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Factors affecting dairy cow milk iodine

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REVIEW ARTICLE

Abstract

There is the potential for problems resulting from excessive amounts of iodine in cow milk. Supplementary feed iodine increases milk iodine and is apparently the cause of many of the high milk iodine values. Iodine teat dips and sanitisers also contribute to increased milk iodine values. Variability of these practices may result in variation of iodine concentrations in milk. In addition, the transportation and processing phases of milk production, where iodophor sanitisers are used, season, geographic region, stage of lactation and iodine antagonists in feeds, may influence milk iodine concentration. In this review, each of these factors will be examined more extensively.

Keywords: milk iodine, pasteurisation, rapeseed, season, stage of lactation, teat dipping

1. Introduction

Iodine is an essential trace element for humans and animals. It is incorporated into the thyroid hormones that have multiple functions as regulators of cell activity. Iodine deficiency affects reproductive capacity, development of brain and progeny as well as growth.

Iodine occurs in nature as iodide and iodate. Its mineral forms occur ubiquitously in igneous rocks and soils, most commonly as impurities in saltpetre and natural brines. It is liberated by weathering and erosion, and, because of its water-solubility, it leaches by rainwater into surface water, the sea and the oceans, so soils in mountainous regions become low in iodine. In many areas of the world the surface soil becomes progressively poorer in iodide through leaching processes (Fuge and Johnson, 1986). Iodides in the sea accumulate in seaweeds, sea fish and shellfish. On land, small amounts of iodide are taken up by plants, which do not need this element. The major natural sources for animals (and humans) are iodides in feed (and food) and water which rarely contains enough iodine to meet animal and human needs. However, iodine deficiency is not as likely to occur today as it did several decades ago. In fact, it has been suggested that iodine toxicity is more likely to occur than iodine deficiency. The increased iodine levels in food are due to greater usage of iodine in food processing, an increase in the iodine content of farm animal rations, and increased use of iodine as antibacterial agents both on and off the farm. As a result, in today's nutritional situation there is the potential for problems resulting from excessive amounts of iodine in human diets to cause problems (Hemling, 2000). Currently, whole milk and dairy products contribute the highest proportion of iodine to the human diet (Cressey, 2003; Norouzian *et al.*, 2009b). A survey of iodine content in 18 brands of cows' milk was performed between 2001 and 2002 in the Boston area and showed that the average iodine content of milk was 110 μg per cup (Pearce *et al.*, 2004). The recommended intake for adequate calcium nutrition of 4 cups daily would provide 440 μg iodine daily. This intake is 4.8 times the recommended intake for children and 2.9 times the recommended intake for adults. A combination of 4 cups of milk and two slices of bread could result in a daily ingestion of greater than 1,700 μg iodine, or 11.3 times the recommendations and 600 μg above adult tolerable limits (Pearce *et al.*, 2004).

As a result, the dairy industry in many countries has looked into the potential sources of iodine in milk in order to prevent over-consumption of this trace element. There are various reasons for increased iodine concentrations in dairy cow milk. This review discusses factors that affect the iodine content of dairy cow milk at farm and processing unit levels.

2. Effect of iodine intake: source and level

The iodine content of milk can be increased by a number of different sources. Natural feed sources have been shown to vary considerably in terms of iodine levels and will differ greatly by areas of the country and world. There were also marked differences between crops, with corn silage having a lower iodine content per unit of dry matter than alfalfa. In investigations using inductively coupled plasma-mass spectrometry (ICP-MS) the iodine concentrations in barley and wheat were undetectable (<20 μg/kg) (Schöne *et al.*, 2001a). Low concentrations of iodine (6 μg/kg) were detected in durum wheat (Triticum durum) flour by ICP-MS (Haldimann *et al.*, 2005) and neutron activation analysis (3 and 9 μg/kg) (Dermelj *et al.*, 1991). Iodine concentrations in the range 2-30 μg/kg (mean 6.1, median 4.6) were detected in cereal grains from 38 different sites in Austria using neutron activation (Shinonaga *et al.*, 2001). Dermelj *et al.* (1991) found concentrations of 15 and 19 μg/kg in two samples of soybean meal feed.

