09.2. P13
UDC636.2.034.087.7:546.15

IODINE IN DAIRY CATTLE: A review[1]

Petar Dodovski*, Natasa Pejcinovska*, Maja Angelovska*, Milena Jankulovska-Petkovska*, Talija Hristovska*, Igor Zdraveski *, Nikola Karabolovski*, Pance Dameski*, Mimi Ristevski*

*Veterinary Faculty Bitola, Prilepska nn, Bitola
petar.dodovski@uklo.edu.mk

Abstract

This review should provide more information about the importance of iodine in dairy cattle, since milk is considered as valuable source of iodine in newborn animal nutrition and in recent years in human nutrition. Iodine is an essential element for thyroid gland function and it is incorporated into the thyroid hormones, which play key role in energy metabolism, growth and brain development. Iodine also exert multiple and complex actions on many organs that capture it, not including its effects as part of thyroid hormones. Therefore, the adequate iodine bioavailability and optimal feed intake in dairy cattle is of pivotal importance for optimal iodine concentration in milk. Its concentrations in milk may be variable as it is influenced by many factors: iodine intake in feed, iodine forms used for feeding, iodine supplementation of feed, presence of goitrogenic substances and its ratio in animal feed, milk yield, seasonal fluctuations and also farm management.

Key words: dairy cattle, iodine, milk, supplementation

---
[1] review scientific paper

Introduction

Iodine (I_2) is one of the most important micro-mineral which can be categorized as an essential in dairy cattle and other animals (Kupper et al., 2011). Iodine is predominantly needed for production of thyroid hormones which play a pivotal role in maintaining energy metabolism and also important for reproductive and productive performance in dairy cattle. It is essential in fetal development since the utilization of iodine starts in very early fetal stages and important for thyroid axis maturation during the intrauterine period (Koneff et al., 1949). Adequate iodine availability during prenatal period also reflects on postnatal growth and development in newborn animal (Cardoso at al., 2021)[1]. Furthermore, recent investigation has reviled that iodine directly neutralizes free radicals, induces the expression of type II antioxidant enzymes, inactivates proinflammatory pathways and have strong immunomodulatory effect (Aceves et al., 2021).

Meeting the optimal iodine requirements in dairy cattle is substantial not only in fulfilling the maximal productive and reproductive performance in cattle, but also to ensure the adequate iodine supply through milk consumption in human population, especially in iodine-deficient regions (Flachowsky et al., 2014). Nowadays, despite the WHO/UNICEF/Iodine Global Network recommendation in universal salt iodization at a fortification level of 20-40 mg iodine per kg salt, iodine deficiency remains as a global health concern in risk of insufficient iodine intake (World Health Organization, 2007). Therefore, milk and dairy products have become important sources of iodine in human population especially in countries of continental geographical location.

Bioavailability

Iodine is naturally accruing environmental constituent and the least abundant of all halogen elements in both, organic and inorganic forms. Transport, distribution and transformation include various complex physical, chemical and biological processes referred as the global iodine cycle (Cox and Aray, 2014). Iodine can be found naturally in air, water and soil in several chemical forms - molecular iodine (I_2), iodide (I^-), iodate (IO_3) and periodate (IO_4). Iodine in water exists as I^- and IO_3 and is related to the content of iodine in soil. Oceans are the most abundant sources of natural iodine compared to fresh water. The more distance from the sea, the less content of iodine in fresh water. The average iodine concentration in air and soil is also variable and mostly depends on geological structure of the soil (Whitehead, 1984). Iodine concentration in plants varies depending on location, climatic and seasonal conditions, plant species and use of agro-technical measurements (use of iodine-containing fertilizers). Iodine cannot be synthesized in animal organism, so air, soil and consequently plants are the main source. Therefore, the type of diet and feeding management closely correlates with iodine uptake in animals.

