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# Factors affecting iodine content of cow milk-A review

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## ABSTRACT

This review discusses the importance of iodine as an essential nutrient for human health and the factors that can influence the concentration of iodine in cow milk. For an adult, the daily recommended requirement of iodine is 150 µg/day and the maximum tolerable limit ranges from 600 to 1100 µg/day. Cow milk is a significant source of iodine in many countries, particularly in areas where iodine-rich foods are not readily available. Therefore, evaluating the variables that affect the iodine content of cow milk is important. The iodine concentration of cow milk can vary depending on several factors such as genetics, diet, environment, management practices, season, and processing. Particularly, dietary supplementation and feed composition have been identified as the most impactful on milk's iodine levels, offering a practical approach to mitigating iodine deficiency. Furthermore, environmental factors like soil and water iodine content and management practices, including the type of farming, play substantial roles. Seasonal changes also significantly affect iodine levels, with higher concentrations typically observed in winter due to different feeding practices. The iodine content of cow milk falls between 147 to 605 µg/kg and the highest value of 11100 µg/L was recorded in camel milk. Milk could supply up to 60% of the daily dietary requirement of iodine for an adult person. To fight iodine deficiency through the appropriate approach to such concerns, one must have an in-depth understanding of these issues. This review paper aims to provide a comprehensive analysis of these factors and their implications for human and public health strategies.



## Introduction

Iodine is an essential micronutrient for human health, with important roles in thyroid hormone synthesis and brain development. Thyroid hormones are crucial for normal growth and development, particularly in infants and young children (Zimmermann and Boelaert, 2015). Despite being a crucial nutrient for human development and health, iodine deficiency remains a significant public health issue worldwide, affecting an estimated 1.9 billion people globally (World Health Organization, 2007), particularly in developing countries (Zimmermann and Boelaert, 2015). While iodine can be obtained from various dietary sources, cow milk is a significant source of iodine in many countries, particularly in areas where iodine-rich foods are not readily available (Dahl *et al.*, 2003). In areas where soil iodine content is low, supplementation of cow feed with iodine can increase the level of iodine present in milk (van der Reijden *et al.*, 2017). Additionally, management of the cow's diet and environment can also influence the iodine concentration in milk

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(Flachowsky *et al.*, 2014). However, the content of iodine in cow's milk may vary widely depending on several factors, including genetics, diet, environment, management practices, season, and processing (Flachowsky *et al.*, 2014; Mikláš *et al.*, 2021). Understanding the factors that influence milk iodine content is important for ensuring an adequate intake of this essential nutrient for human health. In addition, identifying best practices for maintaining milk iodine levels can have important implications for public health and nutrition strategies.

Several studies have investigated the factors influencing the iodine content of cow milk (Johner *et al.*, 2012; Flachowsky *et al.*, 2014; O'Kane *et al.*, 2018; Costa *et al.*, 2021; Mikláš *et al.*, 2021). Some examples of such studies are summarized in Table 1. Nevertheless, a comprehensive review of the literature is needed to synthesize the current knowledge and identify the gaps in understanding. Therefore, this review paper aims to provide a comprehensive analysis of the factors affecting the iodine content of cow milk, including genetics, dietary, environmental, management, seasonal, and processing factors. The implications for human health and public health strategies will also be discussed.

## Health implications of iodine concentration in cow milk

*Recommended daily iodine intake for humans*

Iodine is an indispensable micronutrient that is required for the synthesis of thyroid hormones, which plays a critical role in regulating metabolism, growth, and development in humans. The recommended daily intake of iodine varies depending on age, sex, and physiological status. For adults, the World Health Organization (WHO) recommends a daily iodine intake of 150 micrograms (μg) for men and non-pregnant women, 250 μg for pregnant women, and 250-290 μg for lactating women (WHO, 2007). The recommended daily allowance for children varies from 90 μg to 120 μg depending on the age (IMFNB, 2001). The recommendations by different national, regional and international organizations and/or authority are summarized in Table 2.

Deficiency of iodine is the most common cause of avoidable intellectual disability worldwide, and it is estimated that over two billion people are facing the risk of iodine deficiency disorders (IDD) (Zimmermann, 2009). IDD can result in a range of adverse health outcomes, including goiter, hypothyroidism, cretinism, and impaired cognitive function. In pregnant women, iodine deficiency can lead to miscarriage, stillbirth, and congenital anomalies like cretinism and neurological impairments in offspring (Zimmermann, 2009).

