4-2015

Knowledge of dietary iodine and iodine concentration in household iodized salt in rural and urban Jalisco, Mexico

Andrea Guajardo
College of Saint Benedict/Saint John's University

Recommended Citation

Guajardo, Andrea, "Knowledge of dietary iodine and iodine concentration in household iodized salt in rural and urban Jalisco, Mexico" (2015). *Honors Theses, 1963-2015*. 99.
https://digitalcommons.csbsju.edu/honors_theses/99

Knowledge of dietary iodine and iodine concentration in household iodized salt in rural and urban Jalisco, Mexico

An Honors Thesis

College of St. Benedict/St. John’s University

In Partial Fulfillment of the Requirements for Distinction in the Department of Nutrition

By

Andrea del Socorro Guajardo Villar

April 2015

PROJECT TITLE:

Knowledge of dietary iodine and iodine concentration in household iodized salt in rural and urban Jalisco, Mexico

Approved by:

Amy Olson, PhD, RD, LD

____
Title: Professor of Nutrition

Jayne Byrne, MS, RD, LD

____
Chair, Department of Nutrition

Emily Heying, PhD,

____
Title: Assistant Professor of Nutrition

Emily Esch, PhD,

____
Director, Honors Thesis Program

Table of Contents

Abstract……………………………………………………1
Abbreviations……………………………………………2
Introduction………………………………………………3
Background Information…………………………4-12
Methods……………………………………………13-14
Results………………………………………………15-20
Discussion…………………………………………21-27
Conclusion…………………………………………28-29
Appendices A-I……………………………………30-41
Acknowledgements…………………………………42
Bibliography………………………………………43-47

Index of Tables

Table 1. Median Urinary Iodine Concentrations (UIC) to assess iodine status in different target groups……appendix A

Table 2. Iodine Tolerable Upper Intake Levels (ULs)……7

Table 3. Selected Food Sources of Iodine……appendix B

Table 4 - WHO, UNICEF, and IGN iodine recommendations of salt in mg of iodine by kg of salt (ppm)……11

Table 5. Description of methods used in kit "Kit para la determinación de yodatos en sal" supplied by Boiteccsa Laboratorios in Sonora, Mexico……appendix C

Table 6 - KIO_3 and KI concentration, type, and brand of rural salt samples in Jalisco, Mexico……appendix D

Table 7 - KIO_3 and KI concentration, type, and brand of urban salt samples in Jalisco, Mexico……appendix E

Table 8 - KIO_3 and KI concentration, type and brand of newly purchased salt samples at retail level in Jalisco, Mexico……appendix F

Table 9 – KI concentration, type, and brand of CSB salt samples……appendix G

Table 10 - KI concentration, type, and brand of SJU salt samples……appendix H

Table 11 - KI concentration, type, and brand of newly purchased samples at local stores near CSB/SJU……appendix I

Table 12. Survey responses to statements regarding iodine knowledge……20

Table 13. Survey answers to questions regarding salt use……20

Index of Figures

Figure 1. Spraying method of salt iodization in a production plant in Sri Lanka…………………………………………………..10

Figure 2. Manual method of salt iodization in a salt production plant in Ndiemou………………………………………………..10

Figure 3. Salt type of salt samples in rural (n=50), urban (n=50), Jalisco, Mexico…………………………………………………..15

Figure 4. KIO3 concentration levels of rural (n=50), urban (n=50), and newly purchased retail samples (n=27) categorized as “zero”, “low”, “adequate” or “high”. Iodine concentration categories are consistent with WHO’s salt iodization recommendations……15

Figure 5. Average KIO3 concentration levels of rural (n=50), urban n=50), and newly retail samples (n=27). Data presented are means ± SD and includes the analyses of all salt samples, granular and refined of rural, urban, and newly retail samples (n=27)……16

Figure 6. Salt samples (n = 27) were analyzed for KIO3 concentration, and values compared to the label information. Salt samples were purchased from local stores at rural and urban locations; salt samples were varied (granulated or refined, from different brands, container size, or packaging)……………………………………………………………………………16

Figure 7. Salt type of 20 samples collected at the College of Saint Benedict (CSB) and 20 samples at Saint John’s University (SJU) in Minnesota, U.S. All sea salt was not iodized, and only some of the refined salt was iodized………17

Figure 8. KI concentration levels of CSB (n=20) and SJU (n=20), and newly purchased retail samples (n=2) categorized as zero, low, adequate or high. Iodine concentration categories are consistent with WHO’s salt iodization recommendations, to permit comparisons with data from Mexico………17

Figure 9. Salt labeling of 40 samples collected at the College of Saint Benedict (CSB) and Saint John’s University (SJU) in Minnesota, U.S………18

Figure 10. Potassium Iodide (KI mg/kg) concentration of samples collected (n=40) at the College of Saint Benedict (CSB) and Saint John’s University (SJU) in Minnesota, U.S. Samples labeled “Not Iodized” were not analyzed and, are not represented on this graph………18

Figure 11. Salt brands collected at the College of Saint Benedict (CSB) and Saint John’s University (SJU) in Minnesota, U.S (n=40). Starting at the 12:00 position is “No label”, and continues clockwise to “Stonemill Essentials”(5%)……18

Figure 12. Potassium Iodide (KI) concentration of rural (n=50), urban (n=50), and newly retail salt samples (n=27) in Jalisco, Mexico, and from the College of Saint Benedict (CSB) (n=20) and Saint John’s University (SJU) (n=20) in Minnesota, U.S. Lines running across the graph outline the recommended KI concentration levels (44.5 – 75.0 mg/kg) by the World Food Programme…………………………………………………………………………………………………19

