Effect of iodized salt on organoleptic properties of processed foods: a systematic review

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Abstract Despite the global recommendation for fortification of salt with iodine, including salt used in food processing, most salt iodization programs have focussed only on iodization of household salt. Food manufacturers are frequently concerned about the potential instability of iodine and changes in organoleptic properties of their products if iodized salt is used instead of non-iodized salt. To address these concerns, this paper provides a comprehensive review of studies conducted to assess the effect of iodized salt on the organoleptic properties of processed foods and condiments. A comprehensive review was conducted of eligible studies identified by searching electronic databases (PubMed, Medline) and open Internet searches for studies examining the effect of salt iodized with either potassium iodide (KI) or potassium iodate (KIO₃) on processed foods. A total of 34 studies on the effect of iodized salt on 38 types of processed foods are summarized. There is no evidence that the use of iodized salt in production of processed foods or condiments causes adverse organoleptic changes that will affect consumer acceptability or product quality. Universal salt iodization is widely recognized as the most cost-effective intervention to eliminate iodine

deficiency. Taking into account increases in the proportion of dietary salt consumed through processed foods, and declines in salt consumed as household salt, iodized salt should be used in the production of processed foods as a means of assuring optimal iodine nutrition without the risk of affecting the organoleptic properties of foods.

Keywords Iodized salt · Processed foods · Salt iodization · Organoleptic properties · Iodine deficiency

Introduction

Universal salt iodization (USI) has been credited with reducing the prevalence of iodine deficiency disorders (IDD) and enabling countries to supply optimal iodine to meet dietary requirements globally. Legislation on USI is in place in 108 countries (Global Fortification Data Exchange 2018) and 86% of households globally have access to iodized salt (UNICEF 2017). While there has been tremendous progress, sub-optimal iodine intake is still a public health burden in 19 countries and the prevalence of mild iodine deficiency has remained stagnant in several industrialized countries (IGN 2017). The persistence of iodine deficiency and sub-optimal iodine intakes, in spite of global progress with salt iodization, may be attributed to shifting salt consumption patterns with an increased consumption of processed foods that use non-iodized salt and reduced consumption of table salt that is iodized. The majority of sodium is consumed through processed foods and condiments, rather than table salt, in industrialized countries. For example, 71, 95 and 71% of sodium is consumed through processed foods in Japan, United Kingdom and the United States respectively (Andersen et al. 2010). In countries where iodized salt is not used in

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the manufacture of processed foods or condiments, the progressing shift in consumption patterns may therefore correspond with a decline in dietary intake of iodine.

While the WHO recommendation for salt iodization includes all edible salt, including that used at the household level and in food processing, the majority of salt iodization programs have only focused on salt intended for discretionary household use (WHO 2014). Many countries do not actively enforce existing legislation for the addition of iodized salt in processed foods, which leaves countries with high consumption of processed foods at increasing risk of IDD (Bohac 2011).

Iodized salt has been used in the manufacture of processed foods to prevent IDD since the 1940s when the Netherlands encouraged the use of iodized salt in commercial bakeries (Zimmermann 2007). Legislation on the use of iodized salt in processed foods is now in place in 96 countries. In most countries, legislation requires the iodization of salt for human consumption or all food grade salt, including salt for food processing, while in a minority it applies only to the use of iodized salt in a specific type of food such as bread (GFDx 2018). When legislation is applied to the use of iodized salt in all processed food or in a widely consumed staple food like bread, the effect on dietary intake of iodine can be notable. In Belarus and the Netherlands, bread prepared with iodized salt provides over 50% of the daily iodine requirement for the general population and is the most important source of iodine in the diet (Gerasimov 2009). Australia and New Zealand passed legislation for mandatory use of iodized salt in bread making in 2009 and Australia evaluated the impact in 2016; the evaluation found that the iodine content of bread increased from < 2 to 53–70 µg/100 g and the corresponding iodine intake in women increased from 98 to 149 µg per day (52% increase) (AIHW 2016). In 11 Central and Eastern European countries with fortification legislation which calls for the use of iodized salt in all processed foods, adequate iodine status in the population has been achieved and IDD has been virtually eliminated (IGN 2014).

Despite the documented success of using iodized salt in processed food in several countries, the majority of countries do not regularly monitor nor enforce the use of iodized salt in processed food. Without enforcement, food manufacturers are less likely to use iodized salt in their food products. A 2012 review of food manufacturers in 39 countries concluded that manufacturers used iodized salt only when legislation requiring them to do so was enforced (Ohlhorst et al. 2012). In the report, manufacturers expressed concerns about the potential instability of iodine and changes in organoleptic properties of their products, specifically, changes in the color, taste, smell and texture of processed foods when iodized salt is used. The review

concluded that the main reason that there was limited use of iodized salt in processed food was because of manufacturers' fear that iodized salt would negatively affect product quality and thereby consumer acceptance of their product.