Excess intake of iodine, on the other hand, can lead to thyroid dysfunction. Acute iodine toxicity can cause gastrointestinal distress, fever, and thyroid pain, while chronic iodine excess can lead to hyperthyroidism or hypothyroidism (Southern and Jwayyed, 2022).

*The role of cow milk as a dietary source of iodine for humans*

Cow milk is a significant dietary source of iodine for humans, as it contains iodine that is transferred from the cow's diet to the milk. The concentration of iodine in milk varies depending on the cow's diet and the iodine level in the soil where the feed is grown. However, milk from cows fed on a typical diet can provide up to 60% of the recommended daily intake of iodine for adults. The iodine content in different milk and dairy products is summarized in Table 3.

A study by Bath *et al.* (2012) investigated the iodine content of milk from different regions of the UK and found that the average iodine concentration was 52 μg/L. The authors concluded that milk is an important dietary source of iodine, particularly in regions where soil iodine concentration is low. Another study by Pearce *et al.* (2013) investigated the iodine content of milk from different countries and found that the iodine concentration of milk was higher in countries with mandatory iodization programs. The authors suggested that milk could be an effective vehicle for delivering iodine to populations with low iodine intakes.

Low iodine content in cow milk may have adverse effects on human health, especially for individuals who rely on milk as a significant source of iodine. As mentioned earlier, iodine deficiency can result in several health complications, including goiter, cretinism, hypothyroidism, and impaired cognitive development in children (Zimmermann, 2016). Conversely, high iodine content in milk may lead to thyroid dysfunction, such as hyperthyroidism and autoimmune thyroiditis (Laurberg *et al.*, 1998). Therefore, monitoring the iodine content in cow milk is essential to ensure that the milk consumption contributes to a balanced and healthy diet.

However, it is crucial to note that milk is not the only iodine source in the diet, and excessive intake of iodine can also lead to negative health effects, including abnormality of the thyroid. Therefore, it is essential to ensure a balanced and varied diet to meet the recommended daily intake of iodine.

*Various methods for measuring iodine content in cow milk*

Accurate measurement of iodine concentration in cow milk is important for monitoring and maintaining adequate iodine intake in humans. There are several methods available for measuring iodine content in cow milk. The most commonly used methods are spectrophotometry, inductively coupled plasma mass spectrometry (ICP-MS), and ion-selective electrode (ISE) methods. Spectrophotometry is a commonly employed technique to determine the amount of iodine in cow milk.

**Table 1.** Major factors as identified to influence the iodine content of milk and milk products

| Iodine in - | Location | Identified factors | Reference(s) |
|---|---|---|---|
| Milk | Switzerland | Farm type, season and teat dipping | van der Reijden et al. (2018) |
| Milk and milk products | New Zealand | Season and geographical location | Cressey (2003) |
| Camel, sheep and goat milk | Algeria | Species | Morseth et al. (2019) |
| Milk | Ireland | Dietary supplementation, teat dipping | O'Brien et al. (2013) |
| Milk | Czech Republic | Regional and seasonal | Travnicek et al. (2006) |
| UHT milk | Spain | Geographical and seasonal | Arrizabalaga et al. (2020) |
| Cow milk | USA | Breed, Season, location, stage of lactation and supplementation | Franke et al. (1983) |
| Cow Milk | USA | Breed, age, stage of lactation and number of parity | Osland et al. (1980) |
| Cow, goat and sheep | Slovakia | Region, species and season | Paulíková et al. (2008) |
| Cow milk | USA | Volume of milk produced | Miller et al. (1963) |
| Goat Milk | USA | Volume of milk produced | Reineke (1961) |
| Milk | Italy | Farming system, herd size, herd composition, feed, milking system, iodine based products in pre- and post-dipping, season and days in milk | Guerra et al. (2023) |
| Milk | Czech Republic | Farm size | Vorlová et al. (2015) |
| Cow milk | Northern Ireland | Season and housing | O’Kane et al., (2018) |
| Cow milk | Germany | Feed, supplementation and additives | Franke et al. (2009) |
| Milk | Iran | Milk processing, region | Ahvanooei et al. (2020) |
| Milk | China | Region and feed | Su et al. (2020) |
| Sheep milk | Slovakia | Farm, iodine mineral lick supplementation, organic farming | Mikáš et al. (2021) |
| Goat Milk | Israel | Post-milking iodophor teat-dipping | Ovadia et al. (2018) |