Iodine availability also depends on the presence of goitogenic substances in dairy cattle diet. In ruminants, ingestion of natural goitrogenic substances is often associated with intake of plants mainly belonging to the *Brassicaceae* family (*Cruciferae*). These plants contain goitrogenious glucosinolates which can be found within all parts of the plant and during processing and chewing, glucosinolates are quickly hydrolyzed in isothiocyanates, thiocyanates, and other goitrogenic substances, which diminish the iodine uptake in thyroid and mammary gland (Ishida at al., 2014). Thiocyanate content and marginal deficiency or lower iodine content in dam's diet, could be a reason for congenital goiter in newborn calves (Seimiya at al., 1991). Investigations of iodine in milk confirmed that the presence of rapeseed in dairy cattle diet without supplementation significantly lowers the concentration of iodine in milk (Hejtmánkováat al., 2006). Although, ruminants are considered less sensitive to glucosinolates but long-term nutrition with food containing goitrogenic substances in cattle may cause thyroid function disorders and symptoms of iodine deficiency (EFSA, 2008). The allowed measurable residues in dairy milk are set to approximately 0.1% of the given progoitrin dose allowed in animal feed (EFSA, 2008).

Iodine requirements/recommendations

The average concentration of iodine in animals varies depending on the age, genetic differences and production status. Iodine is needed in lactating cow during the maximum lactation since the transfer of iodine from feeds to milk ranges from 7 to 27%, depending on the amount fed to the animal (Moschini et al., 2010). Not every time, cattle meet the optimal requirements through food so iodine supplementation is needed since the majority of farm animal feed is plant matter which may usually contain insufficient iodine concentrations (<20–50 μg/kg dry matter (DM)). Additionally, iodine content of water is also generally low (2–7 μg/l) (Flachowsky et al., 2007). However, iodine concentration in different type of plants is mostly affected by season, its botanical composition and varietal differences (Coneyworth at al., 2020). Iodine concentration of non-fortified feed components (forages) is often <2 mg/kg DM, and typically ranges between 0 and 0.2 mg/kg DM. Based on analysis of mean iodine levels content in forages, as well as on calculations for a typical lactating cow, has been concluded that forages supplied approximately 17% of iodine requirements in average lactating cattle (Castro et al.,2011). Taking in consideration that forage constitute up to 70% of dry matter consumed by the cow, it is clear that the food very often is insufficient iodine supply in cattle.

Iodine demands in cattle is defined under optimal conditions, as nutrient requirements and the recommendations are estimated to meet the average gross demands under certain conditions, plus a safety factor considering the individual variability, iodine availability and potential interaction with other nutrients and substances. Therefore, the European Food Safety Authority (2005) suggested that the maximum iodine content in dairy cow rations be set at 0,44 mg/kg of feed (as fed, 88% DM). According the European Union Commission Regulation EC 1459/2005 maximum iodine concentration requirements in dairy feed stuffs should not be more than 5 mg iodine/kg 88% dry matter. Several authors suggested that iodine requirements for lactating cattle should be based on the fact that in lactating cattle iodine utilization is increased since the rate of thyroxin production increases about 2.5 and increased iodine secretion in milk (Sanchez, 1995; Enjalbert, 2009). But these recommendations may vary in different countries and are limited through country-specific regulations (Flachowsky et al., 2007). Recommended iodine intake in cattle is designed to prevent iodine deficiencies, maintain adequate iodine stores, sustain optimal thyroid function and to facilitate a high performance in reproduction and production in cattle. But some authors point out that these requirements are empirically established on inappropriate approach and suggested that guidelines should be based on targeted dose–response studies in animals using growth and performance data, as well as laboratory diagnostic criteria (Schone and Rajendram, 2009).