It is assumed that most natural feed sources will not produce milk with even adequate levels of iodine to provide a desirable intake of iodine for human and animal needs. Hence the need for iodine supplementations in dairy cow diets. Feed sources of iodine used to supplement dairy cow diet are supplied for several reasons. Some iodine is added to almost all rations to prevent goiter in the newborn animals and other iodine deficiency signs. In addition, organic iodine is added to many rations to prevent foot rot (Berg *et al.*, 1984; Swanson *et al.*, 1990). Some dairy farmers also add organic iodine in an attempt to improve reproductive efficiency and perhaps correct other problems (Weldy, 1978).

The source of iodine supplementation can affect the iodine content of milk. In a study by Miller and Swanson (1973), the dairy cow group receiving potassium iodide had higher serum but lower milk iodine levels than the group receiving the same amount of iodine in the form of ethylenediamine dihydroiodide (EDDI). This demonstrates different metabolism rates or pathways for these two forms and would indicate different limits for different forms of iodine if a limit on milk iodine were to be set.

Also, milk iodine concentration is related to the level of iodine consumed by dairy cows. In the dose-response experiment, five Holstein cows in the last lactation third (7-9 months after calving) were fed increasing amounts of iodine 15, 65 and 132 mg iodine/cow/day; increasing dietary iodine intake significantly increased the iodine content of milk. A fourfold increase in iodine supplementation from 15 mg iodine/day to 65 mg iodine/day resulted in a 3.5-fold increase in milk iodine concentrations. Doubling the daily iodine dose from 65 mg iodine/day to 132 mg iodine/day resulted in a further 2.3-fold increase in milk iodine concentrations. 30-40% of the ingested iodine was transferred to the milk in the three groups given supplemental iodine (Schöne *et al.*, 2006).

Our data indicate that when iodine intake is at the recommended feeding amount of 0.534 mg/kg dry matter (DM) (NRC, 2001), milk iodine will be 162 μg/l. When supplemental iodine added to a low iodine diet was increased from 11 to 62 mg/cow/day (corresponding to NRC recommended level or 2.5 mg/kg DM diets), milk iodine concentration was raised 3.3 times. However, when supplemental iodine was increased from 62 to 165 mg/cow/day (corresponding to 2.5 or 7.5 mg/kg DM diets), milk iodine increased only 12%. This suggests that milk iodine response curves should not be extrapolated linearly for iodine intakes. However, the exact mechanisms for this reduction in secretion ratio at a higher level of iodine supplement are not clear. A possible explanation might be that the mammary gland of the dairy cow acts as a bio-regulator for iodine excretion (Norouzian *et al.*, 2009b). Also, Miller *et al.* (1975) noted that cows secrete less iodine into milk than most other species and have an efficient iodine recycling system via the gastrointestinal tract.

Iwarsson (1973) estimated iodine intake and milk iodine output throughout 40 week lactations and found secretion ratios averaged 20.5% when milk yield averaged 16.5 kg/day. Secretion ratios in our experiment were 21.9% for all cows with mean daily milk yields of 27.5 kg during the experimental period (Norouzian *et al.*, 2009b).

3. Iodine antagonists in feeds

A main dietary factor influencing iodine metabolism seems to be the application of anions which inhibit the sodium iodide symporter. This active transport system extensively investigated in the thyroid also seems to allow iodine accumulation in other extrathyroidal tissues like the mammary gland (Cavalieri, 1997). The most important inhibiting anions in animal diet are thiocyanates, a degradation product of the glucosinolates (e.g. in rapeseed feedstuffs). Since the uptake of iodine in the thyroid and the mammary gland is considerably reduced by thiocyanates feeding (Cavalieri, 1997; Papas *et al.*, 1979) rapeseed also ought to influence the blood, urinary and milk iodine. The mammary-gland-epithelial cells contain peroxidase enzymes. Iodide is taken up via the iodide sodium symporter on the basal membrane of the epithelial cell (Spitzweg *et al.*, 1998). Iodide is oxidised to elemental-iodine in a reaction catalysed by thyroid peroxidase in the apical membrane of the epithelial cells. Iodine is then added to the tyrosyl residues of thyroglobulin and stored in the thyroid as iodised thyroglobulin. Thyroid peroxidase is also involved in the oxidation of oxazolidinethiones, products of glucosinolates degradation (Kohler *et al.*, 1988). The presence of oxazolidinethiones reduces the availability of thyroid peroxidase for oxidation of iodide, resulting in a relative enzyme deficiency. The excess iodide in animals exposed to glucosinolate increases the proportion of total serum iodine which is non-hormone iodine (Schöne *et al.*, 2001b). Higher urinary iodine occurs in dairy cows (Šustala *et al.*, 2003) fed rapeseed meals. In contrast, the milk iodine concentration was reduced by rapeseed glucosinolates.