Abstract

Mexico began the iodization of salt in 1960, which dramatically reduced the incidence of goiter, but in the last year the incidence of goiter tripled in the state of Jalisco, and nationally in Mexico (1,2,3). *PURPOSE*: Assess iodine knowledge of the people and concentration of iodine in salt samples in rural and urban localities of Jalisco, Mexico to explain the rise in goiter incidence. *METHODS*: IRB approval was granted for this cross-sectional study. A convenience sample of 50 individuals, men and women older than 18, were selected from a rural and urban locality of Jalisco. The 100 individuals that completed a survey answered questions about demographics, medical history, iodine knowledge, and iodine dietary sources. A total of 130 salt samples were collected for potassium iodate (KIO3) analysis, 50 from each locality, and 27 were newly purchased samples. KIO3 concentration was measured by a titration method, using a kit supplied by Boiteccsa Laboratorios in Sonora, Mexico. SPSS was used to conduct ANOVA, T-tests, and Coefficient Correlation statistical analyses. *RESULTS*: Surprisingly, 32% of the rural salt, 22% of urban, and 11% of fresh salt samples had no iodine. Only 24% of rural salt samples contained adequate levels (15-40 mg/kg) and only 38% of urban samples. Only 8% of newly purchased salt had the amount of iodine indicated on the label, 48% had less iodine, and 33% had excess potassium iodate (>40 mg/kg). Sadly, 88.1% of rural and 81.6% of urban residents did not know that pregnant women have higher iodine needs, and only 53% of rural and 56% of urban residents know that a lack of iodine can cause goiter. In addition, 78% of urban and 48% of rural residents used non-iodized sea salt. Education levels varied between rural and urban areas; however, education did not determine iodine knowledge (p value ≥ 0.5). *CONCLUSIONS*: Even though Mexico mandates the iodization of salt, most of the salt samples did not meet the recommended potassium iodate concentration. Increased consumption of non-iodized sea salt and great variation in KIO_3 concentrations in salt may explain the recent increase in goiter incidence. Iodizing sea salt might be an acceptable solution.

Abbreviations Page

ADD- Attention Deficit Disorders
CSB- College of Saint Benedict
FAO- Food and Agriculture Organization
FFQ- Food Frequency Questionnaire
GAIN- Global Alliance for Improved Nutrition
ID- Iodine Deficiency
IDD- Iodine Deficiency Disorder
IGN- Iodine Global Network
KIO_3- Potassium Iodate
KI- Potassium Iodide
MI- Micronutrient Initiative
NHANES- National Health and Nutrition Examination Survey
PMTDI - Provisional Maximum Tolerable Daily Intake
PPM- Parts Per Million
SJU- Saint John's University
T3- Triiodothyronine
T4- Thyroxine
TSH- Thyrotropin, Thyroid-Stimulating Hormone
UIC – Urinary Iodine Concentrations
UNICEF- the United Nations International Children's Emergency Fund
USI -Universal Salt Iodization
WFP- World Food Programme
WHO- World Health Organization

Introduction

Iodine is a necessary nutrient for thyroid hormone production (4, 377). Iodine is one of the four major nutritional deficiencies worldwide, and is the most common cause of preventable mental retardation and brain damage (5). Iodine Deficiency Disorders (IDD) describe the clinical and subclinical indicators of iodine deficiency (6, 135). IDD persist as a sustained public health concern in developed and underdeveloped nations (7, 205). Salt iodization, an efficient and low-cost IDD prevention approach, is widely accepted because salt is consumed by all ages every day (8, 3). Consistent amounts supply adequate iodine, but unlike other sources like sugar it is not consumed in extreme amounts. The annual cost for salt iodization is approximately U.S. $0.5 billion, compared to U.S. $35.7 billion in possible losses caused by IDD in underdeveloped countries; a cost: benefit ratio of 1:70 (4, 392). Mexico began regulating salt iodization in 1960 and successfully reduced the incidence of goiter, but in the last year the incidence of goiter tripled in the state of Jalisco, and nationally. Jalisco is mountainous region, and is particularly vulnerable to iodine deficiency since rain removes iodine, a water-soluble mineral, from soil in mountains to lower elevation areas (9, 691).

The World Health Organization (WHO), the United Nations International Children's Emergency Fund (UNICEF), the Iodine Global Network (IGN), the Micronutrient Initiative, and the Global Alliance for Improved Nutrition (GAIN) are agencies that collaborate since the 1990s with salt producers and countries to decrease iodine deficiency (10, 533). Universal Salt Iodization (USI) refers to the iodization of all the salt consumed by farm animals and humans, for home and industrial use (4, 392). The WHO, UNICEF and IGN agree that household iodized salt should contain 15-40 mg/kg of iodine, and report that USI and regular monitoring of iodine intake are the two key approaches to manage iodine deficiency (7, 205).

Unlike Mexico, the United States recommends voluntary iodization of salt. The U.S. Food and Drug Administration (USFDA) recommends Potassium Iodide (KI) and Copper Iodide (CuI) as forms of iodine, with a concentration of 60-100 KI mg/kg (46-76 mg/kg of iodine). Labeled iodine concentration in salt in the U.S.is 45 mg/kg (11, 1315). Mexico utilizes Potassium Iodate (KIO_3) recommended by the WHO, because it is more stable than KI (9). Mexico determines 20-40 mg/kg as adequate iodine concentration for human and animal use (12, 1368).

Goiter incidence in the state of Jalisco has tripled in the last year, and may be explained by the iodine concentration and type of salt consumed. The purpose of this study was to assess iodine knowledge of the people and the concentration of iodine in salt samples in rural and urban localities of Jalisco, Mexico to try to explain the rise in goiter incidence. An additional component to the study was added to compare the results of the salt analysis in Mexico to samples from Saint Joseph, Minnesota to determine the effect of mandatory and voluntary USI policies, and varying forms of iodine on salt iodine concentration. Northwestern states in the U.S. had a high prevalence of goiter before salt iodization was implemented, a region described as “the goiter belt”.(13, 1742). This study analyzed salt iodine concentrations in Saint Joseph, Minnesota, a “goiter belt” state, to assess salt iodine concentration adequacy in an area that was susceptible to IDD.

Background information

Iodine, a word derived from the Greek word “Ioeides” that means “violet-colored,” is a solid dark gray element that forms part of the halogen group in the periodic table (6, 136). The use of seaweed to reduce goiter was first recorded in Chinese medical writings circa 3600 B.C. (13, 1740), but iodine was not discovered until 1811 by French chemist Bernard Courtois (6, 136). The Swiss physician J.F. Coindet first published that iodine, in the form of grains in distilled alcohol, reduced goiter size. In 1896 Eugen Baumann discovered that iodine exists in the thyroid gland (13).

Iodine’s diatomic structure contains two atoms (I_2), but always exists as iodate (IO_3^-) in the environment. Iodine forms iodates when interacting with other elements; for example sodium iodate ($NaIO_3$). Iodine and sodium are very reactive elements, often reacting with each other (6, 136). Natural events such as flooding, leaching, and glaciation in the Ice Age caused unequal distribution of iodine in the soil, and highest iodine concentrations occur along the coasts (13, 1741).