Supplementation

Introducing optimal iodine concentration in dairy cattle very often is achieved by adding iodine supplements in food or other form of iodine uptake. The type of supplementation depends on management system, so range of most suited options for certain system are needed. Therefore, supplementation methods suited to common cattle management are via the feed, water supply, slow-release bolus, solidified free-choice products, skin application, long acting injection, or by periodic drenching. All these methods were examined under experimental conditions as most suitable in which supplements can provide short and long term efficacy (Grace and Knowels, 2012). According to the EU Legislative, iodine nutritive additives for feed supplementation in form of sodium iodide (NaI), potassium iodide (KI), calcium iodate hexahydrate ($Ca(IO_3)_2x6H_2O$) and calcium iodate ($Ca(IO_3)_2$), are approved. Oral drenches, compressed salt blocks, dispensing soluble minerals into a water supply and many varieties of mineral premixes as food supplement, are considered as simple methods that provides short term efficacy, best suited to farming operations where animals are closely managed or handled frequently. In contrary, methods which can provide long term efficacy, like forms of products that create a persistent depot, intraruminal boluses and usage of trace-element fertilizers are more suitable for open system management and reduce labor-using activity. A study based on iodine secretion through milk, urine and feces in dairy cattle, shows the difference of utilization between inorganic and organic iodine supplements (Franke et al., 2009). It is very important to mention that iodine content in supplements used in animal nutrition may be variable, since the physical stability of the inorganic preparations of iodine is significantly lower and depends on the method of storing (EFSA, 2013).

Farm management

Development of organic breeding system and other sustainable production systems are very popular in recent years. Today, organic production and organic livestock farming, which contribute to the improvement of the environment and the health of animals and humans, are increasingly relevant. Due to the strict rules regarding the use of mineral-vitamin supplements in the diet of domestic animals, the iodine content in organic milk can be in a very low range (Payling et al., 2015). In order to enable sufficient iodine supplementation and to support animal health, organic producers are using preventive approaches in accordance to organic dairy feeding systems. (Combet et al., 2014; Lopez et al., 2016).

Iodine metabolism - absorption, distribution and elimination

Iodine species (iodide, iodate) enters the body through food and water mainly as inorganic and in a very small amount as organic form (iodinated amino acids). Absorption largely occurs by the gastrointestinal tract but there is significant absorption by the lungs and dermal/mucosal surfaces (Vandecasteele al., 2000). Almost 80 to 90 % of dietary iodine is absorbed in form of iodide by the gastrointestinal system, mediated by the expression of NIS (Na^+/I^- symporter) on the apical surface of the small intestinal epithelium (Nicola et al., 2009). Absorption may be influenced by the different chemical form and stability of dietary iodine sources (Zicker and Schoenherr, 2012). Abomasus plays an important role in iodine concentration and secretion (Miller at al., 1975). The abomasus promote iodine conservation and forms an extravascular iodine pool, thus preventing the urinary excessive loss of iodine which ensures the optimal availability of iodine for further uptake by the thyroid gland (Mertz, 2012). The secretion of iodine in abomasus is 18 times greater than its absorption. Most of the secreted iodine in abomasus later is absorbed by small and large intestines. The recycling of iodine also includes iodine secretion in small rate by the rumen epithelium and salivary gland (Mertz, 2012). But the rumen and other forestomach fluids do not concentrate iodine in bovine. On the other hand, iodine pool incorporated in thyroid hormones are secreted by the bile and only 10% is reabsorbed by the intestine. After absorption iodine is distributed through blood in form of inorganic nonprotein- bond iodine and the most bond-protein organic iodine, after what is mainly transferred in to extracellular pool and tissues specialized for the accumulation of iodide. The half-life of plasma iodine is approximately 10 hours under normal circumstances and mainly vary depended on thyroid activity and iodine utilization (Chung, 2014). The blood clearance of iodine is through many tissues that are specialized in utilization of iodine, predominantly in thyroid gland, and excretion of iodine in urine, feces and milk. The thyroid gland is major organ that uses over 70% of total iodine and its uptake is moderated by specific active transport system specialized for iodine transportation in thyroid follicular cells (Underwood, 1999; Ahad and Ganie, 2010). The amount of received iodine manifested as concentration of iodine in thyroid gland, induces morphological changes in thyroid gland (Peksa et al., 2011). The uptake of iodine may be influenced by many factors that may reflect the activity of the thyroid gland. The increased peripheral utilization of thyroid hormones activates thyroid feedback control mechanism and stimulates secretion of hypothalamic thyroid realizing hormone (TRH) and pituitary thyroid stimulating hormone (TSH), that increase the iodine capture by the thyroid gland (Sarne, 2016). Nevertheless, the content of thyroid gland not always is indicative on thyroid gland activity since the thyroid gland has very good storage capacity of iodine which can be used in situations of increased need for thyroid hormones secretion.