According to Laarveld *et al.* (1981) feeding low-glucosinolates diets resulting in the daily intake of 14 to 47 mmol glucosinolates did not change milk iodine content, while feeding low- glucosinolates rapeseed meal at higher levels in dairy cows (intake of 37-63 mmol glucosinolates /day) reduced milk iodine content.

In the study by Veselý *et al.* (2009), the daily intake of 50.14 mmol glucosinolates resulted in a significant decrease in iodine concentration in milk (196.7 μg/l for diet containing glucosinolates in comparison with 367.0 μg/l in control diet). This reduction by feeding glucosinolates was reported by other researchers (Schöne *et al.*, 2001a; Šustala *et al.*, 2003).

4. Organic or conventional milk

Although conventional milk is the usual choice, organic milk is increasing in popularity because of its perceived health and environmental benefits (Bath *et al.*, 2011). Due to the strict organic farming regulations that govern the use of mineral supplements in livestock feed (EC, 2007), organic milk may contain lower concentrations of trace minerals, thereby reducing or even reversing the potential health benefits. Studies in Europe have shown conventional milk to have a higher iodine concentration than organic milk (Bath *et al.*, 2011; Dahl *et al.*, 2003; Rasmussen *et al.*, 2000). Iodine concentrations of the Norwegian (Dahl *et al.*, 2003) and Danish (Rasmussen *et al.*, 2000) summer organic milk samples were 31.8 and 40.8% lower than those of conventional milk, respectively. In UK this difference was reported to be 42.1% (Bath *et al.*, 2011).

The lower iodine concentration in organic milk can be explained by differing practices on organic and conventional farms. Organic farming regulations do not allow the routine use of vitamin and mineral preparations (EC, 2007). Regulations also stipulate that at least 60% of the feed on organic farms must be fresh or conserved forage, thus limiting the use of concentrates and relying on soil minerals, levels of which can be low in some areas. Due to these restrictions, deficiencies in some minerals, including iodine, can occur in organically farmed livestock (Rosati and Aumaitre, 2004). Nitrogen-fixing crops, such as clover, are important in organic farming and are used in place of artificial fertilisers (Foster *et al.*, 2010). While clover contains cyanogenic glucosides (Bjarnholt *et al.*, 2008) that are thought to exhibit goitrogenic properties, as suggested by Rasmussen *et al.* (2000), greater use of goitrogenic feed could lower milk-iodine concentrations through the inhibition of the sodium-iodide symporter in the mammary gland of the cow.

5. Teat dipping and udder wash

Iodine is commonly used as the key ingredient of pre- and post-milking teat disinfecting solution. Teat-dipping practices showed associations with iodine levels in milk. However, the effect appeared to be modulated by the way in which the sanitiser was applied. Borucki Castro *et al.* (2012) reported that the iodine concentration in milk was not affected by dipping teats in 1% iodine sanitiser after milking. However, in other studies the effect of post-milking iodine teat dipping ranged from no effect (Berg and Padgitt, 1985) to an increase of 184 μg/l (Iwarsson and Ekman, 1973). Post-dipping with 0.3% (Flachowsky *et al.*, 2007) and 0.5% (Galton, 2004) iodine increased milk iodine between 33 and 54 μg/l.

Spraying with 1% iodine sanitiser in the post-milking phase resulted in greater milk iodine concentrations than with chlorhexidine-based sanitiser (+409 μg/l) or dip (+360 μg/l) (Borucki Castro *et al.*, 2012). Conrad and Hemken (1978) reported that teat dipping of only the right udder half with an iodine-based sanitiser resulted in similar iodine increases in both left and right udder halves.