Only 50% of dietary iodine is absorbed in the stomach and small intestines, of which 80% is lost in urine and 20% is utilized by the thyroid gland to produce hormones (6, 137). Iodate is reduced to iodide before being absorbed (14), and the thyroid gland reverses iodide back to iodine. The gastric and salivary glands secrete iodine back to the digestive system; however, this cycle fails if no iodine is ingested. About 10-15% of a pregnant women’s daily iodine intake is excreted through breast milk. The stomach, kidneys, salivary and thyroid glands, placenta, and breast tissue take up iodine from the blood and store it (6, 137).

Thryroid hormones triiodothyronine (T3) and thyroxine (T4) contain iodine; T3 contains 3 iodine molecules, and T4, four (6, 138). Thyroid hormones are responsible for cell maturation, production, and secretion of growth hormone from the pituitary gland, bone metabolism and growth, synaptic transmission, and myelination (6, 138). Myelination, the development of a myelin lipid bilayer around the axon during and after fetal growth, supports cognitive, emotional, and behavioral functions (15, 183-184). Iodine has a function in immune action, and a possible effect on mammary dysplasia and fibrocystic breast disease, a disorder in women of reproductive age that causes pain and lumps in the breasts with palpable fibrosis (14).

The pituitary gland secretes thyrotropin (TSH, Thyroid-Stimulating Hormone), which regulates the synthesis and secretion of T3 and T4 production, and iodine absorption by the thyroid. The underdeveloped thyroid gland of the fetus is dependent on the mother’s T4 supply, which increases by 50% during pregnancy (14). Pregnancy iodine requirements increase, as elevated glomerular filtration rates increase urine iodine excretion. TSH production in the fetus begins in weeks 14-16, but maternal TSH supplies continue to support fetal needs (10, 534). Thyroid hormone levels decrease to normal during lactation, but iodine needs stay high as iodine is released through breast milk to supply infant iodine needs (17, 3). Daily iodine intake under 100 µg decreases T3 and T4 release, and increases iodine absorption from the blood by the thyroid. Yet, even with high TSH levels, thyroid hormone synthesis decreases when iodine intake is extremely low. (14). Iodine uptake by the thyroid increases by 80-90% when iodine stores decline (6, 137). Constant elevated TSH levels result in goiter, or the expansion of the thyroid gland, a physiological adaptation to absorb more iodine for thyroid hormone production (14).

The WHO, UNICEF, IGN advocate for daily iodine intakes that vary based on age; 0-5 years of age (90 µg), 6-12 years of age (120µg), 12 years of age and over (150 µg) and pregnant women (250 µg) (6, 137). Adequate iodine intake in U.S. adults ranges from 138-353 µg per day (16, 4).

Iodine Status Testing

There are various ways to assess iodine status. Food Frequency Questionnaires (FFQ) measure the amount, type and regularity of consumed foods and supplements. However, calculating iodine intake is particularly difficult because food composition information for iodine is not always available (10, 533). Spot Urinary Iodine Concentrations (UIC) are also used as a maker for population iodine status. More than 10 spot UIC samples (18, 1958) or at least 3 24-hour urine collections for urinary iodine are better indicators in individuals (14). Low compliance to urine collection is an obstacle to 24-hour urine samples. Naturally elevated UIC levels in early pregnancy due to the hormonal effects on the kidney can be misinterpreted as adequate iodine status, therefore, recommended UIC levels should be adjusted for varying gestational stages (18, 1959). See Table 1 in appendix A to review UIC for determining iodine status in populations.

Dried urine strips are an innovative way to measure UIC. The strips are low in weight, small size, and remain stable for one month when stored in a plastic bag with desiccant at room temperature, making them easy to transport. The strips are easily tested and can be stored for further testing. The assay has a sensitivity of (15.0 µg L^{-1}), and can detect severely deficient or excessive iodine levels. A disadvantage is that several assays are needed to determine true individual median UIC levels; a minimum of 10 random urinary samples report individual iodine status with 20% accuracy, and 500 individual urinary samples determine a population's iodine intake with only 5% accuracy (19, 68).

TSH tests are an alternative method to assess iodine status. TSH in infants cannot be accurately measured until after 48 hours of life, to allow the high levels associated with birth to return to normal levels. The WHO states that <3% of infants in iodine sufficient populations should have >5 mIU/L (milli-international units per liter), an approach that both tests infants for hypothyroidism and provides insight on a population's iodine status. The TSH upper limit in pregnant women in the first trimester is 2.5 mIU/L, and during the second and third trimesters 3.0 mIU/L. (10, 534).

Iodine Deficiency

In 1991 the WHO described IDD as a public health problem, and together with UNICEF and IGN, hold meetings every three years to discuss worldwide iodine status (6, 140). Iodine levels can decrease due to one or a combination of dietary, biological, and environmental factors. Dietary factors contributing to iodine deficiency include deficient iodine intake and constant use of antithyroid drugs (eg. Methimazole) (14). Decreased dietary intake of fish and seafood rich in iodine, and discontinued use of iodine-rich cleaning agents in milk production contribute to decreased iodine intake (20, 26). Iodine absorption is reduced when combined with certain compounds, goitrogens. Goitrogens include thiocyanate and perchlorate. Thiocyanate is a compound that inhibits iodide transport and incorporation into thyroglobulin to produce thyroid hormone. Thiocyanate is present in some vegetables and smoking tobacco (11, 1316). Soy, cassava, cabbage, broccoli, cauliflower, and other cruciferous vegetables are rich in goitrogens (14). Perchlorate is a potent goitrogen, having an affinity for the human sodium-iodide symporter (NIS) 30 times higher than iodide. NIS is the membrane protein that allows iodide transfer into the thyroid gland and breast milk. Perchlorate is present in many foods and beverages, including human and cow milk (11, 1316). Goitrogens aggravate the risk of IDD even if iodine intake is adequate, but pose even a greater danger to iodine deficient populations.

Biological factors contributing to iodine deficiency include inadequate intestinal absorption, increased renal excretion, and increased thyroid hormone or iodine needs (6, 138). A newborn's thyroid holds only a 24-hour iodine supply of 300 µg (10, 534); hence continuous iodine supplies must be provided after birth (11, 1316). Thyroid hormone requirements per kilogram are highest during infancy compared to other life periods, a time when thyroid hormones are crucial for continuing neurodevelopment (10, 534). Therefore, infants are more prone to iodine deficiency than adults (6, 140) Environmental factors include low iodine levels in the soil where food is grown (20, 26), and the geographical characteristics of the region. River valleys that flood easily and mountain areas are regions with some of the highest iodine deficiency incidence (14).

