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Iodine concentration in milk and human nutrition: A review

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Abstract: The aim of the review was to provide information about the importance of iodine in human nutrition and to review milk as an important source of iodine, and also to summarize the main factors affecting iodine concentration in milk. Iodine is an essential element for the thyroid gland function and synthesis of thyroid hormones, which regulate key processes of metabolism, brain development and growth. Therefore, it is important to ensure adequate, neither deficient nor excessive, intake of this element in animal nutrition, but more importantly in the nutrition of humans. Milk and dairy products are very valuable sources of iodine. However, its concentration in milk is very variable, as it is affected by many different factors – iodine intake in feed, antinutritional factors, iodine species (forms) used for feeding, animal keeping, farm management and possibly also milk yield. Additionally, milk iodine concentration is also affected by teat dipping with iodine disinfection, and by milk processing (e.g. skimming and heat treatment). All these aforementioned factors may possibly play its role in improving the human nutrition, especially the nutrition of pregnant, lactating women, and people on low-salt diet who are the most vulnerable to insufficient iodine intake.

Keywords: iodine content; dairy animals; dairy products; feeds; factors; supplementation

Introduction

Iodine is a reactive trace element, not occurring in its pure form (SCF 2002). It is essential for the thyroid gland and thyroid hormone production (Walther et al. 2018). Thyroxine and triiodothyronine contain 65% and 59% of iodine, respectively (SCF 2002). These hormones regulate key processes of metabolism, brain development (Grau et al. 2015) and growth (SCF 2002). Moreover, iodine might also be important due to its immunomodulatory effects on human immunity (Iannaccone et al. 2019). Therefore, iodine is very important for maintaining physiological processes (Flachowsky et al. 2014).

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The needs of iodine in human nutrition are affected by age, body weight, physiology, and gender (Flachowsky et al. 2014). If these demands are not fulfilled, the insufficient iodine status may result in the deficiency of thyroid hormones and subsequently in deficiency symptoms including cretinism, brain damage, irreversible mental retardation, deaf-mutism, and goitre (Walther et al. 2018). In this respect, it is estimated that more than 2 billion people worldwide (Zimmermann 2009) and 30% of the European countries have insufficient iodine intake and are at risk of iodine deficiency (Lazarus 2014). This might be confirmed by Johner et al. (2012), who found insufficient iodine intake in 30% of the participants of a German study.

Milk and dairy products, as important sources of iodine (van der Reijden et al. 2019), might help to alleviate this problem, in case of proper supplementation of mineral premixes and licks to dairy animals (Schone and Rajendram 2009), which can bring a positive outcome not only for human but also for animal nutrition (Flachowsky et al. 2007).

Therefore, the aim of this review is to describe the role of iodine in human nutrition and to characterise milk and dairy products as sources of iodine, and factors that might possibly influence the efficiency of their further use.

Human nutrition

Iodine requirements

Iodine overconsumption as well as deficiency cause adverse effects (Pearce 2018), therefore limits for the iodine intake were defined. Based on the publication of WHO (2007) the recommended iodine intake for adults is 150 μg/day and for pregnant women 250 μg/day. Recommended doses for other age categories/physiological states of people are listed in Table 1.

In relation to the tolerable upper intake level of iodine the Scientific Committee on Food (SCF 2002), based on an assignment given by the European Commission, examined the tolerable upper intake level of iodine and recommended a maximal dose of 600 μg/day for pregnant, breastfeeding women, adults and 500 μg/day for people living in areas with the occurrence of endemic goitre (SCF 2002). Recommended values for other age groups can be found in Table 1. This implies that iodine in human nutrition might be easily overconsumed (Laurberg et al. 2010), but also deficient as a difference between desirable and undesirable iodine content in foods is very low (Flachowsky 2007). This problem is also amplified by variability of iodine, even in similar groups of foods (Haldimann et al. 2005). Therefore, the regulation of iodine in human nutrition is important in the prevention of iodine associated disorders (Laurberg et al. 2010). However, human individuality has to be taken into account when considering iodine requirements (Kursa et al. 2005), as for instance Japanese can consume 50–80 mg iodine/day without any occurrence of adverse effects (SCF 2002).