The primary mode by which post-milking teat dipping affects milk iodine concentration is absorption from the teat's surface and secretion into milk rather than contamination from the skin's surface. Spraying requires about 50% more disinfectant than dipping to achieve the same degree of teat cover (Blowey and Edmondson, 1996). In addition, a larger skin area is covered with the sanitiser when the teats are sprayed rather than dipped, increasing the absorption area. Finally, the skin of the teat is washed at each milking, whereas the skin of the mammary gland is not routinely washed, leaving more time for residues to be absorbed. These factors probably explain why spraying 1% iodine post-dip dramatically increased the iodine in milk. These results suggest that automatic teat disinfection systems, which use more disinfectant and cover a larger skin area, would increase the milk iodine level even further.

Galton *et al.* (1984) and Rasmussen *et al.* (1991) reported that pre-dipping with 0.5% iodine pre-dip solutions followed by complete drying of the teat did not significantly increase milk iodine content. However, pre-dipping with 1% iodine post-dip solution increased milk iodine content (Galton *et al.*, 1984). The higher iodine content of the post-dip solution probably plays a role, given that Galton *et al.* (1986) reported an increase in milk iodine with a 1% iodine sanitiser but not with 0.1% sanitiser. In another study, Rasmussen *et al.* (1991) observed greater milk iodine concentrations with a 0.25% than with a 0.5% iodine post-teat dip. These authors attributed this surprising result to the fact that the 0.5% teat dip was easier to remove, leaving less residue on the teat skin. Galton *et al.* (1984) reported that installing the milking unit without drying the teats after dipping in 1% iodine sanitiser increased milk iodine by 600 μg/l above the level observed when teats were dried before milking.

Few studies focused on the potential effect of iodine udder wash on iodine concentration in raw milk. Cantor and Most (1976) did not detect a significant increase in milk iodine levels when comparing the use of pre-milking iodine udder wash with a non-iodophor product. On the other hand, two other studies performed by Dunsmore and Nuzum (1977) and Hemken (1981) reported increases of 35 μg/l in mean milk iodine concentrations in cows washed with an iodine-based product.

6. Stage of lactation and milk yield

Although Lamand and Tressol (1992) and Moschini *et al.* (2010) did not find a correlation between stage of lactation or age of animal and milk iodine levels, other studies have reported more definitive results (Iwarsson, 1973; Pennington, 1990). Franke *et al.* (1983) showed that milk iodine levels increased with the stage of lactation. Iwarsson (1973) found statistically significant changes in iodine levels with the progression of lactation. In this study, during weeks 1 to 5 of lactation, the iodine concentration ranged between 5 and 30 μg/l. For weeks 36 to 40, the milk iodine levels were between 35 and 115 μg/l. It seems that this increase in iodine concentration with the progression of lactation is due to a decrease in milk yield. Iwarsson (1973) found a negative correlation between iodine concentration and total milk yield. This reinforces the idea that milk yield does play a role in the secretion of iodine into the milk.

7. Region and season

Mean concentrations of iodine in bovine milk from some studies in many countries, published between 1976 and 1986, ranged from 25 to 768 μg/l (Pennington, 1988). The iodine content of milk in Great Britain, based on monitoring of 30 regions performed in 1990 and 1991, was 150 μg/l (range 40-310 μg/l) compared to 230 μg/l in 1977-1979 (Lee *et al.*, 1994).

Monitoring of iodine levels in raw milk purchased by 28 Bavarian dairy plants showed a content of 115 μg/l (from less than 100 μg/l in South Bavaria to over 150 μg/l in North Bavaria (Preiss *et al.*, 1997). Monitoring of the iodine content of milk in Ireland showed that it averaged 139 μg/l (range 2-435 μg/l) (Rogers, 1999).

Variable use and variable levels of use of iodophors and EDDI and veterinary medication are primarily responsible for the variation of iodine concentrations in milk observed among countries, among regions within countries, and among dairy farms within regions.

A few studies indicated seasonal variation in the iodine content of milk. A study of 50 herds with 33 to 293 cows demonstrated that 38% of the herds had low iodine status in the spring and 70% had low iodine status in the autumn (Mee *et al.*, 1993).