Various studies have been conducted to assess the effects of iodized salt on the quality of processed foods and the retention of iodine. The earliest studies were conducted in the 1920s, while the most recent work identified by this review was conducted in 2013. This review includes the findings of three prior papers that summarized the results of different studies (West and Merx 1995; Winger et al. 2005; de Jong 2007) and provides the most comprehensive review of all available published documentation on the impact of using iodized salt in processed foods to date. The findings are intended to inform policy makers and food manufacturers on the effect of using iodized salt in processed foods and to address concerns of manufacturers over the potential impact of iodized salt on product quality. Governments can use this review to support policy decisions for iodized salt programs and legislation.

Methods

Studies eligible for inclusion in this review were identified in March 2016 by searching electronic databases (PubMed, Medline) and open Internet searches for studies examining the effect of salt iodized with either potassium iodide (KI) or potassium iodate (KIO₃) in processed foods. The terms “organoleptic properties” and “sensory properties” and “sensory characteristics” along with “taste”, “smell”, “texture” and “color” were used for search phrases. References to studies in previous reviews were included and original papers were obtained for review where possible (West and Merx 1995; Winger et al. 2005; de Jong 2007). In cases where the original papers were not available, summaries of conducted studies were included based on prior reviews or abstracts with reference noted. Only papers available in English or with abstracts in English were included for review with no limitation on year of publication. A total of 34 studies of the effect of iodized salt on 38 types of processed foods and condiments are summarized. All 34 studies meeting the inclusion criteria were included in the review with the concentration of iodine in salt and the final concentration of iodine in processed food presented in parts per million (ppm).

Table 1 Summary findings on the effect of iodized salt on the organoleptic properties of processed foods

Food	Citation	Fortificant	Concentration of iodine in iodized salt	Organoleptic changes	Concentration in processed food
<i>Condiments</i>					
Mayonnaise	Harrison and Cunningham (1986)	NA	NA	In objective analysis, no effect on viscosity at 10% concentration of iodized salt with iodized salt having significantly less viscosity than non-iodized salt at 15% concentration. No effect on color or spread at any concentration of salt after 24 h of storage	NA
Margarine	Harris et al. (2003)	KIO ₃	40–60 ppm	No subjective changes in reported quality of product after national distribution	NA
Fish sauce	Chanthilath et al. (2009)	KIO ₃	30 ppm	In objective analysis, fish sauce made with iodized salt scored slightly better than with non-iodized salt for general appearance, colour, flavour and overall acceptability. Colour of fish sauce made with iodized salt was lighter than with non-iodized salt	87% retention after 12 months' fermentation in the shade; 44% retention after 12 months' fermentation in the sun
Fermented fish	Chanthilath et al. (2009)	KIO ₃	30 ppm	In objective analysis, fermented fish made with iodized salt had similar or slightly higher acceptability scores to that made with non-iodized salt	91–84% retention of iodine after 6 months' fermentation
Soy sauce	CNSIC (2004b)	NA	61.95 ppm	Objective analysis found no differences in organoleptic characteristics of soy sauce made with iodized and non-iodized salt as analysed by 10 experienced panellists and no differences in measured colour or lustre	60% at the end of production and 58% retention after 3 months' storage
Flavoring cubes	Spohrer et al. (2013)	NA	1.3–20 ppm	Global use of flavoring cubes containing iodized salt with no reported effects of sensory or technological characteristics of prepared foods since 1997	Not specified, reference to high retention after 6 months' storage in humid conditions
<i>Cheese</i>					
Emmenthaler	Koestler and Wegmüller (1926) reference only	KI	3.8 and 38 ppm	No objective effect after 4 months' storage	NA
Gruyere	Hostettler (1953) reference only	KI	3.8 and 38 ppm	No objective effect after 8 months' storage	NA
Camembert	Zimmermann et al. (2005)	KIO ₃	39 ppm	No effect on sensory or technological characteristics mentioned	Final iodine content was 26 µg/100 g cheese when made with cow milk and 59 µg/100 g cheese when made with goat milk. Differences were attributed to levels of iodine already in milk