Iodine sources

Iodine concentration in food, as a primary source of iodine, is dependent on geochemical and soil composition (SCF 2002), distance from the sea and growing practices on farms (Zimmermann 2009), frequency of floods (Arrizabalaga et al. 2015) etc. Therefore, it might be very variable (Haldimann et al. 2005). Iodine concentration in selected types of foods is presented in Table 2.

Globally, iodized salt is the most important source of iodine used for improvement of iodine intake in the human population (WHO 2007). The use of iodized salt is highly cost-effective in terms of iodine supplementation in human nutrition, although Lazarus (2014), who exam-

Table 1. Recommended daily iodine requirements and upper tolerable iodine intake (μg/day) for chosen age categories and physiological states

Age/physiological stage	Iodine requirements (WHO 2007)	Tolerable upper intake level of iodine (SCF 2002)
0–5 years	90	–
1–3 years	–	200
4–6 years	–	250
6–12 years	120	–
7–10 years	–	300
11–14 years	–	450
> 12 years	150	–
15–17 years	–	500
Adults	150	600
Pregnant and lactating women	250	600

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Table 2. Iodine concentrations of selected foods and feeds

Food item	Iodine concentration			References
	mean	median	min.–max.	
Dairy products (μg/kg)				
Cow milk	251 ± 110	–	147–605	Hejtmankova et al. (2006)
Cow cheese	473 ± 289	396	146–1 323	Haldimann et al. (2005)
Goat cheese	700	–	250–1 040	Carlsen et al. (2018)
Sheep cheese	861	–	–	Schirone et al. (2018)
Yoghurt	670 ± 313	556	347–1 239	Haldimann et al. (2005)
Meat, protein sources (μg/kg)				
Egg	360	–	340–380	Carlsen et al. (2018)
Meat	40	–	2–430	Carlsen et al. (2018)
Fish, marine	2 112 ± 1 713	1 440	387–6 926	Haldimann et al. (2005)
Fish, freshwater	375 ± 436	205	11–1 571	Haldimann et al. (2005)
Fruit, vegetables and cereals (μg/kg)				
Fresh fruit	18 ± 15	15	2–75	Haldimann et al. (2005)
Fresh vegetables	47 ± 43	33	9–203	Haldimann et al. (2005)
Bread	393 ± 213	392	25–1 032	Haldimann et al. (2005)
Rice	333 ± 341	250	11–934	Haldimann et al. (2005)
Potatoes	16 ± 11	18	4–26	Haldimann et al. (2005)
Feeds (μg/kg dry matter)				
Corn silage	125 ± 22	94	29–479	Castro et al. (2011)
Grass silage	321 ± 278	176	105–949	Schone et al. (2017)
Maize silage	109 ± 42	102	54–197	Schone et al. (2017)
Hay	112 ± 94	78	23–523	Travnicek et al. (2004)
Pasture	149 ± 105	119	27–555	Travnicek et al. (2004)
Grains	55 ± 7	40	28–270	Castro et al. (2011)
Soy products	101 ± 21	62	29–320	Castro et al. (2011)

ined countries of Western and Central Europe, showed that only 13 countries out of 38 had introduced mandatory salt iodization. Nevertheless, increased salt consumption might pose a risk of the increased incidence of cardiovascular diseases (van der Reijden et al. 2017).

This fact might point to another important source of iodine, dairy milk and dairy products (van der Reijden et al. 2019), which already cover a substantial portion of adults' dietary iodine requirements in countries like USA (Abt et al. 2018), United Kingdom (Coneyworth et al. 2020), Ireland (O'Kane et al. 2018) and Norway (Troan et al. 2015). Milk and milk products as a significant source of iodine in human nutrition are discussed in another part of the review. On the other hand, the Swiss population consumes bread added iodized salt as the most important source of iodine, which is however voluntary and therefore it might be quite variable (Haldimann et al. 2005).

Animal nutrition

Iodine requirements

According to several authors, the lactating cows require intake of 0.5 mg iodine/kg dry matter (van der Reijden et al. 2017). On the other hand, according to Commission Regulation (EC) No 1459/2005, the lactating cows should not consume more than 5 mg iodine/kg dry matter. That reflects the importance of the iodine intake regulation in dairy animals (Flachowsky et al. 2014) due to a risk of their iodine overconsumption (Kursa et al. 2005), but more impor-

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tantly because of its impact on human nutrition (Flachowsky et al. 2014).