Monitoring studies of the iodine content of fluid milk published in the USA showed milk iodine content was 190μg/l milk in the summer season and 270 μg/l milk in the winter season (Pennington, 1990).

The iodine content of Norwegian milk was 88 μg/l (range 63-122 μg/l) in the summer and 232 μg/l (range 103-272 μg/l) in the winter (Dahl *et al.*, 2003). A study of milk iodine content in Finland showed 280 μg/l in summer and 400 μg/l in winter (Lamberg, 1986).

Seasonal variations in the iodine content of milk are usually attributed to the proportion of pasture feeding versus the use of prepared feed containing supplemental iodine. Pasture feeding may predominate in the summer, prepared feed may predominate in the winter, and spring and autumn feeding may be a mixture of both. The length of each season is influenced by the climate of the geographical location (Pennington, 1990).

Other authors (Binnerts, 1979; Brzóska *et al.*, 2009) noted that higher concentrations of iodine in winter months might reflect decreased milk production that would account for a higher concentration of iodine in the milk.

8. Processing the raw milk

Increased iodine concentration in milk can occur due to processing when there is inadequate drainage of milk lines following cleaning or contamination of the milk contact surface (Wheeler *et al.*, 1983). Povidone iodine disinfecting solutions are used to clean tanker trucks, vats, and milking equipment and residues from these solutions add a substantial amount of iodine to the milk.

There are few studies indicating that heating and boiling the milk in the pasteurising process reduces milk iodine concentration. Magee and Glennie (1928) found a 20 and 26% decrease in iodine content of milk in pasteurisation and boiling point, respectively. In our study we found a 27.1±7.1% decrease in iodine after high temperature short-time pasteurisation (Figure 1) (Norouzian *et al.*, 2009a).

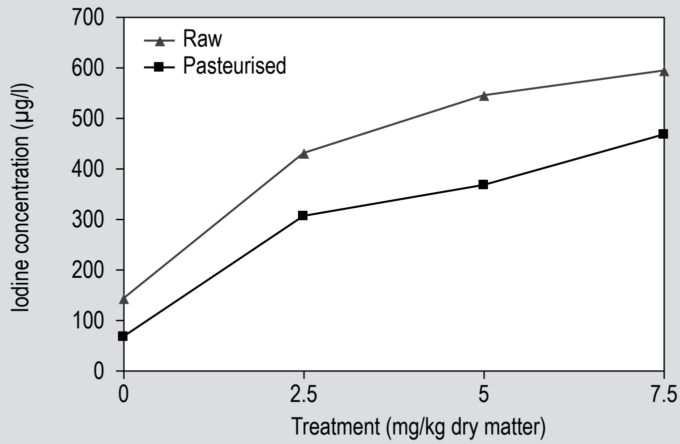

Figure 1. The effect of different levels of potassium iodide and of the pasteurisation process on milk iodine concentration.

The reason for the decrease in iodine concentrations after heat processing is the sublimation characteristic of the iodine element. Iodine in milk includes two forms, free and protein binding iodine. Magee and Glennie (1928) reported that the free form concentration of iodine in milk is 83%. High levels of milk iodine in free form cause a decrease in iodine content after heating.

It has also been reported that spray and roller drying of milk reduces iodine concentration by 40% (Wheeler *et al.*, 1983). Finished fluid milk has been found to have lower iodine concentrations than bulk tank raw milk. This could be due to a dilution effect when large volumes of milk are pooled (Wheeler *et al.*, 1983).

On the other hand, a study by Aumont (1987) reported that further processing including pasteurisation, ultra-high temperature pasteurisation, and spray drying had no impact on finished milk iodine concentration compared to the raw milk iodine levels.

9. Conclusions

In recent years, the iodine content of milk has increased considerably. Nowadays, it is particularly common to control the supplementation of feed rations with additives containing iodine according to the physiological requirements and production conditions. It seems appropriate to continue the systematic general monitoring of iodine content in fresh cow milk with the possibility of providing feedback to the agribusiness. Also, with continued research on factors affecting iodine concentration in milk as well as the on-going education of producers, the dairy industry will be able to continue to provide consumers with a safe and healthy source of essential nutrients.