Table 1 continued

Food	Citation	Fortificant	Concentration of iodine in iodized salt	Organoleptic changes	Concentration in processed food
White cheese, cream cheese and yogurt	UNICEF (2005)	KIO ₃	28–55 ppm	Mandatory fortification of all processed foods. No effects observed on quality after national distribution of products	NA
<i>Cereals and baked goods</i>					
Breakfast cereal: Weetabix and muesli	Thomson (2009)	KIO ₃	25–65 ppm	No effect on quality mentioned	100% retention with final concentration of iodine: 0.4 ppm Weetabix and 0.5 ppm muesli
Sweet biscuits	Thomson (2009)	KIO ₃	25–65 ppm	No effect on quality mentioned	100% retention with final concentration of 0.3 ppm iodine
Lemon cake mix	Sevenants and Sanders (1984)	NA	NA	In objective analysis, bitter taste formed on addition of iodized salt	NA
<i>Bread</i>					
All bakery bread-Bulgaria	UNICEF (2005)	KIO ₃	28–55 ppm	Mandatory legislation for fortification with all bakeries using iodized salt. No noticeable effects on quality reported after national distribution	Estimated from production 0.36–0.72 ppm iodine in bread with 36–72 ug/100 g bread
All commercial bread-Belarus	Gerasimov (2009)	KIO ₃	40 ± 15 ppm	Mandatory fortification of all processed foods. No subjective effects on reported quality after national distribution since 2001	0.1–0.2 ppm iodine in bread depending on type with 10–20 ug/100 g bread
All commercial bread-Tasmania	Winger et al. (2005), Seal et al. (2007)	KIO ₃	25–65 ppm	Voluntary fortification with 70% compliance in Tasmania. No reported technical and organoleptic changes to the product after statewide distribution with 80% of the market	90% retention of iodine. 35 ppm iodine in bread with 35 ug/100 g bread
All commercial bread-Australia	Charlton et al. (2013)	KIO ₃	25–65 ppm	Mandatory fortification of all bread and bread products. No subjective effects on quality reported after 3 years of national distribution	0.3–0.7 ppm iodine in bread with average iodine content of 48 ug/100 g bread
All commercial bread-New Zealand	Edmonds and Ryan (2012)	KIO ₃	25–65 ppm	Mandatory fortification of all bread and bread products. No subjective effects on reported quality after 2 years of national distribution	0.3–0.5 ppm iodine in bread with 32–53 ug/100 g bread
All commercial bread-Denmark	Rasmussen et al. (2007)	NA	13 ppm	Mandatory fortification of all bread with 90% bakeries complying. No subjective effects on reported quality after National distribution since 2000	0.21 ppm iodine in bread with 21 ug/100 g bread
Commercial bread-Belgium	Vandevijvere (2012)	NA	10–15 ppm	44% of bakeries use iodized salt. No subjective effects on reported quality after national distribution since 2009	0.18 ppm iodine in bread with 18 ug/100 g bread
White bread-South Africa	Harris et al. (2003)	NA	61 ppm	Unintentional use of iodized salt in the product with no subjective effects on reported quality after national distribution	0.3 ppm iodine in bread with 30 ug/100 g bread