Iodine deficiency causes growth retardation, intellectual deficiencies, cretinism, goiter, hypothyroidism in newborns, miscarriage, and infant mortality (21, 523) and infertility (6, 139). Cretinism results in stunted growth, hindered sexual maturation, motor spasticity, deaf muteness, and mental retardation (14). Iodine deficiency is also linked to attention deficit disorders (ADD), which are diagnosed in approximately 3–5% of all children (approximately two million) in the U.S. (11, 1316). Goiter is typically the first physical sign of iodine deficiency. Hypothyroidism is usually present if daily iodine intake is lower than 10-20 µg, and is related to reduced work productivity. Iodine deficiency causes a higher uptake of radioactive iodine, which is released to the environment as result of nuclear incidents. Radioactive iodine increases the risk of thyroid cancer, making iodine deficient individuals susceptible to thyroid cancer. Chronic deficiency is related higher risk of follicular thyroid cancer in adults (14).

Moderate or severe iodine deficiency can result in a deficit of 12-13.5 IQ points (14). Even mild iodine deficiency can have long lasting cognitive impacts. Children of mothers with UIC <150 µg/L had lower scores (by 10% in spelling, 7.6% in grammar, and 5.7% in English) than children whose mothers had UIC ≥150 µg/L. Scores were adjusted for socioeconomic (mother's education and occupation) and biological factors (gestational age, birth weight, sex, maternal age and gestational age) at the time urinary collection (18, 1954). Cognitive function in children may improve if iodine deficient levels are restored to adequate levels. The median UIC of children of ages 10-13 (63µg/L) improved considerably (145µg/L) after receiving a daily iodine supplement of 150µg/day for 28 weeks, and resulted in higher perceptual reasoning and cognitive scores than the placebo group.

Iodine deficiency is present in 36% of women of reproductive age in North America (6, 135). About 26%-70% of children in the “goiter belt”, Northwestern areas of the U.S. including the Great Lakes and Appalachians, had goiter before the introduction of salt iodization to the U.S. (13, 1742). Jalisco was the state with the second highest number of cases in March 2013 (18 of 137 national cases), highest in September 2013 (47 of 376 national cases), and again second highest in June 2014 (62 of 624 national cases) (1,2,3). Goiter incidence in Jalisco more tripled from March 2013 to June 2014. While Cretinism, dwarfism, and *incapacitating* goiters burden only a small number of individuals, usually in communities set in mountains, mild goiter is still present in 16% of the world (22). Goiter without extreme physical symptoms is present in a substantial portion of the world, demonstrating iodine insufficiency continues to burden populations.

Iodine Supplementation

Iodine supplementation can have adverse effects when high iodine doses are introduced in a population that has been iodine deficient. Abrupt increases of median UIC of more than 200 µg/L in adults can result in hyperthyroidism (17, 3). Iodine intake from foods and supplements are usually not a source of iodine excess, but iodine intakes higher than the recommended ULs can have negative effects. Individuals receiving any medical treatments containing iodine should limit their iodine intake following a physician’s recommendation (14).

Side effects of excess iodine vary significantly. Iodine excess decreases thyroid hormone production, resulting in effects similar to iodine deficiency (hypothyroidism, goiter, and elevated TSH levels) (14). Hyperthyroidism is the main side effect of iodine excess (17, 3). Thyroiditis and papillary thyroid cancer are also associated with iodine excess. Fever, low pulse, nausea, vomiting, diarrhea, abdominal pain, burning sensation in the mouth, throat and stomach, and coma are symptoms of severe poisoning. Severe iodine poisoning is not common and is usually a result of gram doses (14), so concerns over overconsumption should not impair adequate iodine consumption. Iodine deficient individuals with autoimmune thyroid disease may have unfavorable side effects with iodine intake recommendations safe for the general population (14). Excessive daily iodine intakes result in UIC levels higher than 300 µg/L, and may cause autoimmune thyroid diseases and hyperthyroidism (17, 3). See Table 2 for UL levels.

Table 2. Iodine Tolerable Upper Intake Levels (ULs)

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	Not possible to establish*	Not possible to establish*		
7-12 months	Not possible to establish*	Not possible to establish*		
1-3 years	200 mcg	200 mcg		
4-8 years	300 mcg	300 mcg		
9-13 years	600 mcg	600 mcg		
14-18 years	900 mcg	900 mcg	900 mcg	900 mcg
19 + years	1,100 mcg	1,100 mcg	1,100 mcg	1,100 mcg
*Formula and food should be the only sources of iodine for infants.				

Source: NIH (National Institutes of Health). Office of Dietary Supplements. Iodine – Fact Sheet for Health Professionals. http://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/

Sources of Iodine

Iodine is present in water, air, but mainly in soil, which contains approximately 50-500 µg/kg (6, 137). Iodine concentration can be as little as 10 µg/kg (dry weight) in plants from iodine deficient soils, or as much as 1,000 µg/kg in plants from iodine rich soils. The average iodine content in food as eaten varies from 3-15 µg/kg (13, 1741). Different fertilizers and irrigation methods also affect food iodine content. Iodine content of stock feed affects iodine levels in animal products, such as meat. Seaweed is a major source of iodine, but levels differ greatly depending on plant species. Seafood is also a good source. Milk and grains are the main source of iodine in the U.S. (14). See Table 3 in appendix for iodine content of some foods.

Iodine content of breast milk depends on maternal iodine levels (14), and ranges from 29 to 490 µg/mL (23, 354). Iodine concentration in breast milk of women with adequate iodine levels ranges from 100-150 g/dl (24, 803). The average iodine concentration of breast milk from 57 women in Boston was 155 µg/L, but 47% had insufficient iodine levels based on infant needs and usual breast milk intake (14). Mineral and multivitamin supplements are another source of iodine in the forms of KI or NaI. Kelp seaweed supplements are also available. NHANES (National Health and Nutrition Examination Survey) data from 1999-2004 reported that 29% of adults consumed supplements that contain iodine. Some iodine supplements may have adverse interactions with certain medication, including anti-thyroid medications (may cause hypothyroidism), ACE inhibitors and potassium-sparing diuretics (may cause hyperkalemia) (14).