Iodine in other tissues and mammary gland

The mechanism of iodine accumulation also exists in the salivary glands, gastric mucosa, choroid plexus, ovaries, placenta, and the mammary glands during pregnancy and lactation. NIS transporters are present on the epithelial lining on these tissues and accept iodine via simport transport by the same mechanism as in the thyroid gland. This structural and functional similarity of the NIS molecule with the thyroid molecule exists, especially on the epithelial cell in salivary gland and the gastrointestinal tract (Ravera et al., 2017). But the expression and function are not under TSH control as it is in the thyroid gland.

In mammary gland, the processing and expression of the NIS molecule differs and increases by increasing the level of lactation (Wen et al., 2016). Prolactin, estrogen and oxytocin regulate the expression and function of iodine transporters in mammary gland tissue (Tazebay et al., 2000). The concentration of iodine is also influenced by the expression and activity of deiodinase. In cattle, during lactation, type 2 deiodinase (5´D-2) is predominantly active, which is important for maintaining T_3 concentrations in mammary gland cells. This could be considered as an adaptive mechanism to high milk production, providing enough energy for intensive work of the mammary gland and maintaining the euthyroid state (Pezzi et al., 2003).

The concentration of iodine in milk is positively correlated with the iodine nutritional intake. Iodine supplementation has also resulted in higher milk iodine concentration. But increased iodine intake in feed did not have any effect on milk yield or protein and fat content in the milk (Grace and Waghorn, 2005). In recent study, reduced iodine transfer was observed in high yield cow assuming on effect of iodine dilution in milk which can be minimized by controlled iodine supplementation (Coneyworth et al., 2020). Inconsistent data has been reported regarding the iodine concentration and milk yield, but according Flachowsky and coworkers (2014) iodine concentration in milk should not be changed in the case of linear correlation between iodine intake and milk yield.

However, negative correlation was shown between the lactation phase and the concentration of iodine in milk. Colostrum has two to three time higher concentrations (264±100μg/L) than milk (98±82μg/L) and the concentration of iodine decreases towards the end of lactation (NRC, 2005).

Iodine concentration in milk can also be affected by the use of iodine-containing solutions for teat disinfection before and after milking. Increased iodine in milk was recorded in dairy cattle that were treated before and after milking with iodine-based disinfectant. Some authors suggest that the time of dipping and application of spray iodine disinfectant could have more impact on iodine in milk (Mikláš et al., 2021). The available level of iodine in disinfectant and also milk yield seems to be also important (Flachowsky et al., 2014), although there is an argument about the mode that iodine enters in milk (van der Reijdenet al., 2017). Therefore, usage of iodine-based disinfectants in combination with iodine supplementation could significantly increase the iodine content in cow milk.

Conclusion

Meeting the optimal iodine requirements in dairy cattle is necessary for optimal function of the animal organism and also to provide adequate concentration of iodine in milk, available to newborn animal and the more important optimal iodine supplementation in nutrition of human population. Maintaining the optimal level of iodine in animal's body, is influenced by many endogenous and exogenous factors, but iodine content in milk is more or less linearly related to the available dietary iodine content. Other factors, like farm management, milk yield and at finally milk processing, may cause significant variation in iodine content and also could alter the availability of iodine in milk. Therefore, recommendations given for optimization of iodine intake should be followed but at the same time some measurements of reducing variation of iodine concentration in milk should be considered.