References

Aumont, G., 1987. Milk iodine residues after a post-milking iodophor teat-dipping. Annales de Recherches Veterinaires 18: 375-378.

Bath, S.C., Button, S. and Rayman, M.P., 2011. Iodine concentration of organic and conventional milk: implications for iodine intake. British Journal of Nutrition 107: 935-940.

Berg, J.N., Maas, J.P., Paterson, J.A., Krause, G.F. and Davis, L.E., 1984. Efficacy of ethylenediamine dihydriodide as an agent to prevent experimentally induced bovine foot rot. American Journal of Veterinary Research 45: 1073-1078.

Berg, J.N. and Padgitt, D., 1985. Iodine concentrations in milk from iodophor teat dips. Journal of Dairy Science 68: 457-461.

Binnerts, W.T., 1979. The iodine content of milk no reason for concern yet. Netherlands Milk Dairy Journal 33: 12-23.

Bjarnholt, N., Laegdsmand, M. and Hansen, H.C., 2008. Leaching of cyanogenic glucosides and cyanide from white clover green manure. Chemosphere 72: 897-904.

Blowey, R. and Edmondson, P., 1996. Teat disinfection in dairy herds. Clinical Practice 18: 254-260.

Borucki Castro, S.I., Berthiaume, R., Robichaud, A. and Lacasse, P., 2012. Effects of iodine intake and teat-dipping practices on milk iodine concentrations in dairy cows. Journal of Dairy Science 95: 213-220.

Brzóska, F., Szybinski, Z. and Sliwinski, B., 2009. Iodine concentration in Polish milk – variations due to season and region. Endocrinologica Polska 60: 449-454.

Cantor, A. and Most, S., 1976. Milk iodides: effect of iodophor teat dipping and udder washing and dietary iodide supplementation. Journal of Milk and Food Technology 39: 554-560.

Cavalieri, R.R., 1997. Iodine metabolism and thyroid physiology: current concepts. Thyroid 7: 177-181.

Conrad, L.M. and Hemken, R., 1978. Milk iodine as influenced by an iodophor teat dip. Journal of Dairy Science 61: 776-780.

Cressey, P.J., 2003. Iodine content of New Zealand dairy products. Journal of Food Composition and Analysis 16: 25-36.

Dahl, L., Opsahl, J.A., Mltzer, H.M. and Julshamn, K., 2003. Iodine concentration in Norwegian milk and dairy products. British Journal of Nutrition 90: 679-685.

Dermelj, M., Stibilj, V., Stekar, J. and Stegnar, P., 1991. Trace elements in man and animals. In: Proceedings of the 7th International Symposium on Trace Elements in Man and Animal, May 20-25, 1990, Zagreb, Croatia, pp. 22.

Dunsmore, D.G. and Nuzum, C., 1977. Iodophors and iodine in dairy products. 2. Udder washes and salves. Australian Journal of Dairy Technology 32: 42-45.

European Community (EC), 2007. Council Regulation (EC) no. 834/2007 of 28 June 2007 on organic production and labeling of organic products and repealing Regulation (EEC) no. 2092/91. Official Journal of the European Union 50: L189.

Flachowsky, G., Schone, F., Leiterer, M., Bemmann, D., Spolders, M. and Lebzien, P., 2007. Influence of an iodine depletion period and teat dipping in the iodine concentration of serum and milk of cows. Journal of Animal and Feed Science 16: 18-25.

Foster, C., Audsley, E. and Williams, A., 2010. The environmental, social and economic impacts associated with liquid milk consumption in the UK and its production. A review of the literature and evidence. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69436/pb13644-milk-envsocecon-impacts-080111.pdf.

Franke, A.A., Bruhn, J.C. and Osland, R.B., 1983. Factors affecting iodine concentration of milk of individual cows. Journal of Dairy Science 66: 997-1002.

Fuge, R. and Johnson, C.J., 1986. The geochemistry of iodine - a review. Environmental Geochemistry and Health 8: 31-54.

Galton, D.M., 2004. Effects of an automatic postmilking teat dipping system on new intra mammary infections and iodine in milk. Journal of Dairy Science 87: 225-231.