Iodide (KI) and Iodate (KIO3) are forms of iodine added to salt. Bread, sugar, drinking water, oil, and salt are some of the mediums used for iodine supplementation. Salt is the favored mean of supplementation; salt is fairly inexpensive, and is consumed around the globe. Consistent amounts supply adequate iodine, but unlike other sources like sugar it is not consumed in extreme amounts. Also, iodine does not alter the smell, color or taste of salt; iodization methods can be very simple and don't require complex technology; and as a single method of iodization eases monitoring and implementation of iodine supplementation (6, 138). Surprisingly, 30% of households worldwide do not have access to iodized salt (25). Efforts to decrease risk of stroke and heart disease recommend decreasing daily salt intake to less than 5 grams (12, 1370), which may further decrease iodine intake as iodized salt is a major source of iodine. Salt iodization levels of 20-40 mg/kg are based on a 10 grams daily salt intake (26, 4), and should be re-examined if a country's general salt intake is lower than 10 grams because iodine intake would decrease below desired levels.

Salt iodization is not mandatory in the U.S. The FDA (Food and Drug Administration) favors KI and CuI (Copper Iodide) as forms of iodine supplementation with dextrose and $Na_2S_2O_3 \cdot 5H_2O$ as iodide stabilizers, and $NaHCO_3$, Na_2CO_3, and $Ca_3(PO_4)^2$ as buffering agents to minimize iodine loss. The WHO recommends KIO_3, as a more stable form of iodine. Iodine labeled concentration in U.S salt is 45 µg of per gram of salt. The FDA calls for 60-100 mg KI/kg of salt (46-76 mg iodine /kg salt iodine) in iodized salt (11, 1315), and iodine labeling only for iodine-fortified foods (14). Salt iodization is mandatory in Mexico and the Mexican official norm currently determines 30 parts per million (ppm) (or mg/kg) as an adequate iodization level of salt for human or animal consumption (9, 695).

Kelp (*Laminaria japonica* Aresch) is a sea species that grows copiously and collects iodine, and can serve as an additional iodine source for the soil. Ground dry kelp mixed with diatomite produces an algal iodine fertilizer that is an excellent source of iodine for the soil, and ultimately plants. Iodine from plant or animal sources is more bioavailable than the iodine as KI or KIO_3 in salt. Algal iodine fertilizer is easy to store and transport and can also improve the physical and chemical properties of soil. The production of iodine rich foods is environmentally friendly and sustainable. Iodine-rich soil can supplement dietary iodine intake, and aid in the elimination of IDD (27, 816-817).

Salt Iodine Concentration

The increased prevalence of goiter in areas where naturally iodized salt was not regularly consumed was noted in the 1830's by French chemist Jean Baptiste Boussingault, and suggested general salt iodization. The cost of salt iodization and concerns of causing hyperthyroidism prevented the implementation of iodine supplementation. In the 1920's, almost one hundred years later, Switzerland and the U.S. pioneered iodine supplementation mainly by salt iodization. Iodized salt, with a concentration of 100 mg iodine/kg salt, resulting in a daily iodine intake of 500 µg, was available in Michigan in 1924. The U.S. Endemic Goiter Committee urged for mandatory introduction of iodized salt in all states, but the bill was denied in 1948. Since the 1950's 70-76% of American households use only iodized salt, however data of the use of iodized salt is insufficient. Iodized salt in the U.S. should contain 45 mg iodide/kg of salt, but in 2008, 47 of 88 tested salt brands had lower concentrations than the recommended range by the FDA (46-76 mg iodine/kg of salt) (13, 1742-3).

Iodine, represented by I_2, identifies the element without specifying its chemical form. Generally, the word "iodized" or "iodised" refers to the supplementation of any form of iodine. Iodine is usually in the form of iodate or iodide of potassium, sodium, or calcium. Potassium iodide (KI) and potassium iodate (KIO_3) are common forms of iodine used for table salt iodization. A material is "iodated" when it is supplemented with KIO_3, and "iodinated" when I_2 is added (29).

KI is very soluble and readily disperses on dry crystals but is not stable and easily oxidizes to iodine in the presence of: sunlight, moisture, humidity, air, heat, contaminants, or an acid variable, all increasing its loss through volatilization. Evaporation through damp and porous packages also increases KI loss through flux or evaporation. KI purity (+ 99.5%), dryness (moisture levels ≤0.1%), and addition of stabilizers (sodium thiosulfate and calcium hydroxide) or drying agents (magnesium carbonate and calcium carbonate) reduce loss. KI has higher iodine content than KIO_3 and is less expensive, but easily volatilizes in impure salt (29).

KIO_3 is produced by the reaction of iodine with potassium hydroxide (KOH): $3I_2 + 6KOH =3D\ KIO_3 + 5KI + 3H_2O$. The form of iodine used for IDD programs, KIO_3, is successfully added to salt without other carriers or stabilizers. About 1 kg of iodine produces 1.55 kg of KIO_3. KIO_3 is easily absorbed and rapidly delivered as iodide for thyroid hormones. Iodate is more stable in varying environments, soluble only in low-temperature water. Iodate solutions with concentrations of 40 g/L (about 4%) are easily accessible, and are adequate for the addition of 100 mg KIO_3, /kg of salt levels. Compared to KI, no unfavorable effects appear with additional moisture (0.1%) to salt with existing moisture levels (1-5%). The FAO (Food and Agriculture Organization)/WHO Expert Committee on Food Additives accepts and promotes KIO_3 safe use within the PMTDI (Provisional Maximum Tolerable Daily Intake) of 1 mg of iodine; the current highest recommendation falls under 20% of iodine's PMTDI (29).

Japan and Chile are the main producers and exporters of iodine (29). The cost of KI (99% pure) is $223/kg, and KIO_3 (98% pure) is $338/kg (30). The instability of KI in impure salt may increase the true cost of adding adequate iodine concentration levels to salt. Calcium iodate ($Ca(IO_3)_2$) is a stable alternative, but does not dissolve easily water and is therefore seldom used (29). The World Food Programme (WFP) recommends salt iodization with NaI (Sodium Iodide) or at 44.5 – 75.0 KI mg/kg of salt, and 50.0 – 84.0 mg KIO_3/kg of salt (31, 2). Salt production plants with better technology spray KIO_3 or KI as salt travels through a conveyor belt prior to packing. In smaller plants with lower technology, dry iodine is manually mixed and added to salt (25), see Figures 1 and 2.