Table 1 continued

Food	Citation	Fortificant	Concentration of iodine in iodized salt	Organoleptic changes	Concentration in processed food
White bread	Kuhajek and Fiedelman (1973)	KI and KIO ₃	77 ppm	No objective effect on appearance, taste or aroma of bread	70% retention of iodine throughout processing, 2 days after preparation and after 10 days' storage in freezer
Flat bread	Amr and Jabay (2004a)	KI and KIO ₃	40 ppm	No objective effect on taste	38–42% retention with KI and 38–46% retention of KIO ₃ with 0.1 ppm iodine in bread for 10 ug/100 g in final product
White and whole grain bread	Thomson (2009)	KIO ₃	25–65 ppm	No effects mentioned	100% retention with a final concentration of 1.1 ppm iodine in bread for 110 ug/100 g bread
<i>Other starches</i>					
Boiled rice, potatoes	West and Merx (1995)	KI and KIO ₃	400 ppm	No objective effect on flavor or appearance despite high level of iodine in salt	NA
French fries and boiled potatoes	Amr and Jabay (2004a)	KI and KIO ₃	40 ppm	No subjective effect on color or taste	NA
Potato chips	Kuhajek and Fiedelman (1973)	KI and KIO ₃	77 ppm	No objective effect on taste after 4 weeks' storage	67% retention KI and 48% retention KIO ₃ after 13 weeks' storage
<i>Meat products</i>					
Sausages, cured ham, salami	Wirth and Kuehne (1991)	KIO ₃	15–25 ppm	No objective effect on processing or sensory characteristics of products and no effect on product quality after addition into nitrite curing salt	Retention of 93% for salami and 75% for sausage. Concentration of iodine was 0.3–0.6 ppm in meats with 30–60 ug/100 g product
Hotdogs	Kuhajek and Fiedelman (1973)	KI and KIO ₃	77 ppm	No objective effect on taste, texture or color after preparation	Retention of 93% KI and 65% KIO ₃ after 22 weeks' freezer storage and preparation in hot water
Aspic	Marggrander (1996)-reference only	NA	NA	No objective effect on sensory or technological characteristics of aspic with addition of iodized salt or iodized nitrite curing salt in prepared aspic	NA
Cured meat products	Capanzana et al. (2006)	KIO ₃ ^a	25 ppm	No objective effect on physical or chemical properties of any tested foods except an improvement in the color of meat products. No specification on color changes in meat products	Iodine retention was 67–96% in all foods with high acceptability after 3–6 months of storage
Nitrite cured pork meat	Azanza et al. (1998)	KIO ₃ ^a	62 ppm	No objective effect on sensory properties of any products	Iodine retention of 7–67% in all products with highest losses in foods with long processing methods and multiple processing steps such as drying, smoking, boiling and frying
Mortadella	Amr and Jabay (2004a)	KI and KIO ₃	40 ppm	Objective analysis found change in color with KIO ₃ but not with KI. No change in taste for KI or KIO ₃ . No specification on color changes in mortadella	Iodine retention was 51–63% with KI and 22–23% with KIO ₃ . Iodine concentration was 0.65–0.80 ppm with KI and 0.28–0.33 ppm with KIO ₃

Table 1 continued

Food	Citation	Fortificant	Concentration of iodine in iodized salt	Organoleptic changes	Concentration in processed food
<i>Fish products</i>					
Dried fish, fermented shrimps, anchovies	Capanzana et al. (2006)	KIO ₃ ^a	25 ppm	No objective effect on physical or chemical properties of any tested foods	Iodine retention was 67–96% in all foods with high acceptability after 3–6 months of storage
Dried, salted and smoked fish products, fermented shrimp paste	Azanza et al. (1998)	KIO ₃ ^a	62 ppm	No objective effect on sensory properties of any products	Iodine retention of 7–67% in all products with highest losses in foods with long processing methods and multiple processing steps such as drying, smoking, boiling and frying
Emulsified freshwater fish sausages	Panpipat and Yongsawatdigul (2008)	KI	NA	No objective effect on stability of individual fatty acids, lipid oxidation or textural properties	Iodine retention was 84–86% with KI and iodine concentration was 150 ppm
<i>Pickled vegetables</i>					
Pickled cucumber, turnip, carrot, cauliflower and olives	Amr and Jabay (2004b)	KI and KIO ₃	40 ppm	No objective effect on sensory properties with KI. KIO ₃ had no effect on taste but darkening and softening of the pickles. No effect on vitamin C or A content for either KI or KIO ₃	50% of brine iodine content
Sauerkraut	Doman et al. (1999)	KI	6 ppm	No objective effect on quality after 90 days' storage and no effect on lactic acid production or microflora composition	NA
Sauerkraut	Kojima and Brown (1955)	KI and KIO ₃	120 ppm	No objective effect on taste, color, texture, or odor after 32 days' fermentation and 2 days' storage	NA
Sauerkraut	El Wakeil (1958)	KI	112 ppm	No objective effect on flavor, color, texture or ascorbic acid content after 12 months' storage	1.9 ppm iodine
Vegetable pickles and cucumber pickles	Badran et al. (1996)	KI	40–60 ppm	No objective effect on taste, texture, color or acceptability	NA
Sichuan pickles—summary only	CNSIC (2004a)	NA	52 ppm 56 ppm 10.5 ppm	No objective effect on taste, texture, fragrance, color or quality after 3 months' storage	NA
Potherb Mustard	CNSIC (2004c)	NA	40.9 ppm	No objective effect on fragrance, texture or taste. Mustard prepared with iodized salt was darker than non-iodized salt	50% retention after 3 months' storage
Cucumber, green tomatoes, marinated sweet peppers	Mencinicopschi et al. (2004)	KIO ₃	37 and 56 ppm	No objective effect on color, texture, taste or smell of any products with exception of slight change in taste of cucumber. No effect on vitamin C or lactic acid	NA
<i>Canned foods</i>					
Tomato juice	Kojima and Brown (1955)	KI and KIO ₃	120 ppm (0.012% KI in salt) and 1200 ppm	No objective effect on taste, color, odor, or quality with either concentration of KI or KIO ₃ after 3 months of storage	0.5 ppm retained in tomato juice when 120 ppm concentration added
Tomato juice	El Wakeil (1958)	KI	112 ppm	No objective effect on flavor, color, texture or ascorbic acid content after 12 months' storage	0.7 ppm iodine