In this method, iodine reacts with ceric ammonium sulfate to form a colored complex, which can be measured spectrophotometrically at a specific wavelength. This method is relatively simple, rapid, and inexpensive, and has been shown to provide accurate results in cow milk samples (Judprasong *et al.*, 2016). ICP-MS is another commonly used method for measuring iodine content in cow milk. This method involves the use of an ICP-MS instrument to ionize and detect iodine atoms in the milk sample. This method is highly sensitive and accurate and has been shown to provide precise results in cow milk samples (Dubascoux *et al.*, 2018). ISE methods are also used for measuring iodine content in cow milk. In this method, a specific ion-selective electrode is used to measure the concentration of iodine ions in the milk sample. This method is also rapid, simple, and inexpensive, but requires calibration with known standards and might be influenced by interfering substances in the milk sample (Sakai *et al.*, 2022).

All the methods available for measuring the iodine content in cow milk have advantages and limitations. The iodine content in milk could differ between samples analyzed in different methods. Spectrophotometry, ICP-MS, and ISE methods have all been shown to provide accurate and precise results in cow milk samples. The choice of method may depend on factors such as cost, speed, sensitivity, and equipment availability.

**Factors affecting iodine content of cow milk**

*Cow Genetics*

There is little evidence available about how the breed of cow affects the iodine level in milk. Franke *et al.* (1983) stated a breed effect on the amount of iodine in cow milk. To our knowledge, this statement was then not fully confirmed by any study. The lower genetic effect of cows on their milk iodine content could be explained by the fact that the iodine concentration of cow milk is less heritable and has limited genetic variation (Costa *et al.*, 2021). However, some specific gene variation could have influence on iodine concentration of milk. A study by Golan *et al.* (2020) found that women with a specific variant of the sodium-iodide symporter gene had higher iodine concentrations in their milk than those without this variant. The sodium-iodide symporter gene is involved in the transport of iodine from the bloodstream to the mammary gland, where it is incorporated into milk. We need further information on the sodium-iodide symporter gene regarding cattle species to explain the fact more clearly.

*Diet*

The results of different studies suggest that iodine supplementation of cows' diets is the most effective way to increase the iodine content of cow milk (Flachowsky *et al.*, 2014). The addition of iodine to cow feed has been shown to increase the milk iodine content by up to 80% (Sanchez and Szpunar, 1999). Numerous studies have investigated the effect of cow's diet on the iodine content of milk. A study conducted by McKernan *et al.* (2020) found that increasing the iodine content of the cow's diet by feeding them iodine-supplemented concentrate led to a significant increase in the iodine content of their milk. Another study by Roseland *et al.* (2020) also reported a positive correlation between the iodine content of the cow's diet and the iodine content of their milk.

Furthermore, the iodine content of cow's milk can be affected by the type of feed they consume. A study by Orjales *et al.* (2018) found that cows fed a fresh forage-based diet had higher iodine concentrations in their milk compared to cows fed silage. Similarly, Xue *et al.* (2019) stated that feeding cows a diet of kelp, which is naturally high in iodine, led to a significant increase in the iodine content of their milk.

It is crucial to emphasize that excessive iodine intake can also have negative health effects, such as thyroid dysfunction (Zimmermann, 2016). Therefore, it is essential to maintain a balance between providing adequate dietary iodine to cows while avoiding over-supplementation. Now, researchers are conducting numerous seaweed supplementation experiments to mitigate the methane emissions from dairy cows. The iodine level of such a supplement is too high (Yeh *et al.*, 2014). That's why we need to be more careful while supplementing cows so that the iodine concentration of the milk can be at an optimum level.