Figure 1. Spraying method of salt iodization in a production plant in Sri Lanka

Source: Micronutrient Initiative
https://www.flickr.com/photos/micronutrient_initiative/4656581586/

Figure 2. Manual method of salt iodization in a salt production plant in Ndiemou.

Source: The World Food Programme. Media.
https://www.wfp.org/node/3576/4029/32507

Salt iodization recommendations should specifically indicate whether iodine levels are KIO_3 or KI, or iodine. The recommended chemical form to express salt iodization is iodine for easy comparison. Precise conversion between varying iodine forms is crucial to maintain accuracy. For instance, 40 ppm of iodine equals 67 ppm of KIO_3 or 52 ppm of KI. Iodine deficiency incidence, salt consumption trends, shelf life, and rate of iodine loss from production to consumption are some of the factors that influence the recommended salt iodine concentration in a region (29). Warm and moist climates call for increased recommendations of iodine. See Table 4 for salt iodization recommendations by the WHO, UNICEF and IGN.

Table 4 - WHO, UNICEF, and IGN iodine recommendations of salt in mg of iodine by kg of salt (ppm).

Climate and daily consumption (g/person)	Required at factory outside the country	Required at factory inside the country	Required at retail sale (shop/market)	Required at household level
	Bulk/Retail (<2 kg	Bulk/Retail (<2 kg)	Bulk/Retail (<2 kg)	
Warm, moist				
5 g	100/80	90/70	80/60	50
10 g	50/40	45/35	40/30	25
Warm, dry or cool, moist				
5 g	90/70	80/60	70/50	45
10 g	45/35	40/30	35/25	22.5
Cool, dry				
5 g	80/60	70/50	60/45	40
10 g	40/30	35/25	30/22.5	20

Source: IGN (Iodine Global Network). Iodate or iodide? http://www.ign.org/p142000383.html

Worldwide daily salt consumption levels vary from 3 to 20 grams. Salt iodization levels worldwide vary from 100 ppm of iodine (170 grams KIO_3 /ton salt) in regions with poor salt quality and packaging conditions, and low intakes, to 20 ppm of iodine (170 grams KIO_3 /ton salt) in regions with good salt quality and packaging conditions and high intakes. Almost all countries have iodine concentration recommendations close to 50 ppm (85 ppm of KIO_3) (29). Means of salt iodine concentration in a study in Tehran all salt in household samples varied based on geographic region; South: 3 ppm, West: 22pm, East: 8 ppm and North: 32 ppm (32, 416). Salt iodine concentration varies among countries, and also within different country regions due to changing demographic and environmental factors (humidity, warmer temperatures, mountainous regions) that increase iodine loss in salt.

In Mexico, salt used for direct human consumption in the food industry or for animal consumption must be iodized by law (33). The norm NOM-040-SSA1-1993 establishes sanitary specifications for iodized and iodized-fluoridated salt for human use, and for iodized salt for animal use. Iodine concentration in salt for human and animal use must be 30±10 mg/kg (34). Norm NOM-040-SSA1-1993 was modified in 2003 to specify that salt for human use can only be exempt from mandatory iodization when there is proof iodine changes the quality of the product. This norm states that all packaging for iodized salt should include two yellow stripes (1 cm each) in the top or bottom part of the label or container, and state “iodized salt” or “iodized and fluoridated salt” (35). Salt may also fluoridated in Mexico as a measure to prevent cavities. The recommended concentration is between 200-250 mg flouride/kg of salt, with the exception of states with water that supplies fluoride levels higher than 0.7 ppm, where only iodized salt should be distributed (36). In Jalisco, both iodized salt and iodized and fluoridated salt are distributed (35).

In the U.S. David Marine is considered the “father” of salt iodization. Marine conducted research on goiter and iodine deficiency, and based on his results launched a program to prevent goiter that used iodized salt in 1924. The U.S. approves KI and KIO3 as forms of salt iodization, but salt is iodized with KI mostly due to history. The U.S. was the second country after Switzerland to begin salt iodization, and chose KI as the form of iodine as KI was widely available (11, 1315). Animal feeds typically utilize KIO_3 (25).

Iodine concentration in salt can be estimated or calculated through different methods. A kit that utilizes a titration method, qualitatively measures iodine through a color chart with varying color shades corresponding to 0, 25, 50, 75 and 100 ppm (mg iodine/kg salt) (9, 692). Another kit, that also utilizes a titration method, quantitatively measures iodine concentration (37, 475). The mentioned kits can only measure KIO_3, and not KI. The iodometric titration method measures iodine concentration with ±1 ppm (mg/kg) accuracy (32, 413). Inductively coupled plasma mass spectrometry (ICP-MS) is a much more accurate method, as it has higher iodine sensitivity. ICP-MS, while effective, is also sensitive to other impure materials in salt that could be ionized.

Methods

Design

The Institutional Review Board of the College of Saint Benedict and Saint John's University (CSB/SJU) approved this study before any data collection in Mexico. Due to the international aspect of this study, IRB approval included letters of support from the priests of local churches, allowing participant recruiting, and from Dr. Solis, who facilitated the use of the survey applied. The first portion of this cross-sectional study was carried out in rural and urban areas in the state of Jalisco, Mexico between the months of July and August of 2014. This study included an iodine knowledge survey and the analysis of KIO_3 concentration in table salt samples. Participants gave consent before taking part of the study, and their identity remained anonymous as no names or identifying data was collected. A separate comparison study analyzed KI concentration of samples collected at CSB/SJU in Saint Joseph and Collegeville, Minnesota.