Reference

1. Aceves, C., Mendieta, I., Anguiano, B., Delgado-González, E. Molecular Iodine Has Extrathyroidal Effects as an Antioxidant, Differentiator, and Immunomodulator. International Journal of Molecular Sciences, 22(3), 1228, 2021. https://doi.org/10.3390/ijms22031228
2. Ahad, F., Ganie, S. A. Iodine, Iodine metabolism and Iodine deficiency disorders revisited. Indian journal of endocrinology and metabolism, 14(1), 13–17, 2010. https://www.ijem.in/text.asp?2010/14/1/13/75080
3. Arrizabalaga, J. J., Jalón, M., Espada, M., Cañas, M., Latorre, P. M. Iodine concentration in ultra-high temperature pasteurized cow's milk. Applications in clinical practice and in community nutrition. MedicinaClínica (English Edition), 145(2), 55-61, 2015. https://doi.org/10.1016/j.medcle.2014.04.006
4. Cardoso, C. L., King, A., Chapwanya, A., Esposito, G. Ante-Natal and Post-Natal Influences on Neonatal Immunity, Growth and Puberty of Calves—A Review. Animals, 11(5), 1212, 2021. https://doi.org/10.3390/ani11051212
5. Castro, S. B., Lacasse, P., Fouquet, A., Beraldin, F., Robichaud, A., Berthiaume, R. Feed iodine concentrations on farms with contrasting levels of iodine in milk. Journal of dairy science, 94(9), 4684-4689, 2011. https://doi.org/10.3168/jds.2010-3714
6. Chung, H. R. Iodine and thyroid function. Annals of pediatric endocrinology & metabolism, 19(1), 8-12, 2014. https://doi.org/10.6065/apem.2014.19.1.8
7. Combet, E., Ma, Z. F., Cousins, F., Thompson, B., Lean, M. E. Low-level seaweed supplementation improves iodine status in iodine-insufficient women. British Journal of Nutrition, 112(5), 753-761, 2014. https://doi.org/10.1017/S0007114514001573
8. Coneyworth L.J., Coulthard L.C., Bailey E.H., Young S.D., Stubberfield J., Parsons L., Saunders N., Watson E., Homer E.M., Welham S.J. Geographical and seasonal variation in iodine content of cow's milk in the UK and consequences for the consumer´ s supply. Journal of Trace Elements in Medicine and

Biology. May 1;59:126453, 2020. https://doi.org/10.1016/j.jtemb.2020.126453
9. Cox E. M., Arai, Y., Environmental Chemistry and Toxicology of Iodine. Advances in Agronomy, 128, 47, 2014. https://doi.org/10.1016/B978-0-12-802139-2.00002-0
10. EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP). Scientific Opinion on the safety and efficacy of iodine compounds (E2) as feed additives for all animal species: calcium iodate anhydrous, based on a dossier submitted by Calibre Europe SPRL/BVBA. EFSA Journal, 11(2), 3100, 2013. https://doi.org/10.2903/j.efsa.2013.3099
11. Enjalbert F. The relationship between trace elements status and health in calves. Revue de MédecineVétérinaire, 160(8/9), 429-435, 2009.
12. EU Commission Regulation (EC) No 1459/2005: amending the conditions for authorisation of a number of feed additives belonging to the group of trace elements. Off J Eur Union L233:8–10, 2005.
13. European Union Commission Regulation (EC) No 1459/2005: amending the conditions for authorisation of a number of feed additives belonging to the group of trace elements. Off J Eur Union L233, 8 – 10, 2005.
14. European Food Safety Authority (EFSA). Glucosinolates as undesirable substances in animal feed-Scientific Opinion of the Panel on Contaminants in the Food Chain. EFSA Journal, 6(1), 590, 2008. https://doi.org/10.2903/j.efsa.2008.590
15. Flachowsky G. Iodine in animal nutrition and iodine transfer from feed into food of animal origin. Lohmann information, 42(2), 47-59, 2007.
16. Flachowsky G., Franke K., Meyer U., Leiterer M., Schöne F. Influencing factors on iodine content of cow milk. European journal of nutrition, 53(2), 351-365, 2014. DOI:10.1007/s00394-013-0597-4