*Goitrogens*

Goitrogens are substances that occur naturally, found in several feed and plants that can affect how well the thyroid gland functions by preventing the uptake of iodine (Chandra, 2010). This interference may lead a reduction in the amount of iodine present in the thyroid gland, which may cause thyroid dysfunction and the development of goiters in both people and animals. When it comes to the effect of goitrogens on the iodine concentration of cow's milk, there are several factors to consider. First, the amount of iodine consumed by cows and the level of iodine found in their milk are closely related. So, if cows primarily consume goitrogenic plants or fed with elevated goitrogen content, their iodine absorption can be hindered, subsequently reducing the iodine content in their milk (Piironen and Virtanen, 1963). Second, the presence and concentration of goitrogens in cow feed can fluctuate by region and season (Gaitan, 1990). Particular areas may have higher levels of goitrogenic plants, potentially affecting the iodine concentration in milk from cows in those regions. Canada and the European Union decreased the concentration of goitrogens in rapeseed varieties by about 80% between 1970 and 1980 using effective plant breeding (Flachowsky *et al.*, 2014). Thus, there is a possibility to have more iodine in the milk of cows in those regions. However, farming and feeding methods are quite important in these regards. Proper management and nutrition can help mitigate the impact of goitrogens on the iodine content of cow's milk. Strategies such as supplementing cow feed with iodine or regulating their access to goitrogenic plants could assist in maintaining adequate iodine levels in milk.

**Table 2.** Recommendations for iodine requirement, daily allowance and maximum level of tolerable intake (μg/day) by age and physiological stages

| Age or physiological stage of the population | Requirement (WHO, 2007) | Daily allowance (US institute of Medicine, 2001) | | European food safety authority, 2014 (adequate intake) | Nordic nutrition recommendations, 2014 (daily intake) | Maximum level of tolerable intake (SCF, 2002 and US institute of Medicine) |
|---|---|---|---|---|---|---|
| | | Male | Female | | | |
| 0-6 months | - | 110 | 110 | - | - | - |
| 7-12 months | - | 130 | 130 | 70 | 50 | - |
| 1-2 years | - | - | - | | 70 | - |
| 1-3 years | - | 90 | 90 | | | 200 |
| 1-10 | - | - | - | 90 | - | - |
| 0-5 years | 90 | - | - | - | - | - |
| 2-5 years | - | - | - | - | 90 | - |
| 4-6 years | - | - | - | - | - | 250 |
| 4-8 years | - | 90 | 90 | - | - | 300 |
| 6-9 years | - | - | - | - | 120 | - |
| 6-12 years | 120 | - | - | - | - | - |
| 7-10 | - | - | - | - | - | 300 |
| 9-13 years | - | 120 | 120 | - | - | 600 |
| 11-14 years | - | - | - | 120 | - | 450 |
| >12 years | 150 | - | - | - | - | - |
| ≥13 years | 150 | - | - | - | - | - |
| ≥14 years | - | 150 | 150 | - | - | 900 |
| 15-17 years | - | - | - | 130 | - | 500 |
| 10-18 years | - | - | - | - | 150 | - |
| Adults | 150 | - | - | 150 | 150 | 600 - 1100 |
| Pregnancy | 250 | - | 220 | 200 | 175 | 600 - 1100 |
| Lactation | 250 | - | 290 | 200 | 200 | 600 - 1100 |

*Environmental effect*

Several environmental factors can influence the iodine content of cow milk, including soil iodine, water iodine, and atmospheric iodine levels. Soil iodine levels are particularly important as cows consume vegetation that grows in iodine-rich or poor soils. Studies have shown that cows grazing on soils with low iodine levels produce milk with lower iodine content than those grazing on iodine-rich soils (Roseland *et al.*, 2020). Water iodine levels can also affect the iodine level of milk. Cow's drinking water with high iodine levels can accumulate iodine in their thyroid glands and produce milk with higher iodine content (Papas *et al.*, 1979).