Sampling

The population of the first portion of the study was composed of residents living in rural and urban areas of the municipality of Zapopan in the state of Jalisco, Mexico. INEGI (Instituto Nacional de Estadistica y Geografia) defines a population of less than 2,500 inhabitants as rural, while a population of more than 2,500 inhabitants is considered urban. Rural (Santa Ana de Tepetitlán) and urban (Ciudad Bugambilias) communities are less than 2 miles apart in Zapopan, Jalisco and were the locations for the study. The survey sample size was 100 literate adults; 50 residing in the rural community, and 50 in the urban community. The surveys were conducted in a variety of locations: local churches, homes, and public community areas. Participant recruitment was intended to take place in local churches, as several resident attend church on a regular basis. The head priest of the church at each location provided letters of support before beginning participant recruitment. The salt analysis sample size was 100 homes; 50 in the urban location and 50 in the rural location. Participants received an unopened salt container upon supplying a 2-tablespoon sample of the salt used at home; samples were collected in sealed plastic bags. Participants completed a short questionnaire (regarding the type, brand, packaging, container size, date of purchase of the salt provided, purchasing determinants such as price or brand, and use of other types of salt) before providing the salt samples. The salt analysis also included salt samples from new purchased salt available at local stores in the rural and urban communities; a total of 27 samples from different brands, size containers, and packaging were purchased. Participants took part of the survey, the salt study, or both. Population samples for the survey and salt study were convenience samples, as participants were selected only by proximity to first randomly selected home. All participants gave informed consent, were able to read and write, and were at least 18 years old. Surveys were completely anonymous, as no names or identifying data was collected.

Salt samples collected from students attending CSB/SJU were also analyzed. CSB and SJU have a total enrollment of approximately 2,000 students each. The sample size was 40 salt samples; 20 from CSB (female), and 20 from SJU (male) students residing in campus apartments. Apartments at CSB were randomly selected from 3 apartment buildings housing junior and senior students. Apartments at SJU were also randomly selected from 5 apartment buildings housing junior and senior residents. Samples for salt study were convenience samples, as solicited samples were selected only by proximity to first randomly selected apartment. Each participant exchanged a container of salt for a new container**,** 1 pound of Morton or Food Club iodized salt. The analysis included 2 samples of newly purchased salt available at local stores.

Instrumentation

The survey applied in the rural and urban locations of Jalisco was "Cuestionario para determinal la ingesta de yodo", a modified version of the Leung's dietary iodine questionnaire (DIQ) The survey was translated from English to Spanish and adapted to include cultural foods by the Universidad Autónoma of Querétaro. Dr. Pablo Garcia Solis provided a letter of support that authorized the use of this survey, after meeting to discuss his past research and possible methodology for this study. The survey contains questions regarding socio-demographic characteristics, thyroidal medical history, general understanding about dietary iodine, and sources of dietary iodine. The survey required about 10-15 minutes to complete.

The salt analysis utilized kits that use a titration method (Kit para la determinación de yodatos en sal), provided by Boiteccsa Laboratorios in Sonora, Mexico. This kit measures potassium iodate (KIO_3) concentration, the form of iodine used for salt iodization in Mexico. See table 5 in appendix for kit methods. The "Kit para la determinación de yodatos en sal" cannot analyze KI concentration, the form of iodine used in the U.S. Dr. Dasgupta and Dr. Shelor from the University of Texas at Arlington analyzed the KI concentration in salt samples. Dr. Shelor utilized inductively coupled plasma mass spectrometry to determine KI concentration of 20 salt samples; 22 of the 40 collected salt containers were labeled non-iodized, so the remaining 18 samples and 2 newly purchased samples were analyzed.

Data Collection

Participants were assigned a code corresponding to their locality utilizing the letters U (urban) or R (rural), and a number (1-50) corresponding to the order the surveys or salt samples were received, ensuring confidentiality. The surveys were administered utilizing paper copies. Questions regarding the salt samples were recorded in paper form and, when participants agreed, pictures of the salt-holding container depicting the material and size of the container, and the type and brand of salt. Pictures captured salt analysis data by identifying sample letter and number code, and step of the kit test. A written record outlined the identifying sample letter and number, the type of salt, the number of drops used solution YS4, and any observations. The number of YS4 drops determines KIO_3 concentration using the formula provided by the kit. Data from newly purchased salt samples containers included additional detailed pictures of the container that recorded the type, brand, and package form material and size.

Salt samples collected in the U.S. were coded CSB or SJU, to identify the location, and a number (1-20) corresponding to the order samples are collected. Purchased salt samples were labeled according to their brand. SPSS was used to complete ANOVA, T-tests, and Coefficient Correlation statistical analyses.

Results

Salt Analysis in rural and urban communities of Jalisco, Mexico

Granulated is salt with coarser grains, and is available as iodized or non-iodized, and sea salt. Salt samples collected in the rural area were slightly more refined than granulated; samples in the urban are were mostly granulated. Granulated and refined salt should be equally iodized, yet KIO_3 concentration levels varied greatly. Non-iodized or iodized granulated salt was available at retail level, see Figure 3. Surprisingly, 32% of the rural salt, 22% of urban, and 11% of retail salt samples had no iodine, even though salt iodization is mandatory. Only 24% of rural samples contained "adequate" levels (15-40 KIO_3 mg/kg), while 38% of urban samples were "adequate", see Figure 4

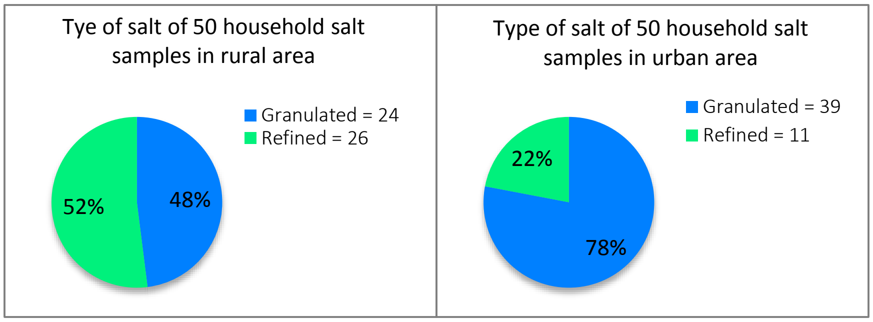


Figure 3. Salt type of salt samples in rural (n=50), urban (n=50), Jalisco, Mexico.

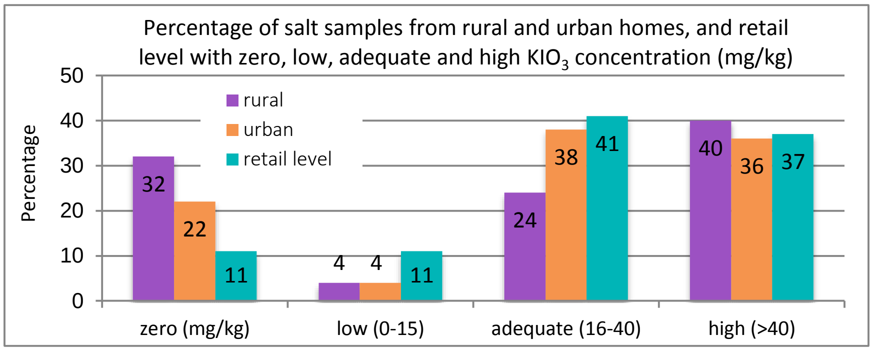


Figure 4. KIO_3 concentration levels of rural (n=50), urban (n=50), and newly purchased retail samples (n=27) categorized as "zero", "low", "adequate" or "high". Iodine concentration categories are consistent with WHO's salt iodization recommendations.