Table 1 continued

Food	Citation	Fortificant	Concentration of iodine in iodized salt	Organoleptic changes	Concentration in processed food
Green beans	Kojima and Brown (1955)	KI and KIO ₃	120 ppm (0.012% KI in salt)	No objective effect on flavor, color, texture or odor and effect on ascorbic acid content after 3 months of storage	NA
Green beans	Amr and Jabay (2004a)	KI and KIO ₃	40 ppm	No objective effect on color or taste after 2 weeks of storage	No retention of iodine
Olives	Kojima and Brown (1955)	KI and KIO ₃	120 ppm (0.012% KI in salt)	No objective effect on color or quality after 2 months of storage	NA
Sweet corn	El Wakeil (1958)	KI	112 ppm	No objective effect on flavor, color, texture or ascorbic acid content after 12 months' storage	0.4 ppm iodine
Sweet corn	Kojima and Brown (1955)	KI and KIO ₃	120 ppm (0.012% KI in salt)	No objective effect on flavor or color after 3 months of storage	NA

^aNo fortificant was specified, however KIO₃ is the mandated fortificant for iodized salt in Indonesia

Results

Table 1 provides a summary of each trial included in the review, including recorded effects on organoleptic and technological characteristics and retention of iodine after processing and storage.

Condiments

The use of iodized salt in various condiments has been examined in 4 studies. Harrison and Cunningham (1986) found no effect on the viscosity, color or spread of mayonnaise that was prepared with iodized salt; unfortunately, the author did not report the fortificant or concentration of the iodine in the salt. Two studies on use of iodized salt in fish sauce and soy sauce (CNSIC 2004a, b, c; Chanthilath et al. 2009) found no significant differences in sauces made with iodized and non-iodized salt. In both, general acceptability was slightly higher for sauce made with iodized salt. Colour of fish sauce made with KIO₃ iodized salt was lighter than with non-iodized salt and the colour and lustre of soy sauce made with iodized salt was measured to be the same. KIO₃ iodized salt at 30 ppm was used for fish sauce but the level and compound of iodine in the soy sauce was not specified. Chanthilath et al. (2009) also tested fermented fish made with KIO₃ iodized salt and non-iodized salt. Panellists in Thailand and Laos found both products to be similar, with slightly higher scores overall for general appearance and odor of raw fermented fish and general appearance and overall acceptability of food products made with fermented fish.

Retention of iodine in fish sauce and fermented fish was high (84–92% at the end of production), but was significantly lower in fish sauce made in sunlight (44% retention) compared to that made in the shade. Retention of iodine in soy sauce was 60% after production and 58% after 3 months of storage.

The use of iodized salt in margarine and flavoring cubes such as bouillon were examined in two published articles (Harris et al. 2003; Spohrer et al. 2013). Harris et al. (2003) discovered that a major producer of margarine in South Africa inadvertently used iodized salt in production with no changes in quality of the product detected after national distribution. Spohrer et al. (2013) found a high usage of iodized salt in flavoring cubes or bouillon, which are mainly comprised of salt. Major manufacturers, such as Nestle, use iodized salt in the production of flavoring cubes with global distribution. There have been no reported effects on organoleptic properties or technological characteristic of prepared foods after the addition of flavoring cubes containing iodized salt.

Cheese and dairy products

Iodized salt (KI and KIO₃) was found to have no effect on the organoleptic properties and technological characteristics of hard and soft cheeses and dairy products as measured in 3 studies and summarized in West and Merx (1995). The retention of iodine in produced cheese was found to be high, with iodized salt complementing existing iodine levels of milk used to make the cheese (Zimmermann et al. 2005). While not examined in a trial, the addition of iodized salt in the production of white cheese,

cream cheese and yogurt has caused no effect on the quality of the products in Bulgaria, where legislation is in place for the mandatory use of iodized salt in all food grade salt including that used in processed foods (UNICEF 2005). Cheese and dairy products produced with iodized salt in Bulgaria have national and international distribution.