**Table 3.** Iodine content of different milk and dairy products

| Name of the products | Iodine content | | Reference(s) |
|---|---|---|---|
| | Average | Minimum-maximum | |
| Cow milk (µg/kg) | 251±110 | 147-605 | Hejtmánková et al. (2006) |
| Camel milk (µg/L) | - | 210-11100 | Morseth et al. (2019) |
| Goat milk (µg/L) | - | 101-9323 | Morseth et al. (2019) |
| Sheep milk (µg/L) | - | 101-9323 | Morseth et al. (2019) |
| Milk (ng/g) | 690±170 | 330-1107 | Haldimann et al. (2005) |
| Milk and other dairy products (µg/100 g) | - | 30 - 63 | EUFIC (2019) |
| Non-fat milk (µg in 1 cup) | 84 | - | USDA (2023) |
| Low-fat milk, winter (mg/l) | - | 103–272 | Dahl et al. (2003) |
| Low-fat milk, summer (mg/l) | - | 63–122 | Dahl et al. (2003) |
| Flavored milk (mg/kg) | 0.09 | <0.04-0.37 | Cressey (2003) |
| Organic milk, winter (mg/l) | - | 35–365 | Dahl et al. (2003) |
| Organic milk, summer (mg/l) | - | 17–87 | Dahl et al. (2003) |
| Extra-low-fat milk, summer (mg/l) | - | 66–128 | Dahl et al. (2003) |
| UHT milk (mg/kg) | 0.12 | 0.05-0.32 | Cressey (2003) |
| Cream (mg/kg) | 0.07 | <0.04-0.14 | Cressey (2003) |
| Soured cream (mg/kg) | - | 44–176 | Dahl et al. (2003) |
| Butter (mg/kg) | <0.04 | <0.04-0.04 | Cressey (2003) |
| Curdled milk (mg/l) | - | 100–221 | Dahl et al. (2003) |
| Yoghurt (mg/kg) | - | 115–179 | Dahl et al. (2003) |
| Cottage cheese (mg/kg) | 0.10 | 0.05-0.23 | Cressey (2003) |
| Cheese (ng/kg) | 473±289 | 146-1323 | Haldimann et al. (2005) |
| Cheddar cheese (µg/ounce) | 14 | - | USDA (2023) |
| Jarlsberg cheese (mg/kg) | - | 132–353 | Dahl et al. (2003) |
| Norvegia cheese (mg/kg) | - | 169–468 | Dahl et al. (2003) |
| Cream cheese (mg/kg) | 0.20 | 0.07-0.58 | Cressey (2003) |
| Whey cheese (mg/kg) | - | 103–1360 | Dahl et al. (2003) |
| Goat milk cheese (µg/kg) | 700 | 250-1040 | Carlsen et al. (2018) |
| Sheep milk cheese (µg/kg) | 861 | - | Schirone et al. (2018) |
| Yogurt (ng/kg) | 670±313 | 347-1239 | Haldimann et al. (2005) |
| Greek plain yogurt (µg in 3/4 cup) | 87 | - | USDA (2023) |
| Ice cream (mg/kg) | 0.14 | 0.05-0.26 | Cressey (2003) |
| Chocolate ice cream (µg in 2/3 cup) | 28 | - | USDA (2023) |
| Milk powder (mg/kg) | 0.10 | 0.05-0.16 | Cressey (2003) |

Atmospheric iodine levels can also affect the iodine content of milk, particularly in regions with high concentrations of atmospheric iodine due to industrial pollution. Studies have shown that cows grazing in such areas produce milk with higher iodine content than those grazing in areas with lower atmospheric iodine levels (Fuge *et al.*, 2015).

*Management practices*

As a management practice, feeding has a greater influence on the iodine content of milk, which we have discussed previously in the diet part. The use of iodine-fortified vitamin-mineral premix in a cow's diet has a large influence on the iodine content of milk (Schone *et al.,* 2017). In addition, the management system is also a key contributor to milk iodine content. Different studies showed that the iodine content of organically managed cows is lower than that of cows in conventional management practice (Dahl *et al.*, 2003; Johner *et al.*, 2012; Bath *et al.*, 2012; Payling *et al.*, 2015; Walther *et al.*, 2018). Organic milk produced in the winter has 32% less iodine than milk produced in the winter conventionally (Payling *et al.*, 2015). This is also true in the summer when the concentration of iodine in organic milk is 42% less than that of conventional milk (Dahl *et al.*, 2003; Bath *et al.*, 2012). Teat dipping with iodine-containing disinfectant before milking is also a considerable factor that affects the iodine content of milk. Guerra *et al.,* (2023) reported a significant effect of iodine-based pre-disinfectants on the iodine content of milk. According to their findings, milk iodine content jumped from 13.20 μg/L to 365.27 μg/L when farmers shifted from using a pre-milking dipping solution containing no iodine to a pre-milking dipping disinfectant with iodine. Other management practices such as milking frequency and time of milking have also been shown to influence milk iodine content, albeit to a lesser extent (Mikláš *et al.*, 2021; Flachowsky *et al.*, 2014).