Not observing the lower limits of iodine intake requirements in dairy animals causes goitre, higher incidence of stillbirths, and increased embryonal mortality (Schone and Rajendram 2009). As already mentioned, there is also a risk of overconsumption, which is particularly risky in the high-producing dairy animals, through accumulation when feeding higher iodine concentrations (Kursa et al. 2005).

In sheep according to NRC (1985) the intake of 0.1–0.8 mg iodine/kg dry matter is required. In goats 0.3–0.8 mg iodine/kg dry matter is recommended (GfE 2003).

In this regard, milk iodine concentration might be used as an indicator of iodine intake in dairy animals, when for instance the milk iodine concentration below 80 μg/l might indicate iodine deficiency in sheep (Travnicek and Kursa 2001) and 60 μg/l in goats (Paulikova et al. 2008).

Iodine sources

In animal nutrition iodine is supplied by feeds (Table 2) and additional supplementation, which is essential for ensuring the sufficient intake of iodine (Flachowsky et al. 2014). On conventional farms it is most often administered using mineral and vitamin premixes and in ecological farming it is via mineral licks (Schone and Rajendram 2009). The mineral supplements contribute 10–40 mg iodine/day to dairy cows' iodine intake (Troan et al. 2015) and therefore they represent an important source of iodine for farm animals (Flachowsky et al. 2014). Concentrations of iodine in forages reach up to 0.2 mg/kg dry matter (Flachowsky et al. 2014), which is comparable with Travnicek et al. (2004), who determined iodine content in grass silage (213.3 ± 169.3 μg/kg dry matter). Moreover, it is also possible to administer organically bound iodine to dairy animals, using algae (Travnicek et al. 2010; Brito 2020).

Nevertheless, iodine content in feeds is very diverse, and to a great extent affected by many factors, like environment, iodine concentration in water, feeds and soil (Flachowsky et al. 2014). Furthermore, the iodine content in feeds seems to differ also in relation to the season, as Travnicek et al. (2004) found that the average iodine content of pasture plants was lower from May to July (101.3 ± 73.6 μg/kg dry matter), compared to the period from August to October (214.5 ± 107.3 μg/kg dry matter).

Milk and dairy products in human nutrition

As already mentioned, according to van der Reijden et al. (2019) milk and dairy products are important iodine sources. This might be supported by findings of Mullan et al. (2017), who observed a significant correlation between urinary iodine concentration and milk consumption. Furthermore, Arrizabalaga et al. (2015) found that one glass of Spanish ultra heat treatment (UHT) milk (200–250 ml) contains 50 μg of iodine, which covers approximately 50% of daily iodine requirements of kids and 20% of the needs of pregnant women. Similarly, the importance of iodine in milk was reported by Hejtmankova et al. (2006), who found that 700 ml of milk or corresponding quantity of dairy products in the Czech Republic can cover daily iodine requirements in humans.

However, milk is typical for its iodine concentration variability (van der Reijden et al. 2019; Roseland et al. 2020) that is caused by several factors like concentration of iodine in feed, iodine species used in feeds (iodide, iodate), use of iodine-containing disinfectants (SCF 2002) and by regional differences (Travnicek et al. 2006). Additionally, the content of iodine in some dairy products can be a result of iodized salt use, for instance in cheese manufacturing (van der Reijden et al. 2019).

Milk iodine status

In the past years, several studies suggested that milk iodine concentration in many European industrialized countries has an overall increasing tendency (Travnicek et al. 2006; Flachowsky 2007; Paulikova et al. 2008).

However, in more recent works, the average milk iodine concentration in industrialized countries ranged between 33 μg/l and 534 μg/l (van der Reijden et al. 2017). In this respect, the Czech study, conducted in 2009–2018, found changes in milk iodine concentrations, where gradual declines from 2010 to 2018 were observed (from 479.5 ± 304.9 μg/l to 231.2 ± 63.5 μg/l), that might be explained by changes in iodine supplementation (Konecny et al. 2019), with the current status better

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meeting requirements for milk iodine concentration (80–250 μg/l) (Kursa et al. 2005). As iodine concentration above 300 μg/l might cause overconsumption of iodine in humans (Flachowsky 2007).