17. Franke K., Meyer U., Wagner H., Hoppen H. O., Flachowsky G. Effect of various iodine upplementations, rapeseed meal application and two different iodine species on the iodine status and iodine excretion of dairy cows. Livestock Science, 125(2), 223-231, 2009. https://doi.org/10.1016/j.livsci.2009.04.012
18. Grace N. D., Knowles S. O. Trace element supplementation of livestock in New Zealand: meeting the challenges of free-range grazing systems. Veterinary medicine international, 2012. https://doi.org/10.1155/2012/639472
19. Grace N. D., Waghorn G. C. Impact of iodine supplementation of dairy cows on milk production and iodine concentrations in milk. New Zealand veterinary journal, 53(1), 10-13, 2005. https://doi.org/10.1080/00480169.2005.36462
20. Hejtmánková A., Kuklík L., Trnková E., Dragounová H. Iodine concentrations in cow's milk in Central and Northern Bohemia. Czech Journal of Animal Science, 51(5), 189, 2006. DOI:10.17221/3928-CJAS
21. Ishida M., Hara M., Fukino N., Kakizaki T., Morimitsu Y. Glucosinolate metabolism, functionality and breeding for the improvement of Brassicaceae vegetables. Breeding science, 64(1), 48-59, 2014. https://doi.org/10.1270/jsbbs.64.48
22. Koneff A. A., NICHOLS N., Wolff J., Chaikoff I. L. The fetal bovine thyroid: morphogenesis as related to iodine accumulation. Endocrinology, 45(3), 242-249, 1949. https://doi.org/10.1210/endo-45-3-242
23. Kupper F.C., Feiters M.C., Olofsson B., Kaiho T., Yanagida S., Zimmermann M.B., Carpenter L.J., Luther G.W., Lu Z.L., Jonsson M., Kloo L. Commemorating two centuries of iodine research: an interdisciplinary overview of current research. Angew ChemInt Ed 50(49):11598–11620. 2011. https://doi.org/10.1002/anie.201100028
24. Lopez C. C., Serio A., Rossi C., Mazzarrino G., Marchetti S., Castellani F., Martino G. Effect of diet supplementation with Ascophyllumnodosum on cow milk composition and microbiota.

Journal of dairy science, 99(8), 6285-6297, 2016. https://doi.org/10.3168/jds.2015-10837
25. Mertz W. Trace Elements in Human and Animal Nutrition: Volume 2 (Vol. 2). Elsevier. pp 145-147, 2012.
26. Mikláš Š., Tančin V., Toman R., Trávníček J. Iodine concentration in milk and human nutrition: A review. Czech Journal of Animal Science, 66(6), 189-199, 2021. https://doi.org/10.17221/167/2020-CJAS
27. Miller J. K., Swanson E. W., Spalding G. E. Iodine Absorption, Excretion, Recycling, and Tissue Distribution in the Dairy Cow1. Journal of dairy science, 58(10), 1578-1593, 1975. https://doi.org/10.3168/jds.S0022-0302(75)84753-9
28. Moschini M., Battaglia M., Beone G. M., Piva G., Masoero F. Iodine and selenium carry over in milk and cheese in dairy cows: effect of diet supplementation and milk yield. Animal, 4(1), 147-155, 2010. https://doi.org/10.1017/S175173110999098X
29. National Research Council. "Mineral tolerance of animals. The Second Revised Edition, 1-469.: 182-193, 2005.
30. Nicola J. P., Basquin C., Portulano C., Reyna-Neyra A., Paroder M., Carrasco, N. The Na+/I− symporter mediates active iodide uptake in the intestine. American Journal of Physiology-Cell Physiology, 296(4), C654-C662, 2009. https://doi.org/10.1152/ajpcell.00509.2008
31. Payling L. M., Juniper D. T., Drake C., Rymer C., Givens D. I. Effect of milk type and processing on iodine concentration of organic and conventional winter milk at retail: implications for nutrition. Food chemistry, 178, 327-330, 2015. https://doi.org/10.1016/j.foodchem.2015.01.091
32. Peksa Z., Trávníček J., Dušová H., Konečný R., Hasoňová L. Morphological and histometric parameters of the thyroid gland in slaughter cattle. Journal of Agrobiology, 28(1), 79-84, 2011.
33. Pezzi C., Accorsi P. A., Vigo D., Govoni N., Gaiani, R. 5′-Deiodinase activity and circulating thyronines in lactating cows.