*Season*

Several studies have investigated the effect of season on the iodine content of cow's milk. A study conducted in Norway found that the iodine content of milk was significantly higher in the winter than in the summer (Dahl *et al.*, 2003). Another study in France also found that the iodine content of milk was significantly higher in the winter than in the summer (Lamand and Tressol, 1992). The higher iodine content in winter is attributed to the higher intake of iodine-rich feed during this season.

Moreover, Ahvanooei *et al.* (2020) analyzed the iodine content of milk in Iran and found that the iodine level of milk was significantly higher in the colder areas than in the tropical regions. Again, a similar study was conducted in Switzerland, and the authors found that the iodine content of milk was higher in the winter than in the summer months (Witard *et al.*, 2022). The authors suggested that the less dense iodine content in summer may be due to the dilution effect caused by the higher milk production during this season.

*Processing*

Pasteurization is a common processing method used to kill the harmful bacteria in milk. The iodine content of cow milk can be affected by pasteurization. The quantity of iodine lost during pasteurization depends on the temperature and time of the heating process. In general, higher temperatures and longer heating times will result in greater losses of iodine. Several studies have examined the effect of pasteurization on the iodine content of cow milk. Most studies have reported that pasteurization has an effect on the iodine content of milk (Norouzian *et al.*, 2011; Nazeri *et al.*, 2015). However, some studies reported that the iodine content of milk was not affected after pasteurization (O'Kane *et al.*, 2018). The loss of iodine during pasteurization is because iodine is a relatively volatile element. When milk is heated, some of the iodine molecules vaporize and are lost from the milk.

Ultra-high temperature (UHT) treatment is a more intense processing method than pasteurization. UHT treatment involves heating milk to a high temperature (135-150°C) for a short period (2-4 seconds). A number of experiments have evaluated the effect of UHT treatment on the concentration of iodine in cow milk. UHT has more effect on the iodine levels of milk than that of conventional pasteurization. A study conducted by Stevenson et al (2018) reported that conventional pasteurized milk was 27% higher in iodine than UHT-treated milk.

A greater amount of iodine content (≥75%) is generally lost during whey production, although the iodine content of cheese is greater due to much dry matter content of cheese than milk (van der Reijden *et al.*, 2019). Though the mechanism is not clear, skimming also influences milk iodine content. Several studies reported semi-skimmed and skimmed milk had higher iodine content than that of whole milk (Rasmussen *et al.*, 2014; Arrizabalaga *et al.*, 2015; van der Reijden *et al.*, 2019). In contrast, Soriguer *et al.* (2011) observed greater iodine concentration in commercial skimmed milk than full-fat and semi-skimmed milk.

## Conclusion

This review paper has highlighted various factors affecting iodine levels in cow's milk. These factors include the cow's diet, the feed iodine levels and supplements provided to the cows, the season, management, processing, and the genetics of the cow. The review also discussed the significance of iodine and its importance in human nutrition and the potential health consequences of iodine deficiency.

It is clear that the iodine content of cow milk can be a significant source of iodine in the diet of humans, particularly in areas where iodine intake is inadequate. Therefore, it is important to consider the factors that can influence the iodine content of cow milk to ensure an adequate supply of iodine in the human diet. Further research is required to better understand the complex relationships between cow diet, milk iodine content, and human iodine nutrition. In conclusion, this review highlights the importance of considering the various factors which have effects on the concentration of iodine in cow milk to promote adequate iodine intake in human nutrition.

### *Data Availability*

Data can be available in reasonable request.

### *Conflict of interest*

The authors declare that there is no conflict of interest of any person, company or any aspect of the impact of the manuscript.

### *Consent to Participate*

The authors provide full consent to participate.

### *Consent for Publication*

All authors are fully agreed to publish this article in the Bangladesh Journal of Animal Science.

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