In this respect van der Reijden et al. (2019) published that the preferable milk iodine concentration, regarding the consumption of milk and milk products in the Swiss population, would be 150–300 μg/l, which could be achieved by addition of 1–2 mg iodine/kg dry matter to the diet of dairy cows. Other authors, like Travnicek et al. (2011) considered 100–200 μg/l sufficient for ensuring iodine intake in the human population.

In sheep, the Slovak investigation of Paulikova et al. (2008) found that in 62.8% of sheep samples milk iodine concentration was below 80 μg/l, which might be considered as iodine deficient. In Czech sheep milk Travnicek and Kursa (2001) reported the average iodine concentration to be 105.5 μg/l. In Slovak goat milk investigated in 2002–2006 had 35.3% of samples concentration below 60 μg/l, indicating iodine deficiency (Paulikova et al. 2008). Investigated Czech goat farms showed also low milk iodine concentrations with average values of 31.6 μg/l in 1998 and 63.0 μg/l in 1999 (Travnicek and Kursa 2001). In this respect, Nudda et al. (2009) observed that iodine unsupplemented Sarda goats had the average milk iodine concentration of 60.1 ± 50.5 μg/l. However, the data on milk iodine concentration in sheep and goat milk are generally very limited (Flachowsky et al. 2014).

Factors affecting milk iodine concentration

It is important to minimize differences in milk iodine concentrations, as it might possibly ensure sufficient intake of iodine in the human population (Troan et al. 2015). The above-mentioned differences in the concentration of iodine in milk are results of variable factors like iodine intake, use of iodine-containing disinfectants for teat dipping (Roseland et al. 2020), intake of goitrogens, milk production, season, animal keeping, milk processing (van der Reijden et al. 2017), environment (Hejtmankova et al. 2006), geographical region, stage of lactation (Norouzian and Azizi 2013), milk yield and some authors also suggested the breed (Flachowsky et al. 2014) and genetics of the sire (Hanus et al. 2011). However, in general milk iodine concentration depends on the amount of iodine the dairy animals are exposed to (Kursa et al. 2005), for instance in the form of mineral mixtures and iodine disinfectants used for teat dipping (van der Reijden et al. 2018).

Iodine intake

Iodine concentration in milk is influenced to a great extent by iodine intake in feed (Flachowsky et al. 2014; Rezaei Ahvanooei et al. 2021) and thus it might be modified to suit human nutritional needs (Kursa et al. 2005). This effect of feeds on milk iodine concentration could be supported by findings of van der Reijden et al. (2019), who observed that the concentration of dairy feeds (0, 0.5, 0.7, 1, 2 mg/kg of dry matter) was linearly related to milk iodine concentration (17, 73, 103, 161, 302 μg/l, resp.). A similar relationship was observed also in the study of Travnicek et al. (2010), who reported the highest milk iodine concentrations in sheep with the highest level of iodine supplementation. Similarly, Franke et al. (2009) considered iodine intake in feed as the main factor affecting milk iodine concentration.

Milk iodine intake is mostly dependent on the concentrates consumed by animals (Troan et al. 2015). However, as already mentioned, the iodine content of most concentrates is less than 0.1 mg/kg (Haldimann et al. 2005), 0.2 mg/kg in forages (Flachowsky et al. 2014), due to the mostly poor iodine content in soils and in this connection also in plants (Travnicek et al. 2006). Therefore, in practice the oral iodine supplementation is mostly used, in form of mineral premixes and lick stones (Schone and Rajendram 2009) that mainly fulfil iodine demand (van der Reijden et al. 2017). Thus, oral supplementation is crucial for optimal iodine intake in animals (Franke et al. 2009). That might be supported by Travnicek and Kursa (2001), who observed the average milk iodine concentration of 47.9 ± 27.8 μg/l in unsupplemented sheep, compared to supplemented animals with the average milk iodine concentration 243 ± 87.2 μg/l. Similarly Franke et al. (2009) observed a relation between iodine supplementation (0, 0.5, 1, 2, 3, 4, 5 mg/kg of dry matter) and milk iodine concentration (83 ± 5 μg/kg, 158 ± 8 μg/kg, 214 ± 12 μg/kg, 550 ± 28 μg/kg, 638 ± 39 μg/kg, 1 085 ± 54 μg/kg, 1 464 ± 67 μg/kg, resp.) (Table 3). As well, Flachowsky et al. (2007) observed high average milk iodine concentrations (2 762 ± 852 μg/kg) in dairy cows fed excessive dos-