Breakfast cereals and baked goods

The effect of iodized salt on the production of cereals and baked goods was examined in 2 studies. Thomson (2009) found no effect of KIO_3 iodized salt at 25–65 ppm used in the preparation of Weetabix and muesli cereals or in sweet biscuits with 100% retention of iodine after processing. Sevenants and Sanders (1984) observed the development of a bitter taste in a lemon cake mix with a lemon-flavoring agent, cresol. It was eventually determined that the off-flavor developed because of an interaction between iodized salt and the cresol. The iodine compound used in the iodized salt was not recorded.

Bread

The use of iodized salt in bread production is a well-known public health intervention to improve iodine intakes and has been implemented in Europe since the 1940s. Bread is a staple food throughout the world and bread made with iodized salt is the leading source of dietary iodine in Australia, Belarus, Denmark, New Zealand and the Netherlands. In Belarus, bread provides 40–70% of daily iodine requirement of the general population while, in the Netherlands, bread is attributed with providing 50% of iodine intake (Gerasimov 2009). Today all salt used in bread making must be iodized in Australia, Austria, Denmark, Lithuania, New Zealand, and Romania (GFDx 2018).

Organoleptic impacts of mandatory and voluntary use of iodized salt in commercial bread production have been reviewed in Australia, Belarus, Belgium, Bulgaria, Denmark, the Netherlands, New Zealand, and South Africa (Gerasimov 2009; UNICEF 2005; Harris et al. 2003; Charlton et al. 2013; Gerasimov et al. 1997; Li et al. 2014; Wiersinga et al. 2001; Vandevijvere 2012; Vandevijvere et al. 2012; Edmonds and Ryan 2012; Seal et al. 2007; Skeaff and Lonsdale-Cooper 2013; Rasmussen et al. 2007). In these countries, the concentration of iodine in iodized salt ranges from 13 to 85 ppm. There have been no reported adverse effects on the quality of bread produced in any of the countries where iodized salt is mandated for use. Neither organoleptic properties nor changes to the technological characteristics of bread production have been affected by use of iodized salt. The lack of effect of iodized salt, regardless of iodine compound, on organoleptic

properties or bread is exemplified by the unintentional use of iodized salt in bread production in South Africa. It was noted that a major bread producer inadvertently used iodized salt in bread production with no reported effects on quality after nation-wide distribution (Harris et al. 2003).

The retention of iodine in bread after production and storage was examined in 4 studies with 70–100% retention of iodine in white and whole grain bread and 38–46% retention in flat bread. There were minimal differences in retention between KI and KIO_3 iodized salt. The authors attributed the lower retention in flat bread to the larger surface area and exposure to high heat during baking (Amr and Jabay 2004a, b). Iodized salt had no effects of the sensory qualities of bread in the studies even when high levels of iodine in iodized salt were used (Winger et al. 2005).

Other starches

Food manufacturers frequently state concerns that iodized salt will lead to discoloration of starchy foods due to the use of starch in iodized salt testing kits where a color change is evident after interaction with iodized salt. To address this concern, 3 studies examined the effect of salt iodized with KI and KIO_3 , on the sensory characteristics of potatoes and rice. West and Merx 1995 used an extremely high concentration of iodine in iodized salt (400 ppm) in the preparation of boiled rice and boiled potatoes. There were no effects on the flavor or appearance of either potatoes or rice and there were no color differences in products prepared with iodized salt (KI and KIO_3) or non-iodized salt. (West and Merx 1995) The use of iodized salt (KI and KIO_3) at concentrations more in line with levels in national salt iodization programs (40–77 ppm) had no effect on the color, taste or overall quality of French fries, boiled potatoes or potato chips in two further studies (Amr and Jabay 2004a, b; Kuhajek and Fiedelman 1973). Retention of KI iodized salt was higher (67%) in potato chips than KIO_3 iodized salt (48%) after 13 weeks of storage (Kuhajek and Fiedelman 1973).

Meat products

The effects of iodized salt on the organoleptic properties and technological characteristics of processed meat products were examined in 6 studies. There was no effect of iodized salt on the organoleptic properties of sausages, salami, hotdogs, or cured ham/meat regardless of the iodine compound used (Kuhajek and Fiedelman 1973; Wirth and Kuehne 1991; Capanzana et al. 2006; Azanza et al. 1998). However, the addition of KIO_3 iodized salt affected the color, but not the taste, of mortadella, a high fat sausage (Amr and Jabay 2004a, b) and Capanzana et al. 2006

reported an improvement in the color of cured meat made with KIO₃ iodized salt. There were no specifics provided in either trial on the type of color changes in the meat products, with both studies stating that the use of KIO₃ iodized salt had no effect on the taste of the final product (Amr and Jabay 2004a, b; Capanzana et al. 2006). Amr and Jabay (2004a, b) attributed the color change in mortadella to impurities in the salt. Retention of iodine in all meat products was high (65–96%), including after storage, with the exception of Amr and Jabay's study on mortadella in which only 22–23 and 51–63% of iodine was retained in mortadella made with KIO₃ and KI iodized salt respectively (Amr and Jabay 2004a, b).