Galton, D.M., Petersson, L. and Erb, H., 1986. Milk iodine residues in herds practicing iodophor premilking teat disinfection. Journal of Dairy Science 69: 267-271.

Galton, D.M., Petersson, L., Merrill, W., Bandler, D., Shuster, D., 1984. Effects of premilking udder preparation on bacterial population, sediment, and iodine residue in milk. Journal of Dairy Science 67: 2580-2589.

Haldimann, M., Alt, A., Blanc, A. and Blondeau, K., 2005. Iodine content of food groups. Journal of Food Composition and Analysis 18: 461-471.

Hemken, R.W., Fox, J.D. and Hicks, C.L., 1981. Milk iodine content as influenced by feed sources and sanitizer residues. Journal of Food Protection 44: 476-479.

Hemling, T.V., 2000. Iodine residues in milk. In: Proceedings of the Pacific Congress on Milk Quality and Mastitis Control, 13-16 November, 2000, Nagano, Japan.

Iwarsson, K., 1973. Rapeseed meal as a protein supplement for dairy cows. I. Influence on certain blood and milk parameters. ACTA Veterinaria Scandinavica 14: 570-594.

Iwarsson, K. and Ekman, L., 1973. The effect of a post-milking teat dip on the iodine concentration of bulk herd milk. ACTA Veterinaria Scandinavica 14: 338-340.

Kohler, H., Taurog, A. and Dunford, H.B., 1988. Spectral studies with lactoperoxidase and thyroid peroxidase: interconversions between native enzyme, compound ii, and compound iii. Archives of Biochemistry and Biophysics 264: 438-449.

Laarveld, B., Brockman, R.P. and Christensen, D.A., 1981. The effect of the level in canola meal concentrate on milk iodine and thiocyanate content and thyroid function in dairy cow. Canadian Journal of Animal Science 61: 625-632.

Lamand, M. and Tressol, J.C., 1992. Contribution of milk to iodine intake in France. Biological Trace Element Research 32: 245-251.

Lamberg, B.A., 1986. Endemic goiter in Finland and changes during 30 years of iodine prophylaxis. Endocrinologia Experimentalis 20: 35-47.

Lee, S.M., Lewis, J. and Buss, D.H., 1994. Iodine in British foods and diets. British Journal of Nutrition 72: 435-446.

Magee, H.E. and Glennie, A.E., 1928. Studies of the effect of heat on milk, the iodine content. Biochemical Journal 22: 11-14.

Mee, J.F., O'Farrell, K. and Rogers, P.A.M., 1993. Incidence of iodine, selenium and copper deficiency in Irish dairy herds. Veterinary Surgeon 15: 27-30.

Miller, J.K. and Swanson, E.W., 1973. Metabolism of ethylenediaminedihydraiodide and sodium or potassium iodide by dairy cows. Journal of Dairy Science 56: 378-84.

Miller, J.K., Swanson, E.W. and Spalding, G.E., 1975. Iodine absorption, excretion, recycling, and tissue distribution in the dairy cow. Journal of Dairy Science 58: 1578-1593.

Moschini, M., Battaglia, M., Beone, G.M., Piva, G. and Masoero, F., 2010. Iodine and selenium carry over in milk and cheese in dairy cows: effect of diet supplementation and milk yield. Animal 4: 147-155.

National Research Council (NRC), 2001. Nutrient requirements of dairy cattle (7th Ed.) National Academies Press, Washington, DC, USA.

Norouzian, M.A., Valizadeh, R. and Azizi, F., 2009a. Heating in pasteurization process reduce milk iodine concentration. Research Journal of Biological Sciences 4: 578-579.

Norouzian, M.A., Valizadeh, R., Azizi, F., Hedayati, M., Naserian, A.A. and Eftekhari Shahroodi, F., 2009b. The effect of feeding different levels of potassium iodide on performance, T3 and T4 concentrations and iodine excretion in Holstein dairy cows. Journal of Animal and Veterinary Advances 8: 111-114.

Papas, A., Ingalls, J.R. and Campbell, L.D., 1979. Studies on the effects of rapeseed meal on thyroid status of cattle, glucosinolate and iodine content of milk and other parameters. Journal of Nutrition 109: 1129-1139.