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Table 3. Effect of the glucosinolate presence and different iodine supplementation (in the form of iodate) in complete feeds on milk iodine concentration of dairy cows (μg/kg) (Franke et al. 2009)

Type of diet	Iodine concentration (mg iodine/kg dry matter)						
	0	0.5	1	2	3	4	5
No glucosinolates	72 ± 3	188 ± 9	231 ± 14	584 ± 30	930 ± 44	1 188 ± 50	1 578 ± 52
High glucosinolates[1]	27 ± 2	59 ± 5	73 ± 6	234 ± 15	262 ± 17	393 ± 27	620 ± 29

[1]0.58 mmol glucosinolates/kg dry matter or 11.0–13.7 mmol of rapeseed glucosinolates/cow/day

es of iodine (10 mg/kg dry matter). However, these results might be altered by other factors (Castro et al. 2012), for instance, by iodine antagonists (van der Reijden et al. 2019).

The effect of higher iodine intake on milk iodine concentration of goats was confirmed by Nudda et al. (2009) and in sheep by Travnicek et al. (2010), who revealed a positive correlation between iodine intake and milk iodine concentration of ewes. This relation indicated that sheep that were offered mineral licks (35 mg iodine/kg) had the higher milk iodine concentration (243.3 ± 87.2 μg/l) compared to unsupplemented animals (47.9 ± 27.8 μg/l), a similar relation was observed likewise in goats (142.1 ± 102.6 μg/l and 19.3 ± 13.2 μg/l, resp.) (Travnicek and Kursa 2001).

Nevertheless, the increased iodine intake in feeds did not have any effect on milk yield, amount of proteins and fat in the milk of dairy cows (Grace and Waghorn 2005) or on the milk yield of goats (Nudda et al. 2009).

Antinutritional factors

Antinutritional factors, also called goitrogens, worsen the ability of the digestive tract to absorb and utilize iodine (Schone and Rajendram 2009). However, it is not their only effect (Franke et al. 2009). They influence iodine concentration in the thyroid gland (Troan et al. 2015) and worsen the transfer of iodine into dairy milk (Paulikova et al. 2008).

In this regard numerous studies proved the important role of feeds containing rapeseed cake and rapeseed meal on milk iodine concentration (Schone and Rajendram 2009; Troan et al. 2015). This effect of rapeseed feeds is mainly caused by the presence of glucosinolates (Franke et al. 2009), isothiocyanates and thiocyanates (van der Reijden et al. 2017). This claim might be supported by findings of Hejtmankova et al. (2006), who observed a significant effect of feeds containing rapeseed on milk iodine concentration. Similarly, Troan et al. (2015) suggested the increased use of rapeseed feeds as an explanation for the decrease of iodine concentration in Norwegian milk. This could be illustrated also on the findings of Franke et al. (2009) in Table 3. However, not only goitrogens in feeds, but also already mentioned goitrogens in drinking water, for instance in the form of nitrates, can negatively affect iodine uptake by animals and increase the incidence of goitres (Kroupova et al. 2001).

Teat dipping

In many countries it is common to use iodine disinfectants before and after milking (Flachowsky et al. 2014). The mentioned practice was found to affect milk iodine concentration (Troan et al. 2015). This statement might be supported by findings of van der Reijden et al. (2018), who observed the increased milk iodine concentration in dairy cows that were treated with iodophors for teat disinfection (97 μg/l vs. 56 μg/l). The same positive correlation was observed in goats, when post-milking teat disinfection was applied (Ovadia et al. 2018). In this respect, Miseikiene et al. (2020) reported the higher milk iodine concentration in cows that went through iodine teat disinfection after milking and also before it (229.5 ± 19 μg/l vs. 153.7 ± 18 μg/l). On the other hand, Rezaei Ahvanooei et al. (2021) observed an increase in milk iodine concentration only when post teat dipping was applied, dipping of teats before milking had no effect on milk iodine concentration. Therefore, teat dipping in combination with iodine mineral supplementation could pose a risk of iodine overconsumption in humans (Troan et al. 2015).