Fish products

The effects of iodized salt (KIO₃) on dried, salted, and smoked fish products and fermented shrimp and anchovies were examined in Capanzana et al. (2006) and Azanaz et al. (1998). KIO₃ iodized salt had no effect on the organoleptic properties or physical characteristics of any of the products. Retention of iodine in dried and fermented products was high with a range of 67–97% retention, however fish that underwent multiple processing steps of drying, salting, smoking and boiling had low retention of iodine with only 7% remaining after preparation (Azanza et al. 1998).

The effects of iodized salt (KI) on freshwater fish emulsion sausages was examined in Panpipate and Yong-sawatdigul (2008).

KI iodized salt had no effect on the stability of individual fatty acids in the sausages after cooking and storage with no lipid oxidation observed in the iodized product. There were no reported textural changes in the KI iodized fish sausages and retention of iodine in cooked emulsion sausages was 84–86% with constant iodine content after 4 weeks of storage.

Pickled vegetables

The effect of KI or KIO₃ iodized salt on the organoleptic properties and nutritional quality of pickled vegetables was studied in 8 studies. The addition of KI or KIO₃ iodized salt at concentrations ranging from 6 to 120 ppm caused no effect on the organoleptic properties or nutrition quality of pickled cucumbers, turnips, carrots, cauliflower, olives, sauerkraut, Sichuan pickles, potherb mustard, green tomatoes or sweet peppers (Amr and Jabay 2004a, b; Doman et al. 1999; Kojima and Brown 1955; El Wakeil 1958; Badran et al. 1996; CNSIC 2004a, b, c; Mencinopschi 2004) with the following exceptions:

- Pickled cucumbers, turnips, carrots, cauliflower and olives prepared with KIO₃ iodized salt were darker and softer than pickles prepared with either KI iodized salt or non-iodized salt (Amr and Jabay 2004a, b).
- Pickled cucumbers prepared with KIO₃ iodized salt had a slightly different taste compared with non-iodized salt (Mencinopschi et al. 2004).
- Potherb mustard, a green leafy vegetable, was darker when prepared with iodized salt compared to non-iodized salt, however there was no difference in acceptability between products among consumers (CNSIC 2004a, b, c).

Badran et al. found no effects on the color, texture and taste of “vegetable and cucumber pickles” (Badran et al. 1996) and Mencinopschi et al. found no effect on the color, texture or taste of “cucumber, green tomatoes and sweet pepper pickles” with the exception noted above of a slightly different taste of cucumbers (Mencinopschi et al. 2004). It is notable that KIO₃ iodized salt is used in the production of cucumber pickles at a national scale in Bulgaria (UNICEF 2005).

Use of iodized salt did not have an impact on the vitamin C and vitamin A content of pickles (Mencinopschi et al. 2004). Retention data was limited but a study did note that the iodine retained in sauerkraut was low (El Wakeil 1958) and about 50% of the iodine was retained in other pickled vegetables (Amr and Jabay 2004a, b; CNSIC 2004a, b, c).

Canned foods

The use of iodized salt, even with iodine concentrations 30× higher than levels in iodized salt, had no effect on organoleptic properties of canned foods such as tomato juice, green beans, olives and sweet corn. Neither KI nor KIO₃ iodized salt affected organoleptic properties or nutrition quality of the canned foods after production or storage. While Kojima and Brown (1955) and El Wakeil (1958) found acceptable retention of iodine (KI and KIO₃) after processing and storage, Amr and Jabay (2004a, b) found no retention of iodine in canned green beans prepared with KI or KIO₃ iodized salt (40 ppm). It was hypothesized that the high heat used in the canning process might result in the loss of iodine.

Discussion

These studies demonstrate that the use of iodized salt in the manufacturing of processed foods has no or limited effects on the organoleptic properties of a wide range of processed foods and therefore should not be a barrier to legislation,

policy and practice of salt iodization programs. Only minor changes in the organoleptic properties of processed foods, attributed to the addition of iodized salt, were observed in 6 studies: bitter taste in a lemon-flavored cake mix (Sevenants and Sanders 1984); improvement in color of cured meat products (Capanzana et al. 2006); change in color in mortadella (Amr and Jabay 2004a, b); darkening and softening of vegetable pickles (Amr and Jabay 2004a, b) darkening of potherb mustard pickle (CNSIC 2004a, b, c) and slight change in taste of cucumber pickles (Mencinopolschi et al. 2004). These changes were not replicated by other studies and were all found to be acceptable.