Pearce, E.N., Pino, S., He, X., Bazrafshan, H.R., Lee, S.L. and Braverman, L.E., 2004. Sources of dietary iodine: bread, cows' milk, and infant formula in the Boston area. Journal of Clinical Endocrinology and Metabolism 89: 3421-3424.

Pennington, J.A.T., 1988. Iodine. In: Smith, K.T. (ed.) Trace mineral in foods. Marcel Dekker, New York, NY, USA, p. 249.

Pennington, J.A.T., 1990. Iodine concentration in US milk: variation due to time, season and region. Journal of Dairy Science 73: 3421-3427.

Preiss, U., Alfaro Santos, C., Spitzer, A. and Wallnöfer, 1997. Iodine content of Bavarian consumer milk [in German]. Zeitschrift für Ernahrungswissenschaft 36: 220-224.

Rasmussen, M.D., Galton, D.M. and Peterson, L.G., 1991. Effects of premilking teat preparation on spores of anaerobes, bacteria, and iodine residues in milk. Journal of Dairy Science 74: 2472-2478.

Rasmussen, L.B., Larsen, E.H. and Ovesen, L., 2000. Iodine content in drinking water and other beverages in Denmark. European Journal of Clinical Nutrition 54: 57-60.

Rogers, P.A.M., 1999. Iodine supplementation of cattle. Beef Production Series no. 20. Available at: http://www.teagasc.ie/research/reports/beef/5165/eopr-5165.pdf.

Rosati, A. and Aumaitre, A., 2004. Organic dairy farming in Europe. Livestock Production Science 90: 41-51.

Schöne, F., Lebzien, P., Bemmann, D., Leiterer, M., Spolders, M. and Flachowsky, G., 2006. Impudence of increasing dietary iodine supplementation of feed on iodine concentration in blood serum and milk of dairy cows. Proceedings of the Society of Nutrition Physiology 15: 172.

Schöne, F., Leiterer, M., Hartung, H., Jahreis, G. and Tischendorf, F., 2001a. Rapeseed glucosinolates and iodine in sows affect the milk iodine concentration and the iodine status of piglets. Britisch Journal of J. Nutrition 85: 659-670.

Schöne, F., Tischendorf, F., Leiterer, M., Hartung, H. and Bargholz, J., 2001b. Effects of rapeseed-press cake glucosinolates and iodine on the performance, the thyroid gland and the liver vitamin a status of pigs. Archives of Animal Nutrition 55: 333-350.

Shinonaga, T., Gerzabek, M.H., Strebl, F. and Muramatsu, Y., 2001. Transfer of iodine from soil to cereal grains in agricultural areas of Austria. Science of the Total Environment 267: 33-40.

Spitzweg, C., Joba, W., Eisenmenger, W. and Heufelder, A.E., 1998. Analysis of human sodium iodide symporter gene expression in extrathyroidal tissues and cloning of its complementary deoxyribonucleic acids from salivary gland, mammary gland, and gastric mucosa. Journal of Clinical Endocrinology and Metabolism 83: 1746-1751.

Swanson, E.W., Miller, J.K., Mueller, F.J., Patton, C.S., Bacon, J.A. and Ramsey, N., 1990. Iodine in milk and meat of dairy cows fed different amounts of potassium iodide or ethylenediamine dihydroiodide. Journal of Dairy Science 73: 398-405.

Šustala, M., Tináctý, J., Kudrna, V., Illek, J. and Šustová, K., 2003. Effects of short-term supplementation of dairy cow diets with surplus selenium and rapeseed meal on milk and blood selenium levels. Czech Journal of Animal Science 48: 170-180.

Weldy, M.L., 1978. Herd health. Dairy Herd Management 15: 4.

Wheeler, S.M., Fleet, G.H. and Ashley, R.J., 1983. Effect of processing upon concentration and distribution of natural and iodophor-derived iodine in milk. Journal of Dairy Science 66: 187-195.

Veselý, A., Krížová, L., Trináctý, J., Hadrová, S., Navrátilová, M., Herzig, I. and Išera, M., 2009. Changes in fatty acid profile and iodine content in milk as influenced by the inclusion of extruded rapeseed cake in the diet of dairy cows. Czech Journal of Animal Science 54: 201-209.