Moreover, not only the use of iodine disinfectants, but also the process of their application might have an effect on milk iodine concentration. This

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was supported by Castro et al. (2012), who observed an increase of milk iodine concentration when iodine disinfectants were applied using sprays (655 µg/kg) compared to teat dipping (295 µg/kg). According to some authors also the time of dipping may affect milk iodine concentration, although it is considered less important compared to the concentration of iodine in disinfectants (Troan et al. 2015). Nevertheless, processes affecting the transfer of iodine from disinfectant into milk are not clear (van der Reijden et al. 2017).

Farm management and animal keeping

Farm management was proved to be an important factor affecting the milk iodine concentration (Stevenson et al. 2018; Walther et al. 2018) as differences in milk iodine concentration between organic (33–306 µg/l) and conventional farms (64–458 µg/l) were found (van der Reijden et al. 2017). The differences in milk iodine concentration between organic and conventional farming systems are shown in Table 4. In this respect, factors affecting the lower concentration of iodine on organic farms might be reduced use of concentrates, higher goitrogen intake (Bath et al. 2012) and possibly lower use of iodine disinfectants (Hanus et al. 2008). The significant effect of production system ($P < 0.000\,1$) was also confirmed by Walther et al. (2018), who found that organic UHT milk contained 36% less iodine than conventional UHT milk. These findings were likewise confirmed by a German study carried out in 2004–2010 (Johner et al. 2012) and also by a study conducted in the United Kingdom (Bath et al. 2012). On the other hand, Vorlova et al. (2014) found that the milk iodine concentrations from organic and conventional dairy farms in the Czech Republic were not significantly different (119.29 ± 40.37 µg/l; 136.55 ± 42.91 µg/l), but they indicated the higher milk iodine concentration on larger farms. In these terms, findings of Mullan et al. (2017) from Ireland are comparable, as they did not find any difference between milk iodine concentrations in relation to the farming system.

Nevertheless, also the animal keeping plays its role in affecting the milk iodine concentration of dairy animals. Since the animals that are kept on pastures in summer tend to have the lower milk iodine concentration compared to the animals kept indoors (Schone and Rajendram 2009). This might be explained by better iodine supplementation in fully housed animals (O'Kane et al. 2018). Therefore, it is not uncommon that milk iodine concentration from conventional dairy cows kept indoors is higher compared to grazing cows (Schone and Rajendram 2009). In this context Hejtmankova et al. (2006) observed that milk iodine concentration in winter was between 147 µg/kg and 605 µg/kg compared to that in the summer season ranging from 35 µg/kg to 484 µg/kg. This effect of the season was observed also by other authors (Schone and Rajendram 2009; van der Reijden et al. 2017; Coneyworth et al. 2020). The ef-

Table 4. Impact of organic and conventional farming systems on cow's milk iodine concentration in several European countries

Country	Milk iodine (µg/l)		References	Notes
	organic	conventional		
Czechia	174	463	Hanus et el. (2008)	raw
Czechia	119	136	Vorlova et al. (2014)	raw
Denmark	17	27	Rasmussen et al. (2000)	–
Germany	58	112	Johner et al. (2012)	pasteurised, UHT
Spain	78	157	Rey-Crespo et al. (2013)	raw
Spain	56	163	Arrizabalaga et al. (2015)	UHT
Switzerland	55	93	van der Reijden et al. (2018)	raw
Switzerland	71	111	Walther et al. (2018)	UHT
United Kingdom	399	578	Payling et al. (2015)	pasteurised
United Kingdom	241	427	Stevenson et al. (2018)	pasteurised
United Kingdom	343	474	Payling et al. (2015)	pasteurised, UHT
United Kingdom	314	427	Stevenson et al. (2018)	UHT

UHT = ultra heat treatment

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fect of the season on milk iodine concentration was also reported by Paulikova et al. (2008), who studied goat milk and sheep milk, however in sheep it was found to be insignificant.