Journal of dairy science, 86(1), 152-158, 2003. DOI:10.2478/v10146-011-0009-4
34. Ravera S., Reyna-Neyra A., Ferrandino G., Amzel L. M., Carrasco N. The Sodium/Iodide Symporter (NIS): Molecular Physiology and Preclinical and Clinical Applications. Annual review of physiology, 79, 261–289, 2017. DOI: 10.1146/annurev-physiol-022516-034125
35. Sanchez J. M. Iodine in bovine nutrition. Nutrition-Animal-Tropical, 2, 95-120, 1995.
36. Sarne D. Effects of the Environment, Chemicals and Drugs on Thyroid Function, MDText. com. Inc, South Dartmouth, MA, USA, 2016.
37. Schöne F., Rajendram, R. Iodine in farm animals. Comprehensive handbook of iodine: nutritional, biochemical pathological and therapeutic aspects. Academic, Burlington, 151-170, 2009.
38. Seimiya Y., Ohshima K. I., Itoh H., Ogasawara N., Matsukida Y., Yuita K. Epidemiological and pathological studies on congenital diffuse hyperplastic goiter in calves. Journal of Veterinary Medical Science, 53(6), 989-994, 1991. https://doi.org/10.1292/jvms.53.989
39. Tazebay Uygar H., Irene L., Wapnir O. L., Orsolya D., Lionel S.Z., Qing H., Z., Hou F. D.The mammary gland iodide transporter is expressed during lactation and in breast cancer. Nature medicine 6, no. 8: 871-878, 2000. DOI: 10.1038/78630
40. Underwood E. J. The mineral nutrition of livestock. Cabi.: 343–373, 1999.
41. Van der Reijden O. L., Zimmermann M. B., Galetti V. Iodine in dairy milk: Sources, concentrations and importance to human health. Best Practice & Research Clinical Endocrinology & Metabolism, 31(4), 385-395, 2017. https://doi.org/10.1016/j.beem.2017.10.004
42. Vandecasteele C. M., Van Hees M., Hardeman F., Voigt G., Howard B. J. The true absorption of 131I, and its transfer to milk in cows given different stable iodine diets. Journal of

environmental radioactivity, 47(3), 301-317, 2000. https://doi.org/10.1016/S0265-931X(99)00047-8

43. Wen G., Pachner L. I., Gessner D. K., Eder K., Ringseis R. Sterol regulatory element-binding proteins are regulators of the sodium/iodide symporter in mammary epithelial cells. Journal of dairy science, 99(11), 9211-9226, 2016. https://doi.org/10.3168/jds.2016-11174
44. Whitehead D. C. The distribution and transformations of iodine in the environment. Environment international, 10(4), 321-339, 1984. https://doi.org/10.1016/0160-4120(84)90139-9
45. World Health Organization: Assessment of iodine deficiency disorders and monitoring their elimination: a guide for programme managers, 2017.
46. Zicker S., Schoenherr B. Focus on nutrition: the role of iodine in nutrition and metabolism. Compendium (Yardley, PA), 34(10), E1-4, 2012.