Salt iodized with KIO_3 was found to cause greater organoleptic changes than salt iodized with KI in vegetable pickles and mortadella as reported by Amr and Jabay 2004a, b. Other studies on bread, other starches, meat products, sauerkraut and canned foods found no differences between salt iodized with the two compounds. However, many studies did not compare the impact of KI and KIO_3 iodized salt; most studies were done with KIO_3 iodized salt only, as this is the most commonly used iodine compound for salt iodization (GFDx 2018).

The studies reviewed tested impacts of iodized salt on a wide variety of foods. It is recognised that the majority of countries in the world have mandatory iodization of all edible salt, including salt use in food processing. Although this component of the legislation is often not actively enforced, stakeholders and industry representatives report the use of iodized salt by a large number of food processors, producing a wide range of processed foods, sometimes unknowingly. (Knowles et al. 2017) At least two countries—Brazil and the Philippines—include ‘exemption clauses’ in their legislation that will allow specific food producers or processed foods to be exempt if negative impacts are proven but no exemptions have been requested. Overall, these studies, and global experience to date, indicate that use of iodized salt does not cause negative organoleptic changes that will affect consumer acceptability.

The addition of iodized salt with up to 85 ppm iodine was found to have no effect on the sensory characteristics of processed foods. High levels of iodine, 120 and 400 ppm, were also found to have no effect on the organoleptic properties of processed foods in 2 studies. The findings from the studies included in this review indicate that the concentration of iodine in iodized salt is highly unlikely to cause any effect on the organoleptic properties or technological characteristics of processed foods.

The use of iodized salt in the production of processed foods greatly increases the iodine content of most foods. Retention of iodine in the processed foods studied varied from zero (canned green beans) to 100% (sweet biscuits and breakfast cereal) but was high (> 60%) in a large variety of foods including fermented fish, fish sauce made

in the shade, some bread, processed meats and fish and some pickles. It is noteworthy that the studies which found the lowest retention (canned foods) are over 50 years old, and it is possible that improvements in processing could lead to higher retention. Having said that, the steps undertaken in food processing, in particular exposure to heat and air, and removal of moisture, may cause losses of iodine but these appear to be moderate except in the most extreme conditions. Losses of iodine from highly processed foods should not be taken as a reason not to use iodized salt in the production of those foods as savings from exempting some foods will be lost in administration and monitoring of a program that allows use of iodized salt for some foods and non-iodized salt for others.

The use of iodized salt in the production of staple foods such as bread has been demonstrated to provide a significant source of iodine to the diet (AIHW 2016). Theoretical estimations of the contribution of iodized salt in processed foods have also demonstrated significant impact. Studies undertaken by the Global Alliance for Improved Nutrition in Egypt, Indonesia, the Philippines, the Russian Federation, and Ukraine calculated the potential iodine intake from iodised salt in selected food products according to the formula: quantity of salt per unit of food product $\times$ minimum regulated iodine level of salt at production $\times$ average daily per capita consumption of the product. The percent of adult recommended nutrient intake for iodine potentially provided by the average daily intake of bread and frequently consumed foods and condiments was from 10 to 80% at the individual product level (Knowles et al. 2017).

Through national legislation, the use of iodized salt in processed foods can reduce iodine deficiency and low iodine intake at the population level. Iodine status and the consumption of iodine from different sources, including iodized salt in processed foods, should be monitored in order to make necessary adjustments to iodization levels to ensure adequate iodine intake, and avoid excess iodine intake, throughout the population. Such monitoring will also enable iodization levels to be adjusted in line with changes in salt intake, in particular efforts to reduce salt levels in processed foods (WHO 2013). The use of iodized salt in processed foods has the advantage of flexibility, with the level of iodization able to be adjusted to meet the dietary needs of a population. For example, the Netherlands monitors levels of iodine deficiency and adjusts the iodization level of bread salt to best address dietary requirement (Wieringa et al. 2001).

Conclusion

Processed foods made with iodized salt are indistinguishable from those made with non-iodized salt. The use of processed foods for iodine delivery has shown demonstrable reduction of iodine deficiency and has been credited with the elimination of IDD in several countries. The use of iodized salt in processed foods is recommended as an excellent strategy to increase daily iodine nutrition without risk of affecting the organoleptic properties of foods.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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