Iodine species

Several nutritive additives were approved for feed supplementation: sodium iodide (NaI), potassium iodide (KI), calcium iodate hexahydrate [$Ca(IO_3)_2{\cdot}6H_2O$], as well as anhydrous calcium iodate [$Ca(IO_3)_2$] [Commission Regulation (EC) No. 1459/2005]. Nevertheless, iodides and iodates may react with each other, therefore their joint use may result in changing their nutritional properties (Flachowsky et al. 2014).

Various authors compared different iodine sources (iodides, iodates) to evaluate their effect on iodine concentration in milk (Flachowsky et al. 2014). Most studies showed no difference between milk iodine concentration and iodine species (Franke et al. 2009).

Milk yield

In the recent study Coneyworth et al. (2020) observed that the transfer of iodine into milk was reduced in high-producing animals and they assumed the effect of iodine dilution in milk. Nevertheless, as reported by Konecny et al. (2019), the minimization of differences in milk iodine concentration between lower- and higher-producing dairy cows could still be accomplished by controlled iodine supplementation. However, according to Flachowsky et al. (2014) the effect of milk yield on milk iodine concentration is valid only if the feed intake of both higher- and lower-producing groups is comparable. On the other hand, Battaglia et al. (2010) did not observe any effect of milk yield on the milk iodine concentration. The physiological explanation for the effect of milk yield on milk iodine concentration is not clear (van der Reijden et al. 2017) nor its impact on iodine intake in human nutrition.

Milk processing

The milk processing, especially heat treatment and skimming, is supposed to be a potential cause of milk iodine loss (van der Reijden et al. 2017). During pasteurization, the loss of iodine concentration in milk was examined by Norouzian (2011), who observed 27.4% loss of iodine. On the other hand, O'Kane et al. (2018) observed no significant or only minimal losses in milk iodine concentration after pasteurization.

Stevenson et al. (2018) found significant differences in milk iodine concentration between UHT milk and pasteurized milk, with the 27% average milk iodine loss in UHT milk. These losses could possibly be explained by iodine sublimation during processing (van der Reijden et al. 2017) and it might also be the cause of differences in milk iodine concentration between raw and heat-treated milk (Flachowsky et al. 2014). Nevertheless, processes behind these findings are unknown to a great extent (Stevenson et al. 2018).

The effect of milk skimming on milk iodine concentration was examined by Roseland et al. (2020), who did not find any significant differences between skimmed, semi-skimmed and whole milk. In this respect, Arrizabalaga et al. (2015) found only small differences in milk iodine concentration due to skimming.

Additionally, it was found that dairy product processing, like cheese manufacturing, causes iodine losses (Haldimann et al. 2005). In this respect van der Reijden et al. (2019) reported that more than 75% of iodine is lost in whey during cheese manufacturing, though this loss is compensated by the addition of iodized salt, and moisture loss.

Conclusion

Dairy milk is an important source of iodine in many countries. According to some authors even a glass of milk can cover a substantial portion of daily iodine requirements in human nutrition (Hejtmankova et al. 2006; Arrizabalaga et al. 2015). However, iodine concentration in milk is very variable, most importantly due to factors like iodine intake in feeds and concentration of antinutrients in feeds. These could be controlled by appropriate addition of mineral concentrates to feeds and by limiting the use of feeds containing antinutrients (goitrogens). Nevertheless, there are also other factors such as use of iodine teat disinfection, farm management, animal keeping, iodine species in feeds, milk yield and milk processing, causing the variation of milk iodine concentration.

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The importance of iodine intake from milk and dairy products should be even more emphasized by tendencies to reduce salt consumption, and also regarding the fact that most of the foods have naturally low iodine concentrations. Moreover, milk and dairy products could be used as an alternative iodine source for people on salt-free diets due to their diagnoses.

Therefore, monitoring, understanding and regulation of factors affecting milk iodine concentration are crucial to ensure the stable milk iodine concentration and to prevent the risk of deficient or excessive intake in human nutrition.

Conflict of interest

The authors declare no conflict of interest.

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