Average KIO_3 concentration of rural salt samples (n=50) (30.1 ± 26.25 mg/kg salt) was lower than urban (n=50) (33 ± 23.47 mg/kg) and the highest was for newly purchased salt (36.2 ± 24.14 mg/kg). Individual KIO_3 concentration values of rural and urban household salt samples ranged from 0 to 86.9 mg/kg, and retail samples from 0 to 76.6 mg/kg, see Figure 5.

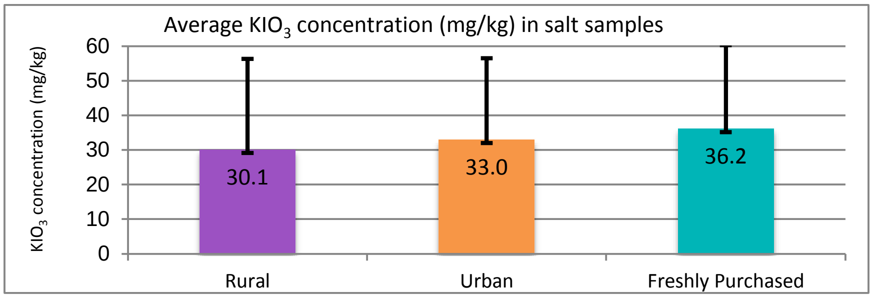


Figure 5. Average KIO_3 concentration levels of rural (n=50), urban n=50), and newly retail samples (n=27). Data presented are means ± SD and includes the analyses of all salt samples, granular and refined of rural, urban, and newly retail samples (n=27).

Sea salt is available in granulated or refined form, as 8 newly purchased salt available at retail level salt samples (36%) were labeled "sea salt"; 63% were granulated (5 samples) and 37% were refined (3 samples). Only 8% of newly purchased salt had the amount of iodine indicated on the label, 48% had less KIO_3 than labeled, and 33% had more KIO_3 than labeled. One of the three newly purchased non-iodized samples was labeled as iodized (Great value), and three iodized salt samples were not labeled iodized (Biosal light, Novoxal with 450 grams and 110 grams). Newly purchased salt was diving according to the size of the company. Big companies include: La Fina, Pegaso, Elefante, and small companies include: Great value, Biosal, Novoxal, Soriana, Cisne, Krisal, Aurrera, Diamante Azul. Companies were grouped based on personal perspective of the companies. The average KIO_3 concentration of small companies (21.63 mg/kg) was statistically different from the average KIO_3 concentration of big companies (52.22 mg/kg), with a p value of 0.001. See Figure 6. Tables 6-8 in the appendix provide the complete raw data of rural, urban, and newly purchased salt in Jalisco, Mexico.

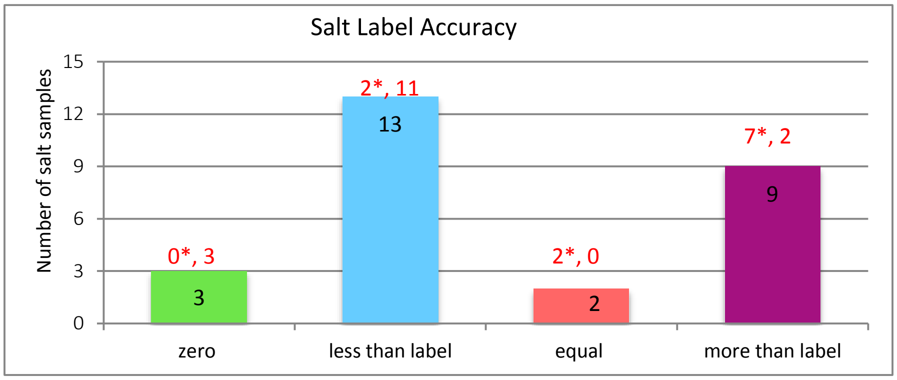


Figure 6. Salt samples (n = 27) were analyzed for KIO_3 concentration, and values compared to the label information. Numbers in red describe the number of salt according to the size of the company; the first number with an asterisk refers to the salt samples from small companies, and the second number to the salt samples from big companies. Salt samples were purchased from local stores at rural and urban locations; salt samples were varied (granulated or refined, from different brands, container size, or packaging).

Salt Analysis in Saint Joseph, Minnesota, United States

All granulated salt was sea salt. Granulated sea salt was the main type of SJU salt samples (50%) compared to CSB (15%). Refined salt was more prevalent in CSB salt samples (80%) than at SJU (50%), and only one CSB salt sample was labeled Kosher salt (5%). SJU had a higher percentage of non-iodized salt samples (65%) compared to CSB (45%). All sea salt was non-iodized, and refined salt was available either non-iodized or iodized, see Figure 7.

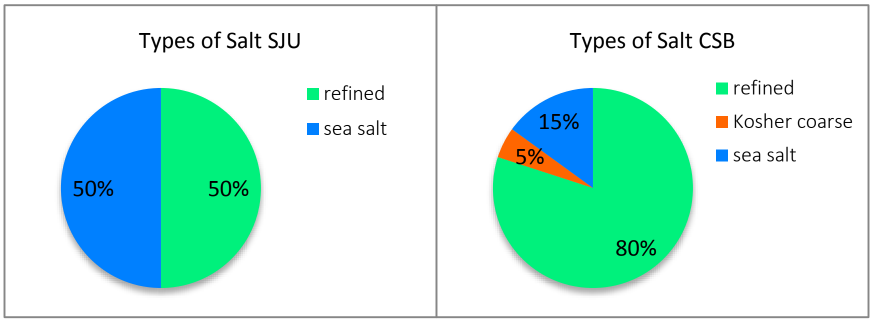


Figure 7. Salt type of 20 samples collected at the College of Saint Benedict (CSB) and 20 samples at Saint John's University (SJU) in Minnesota, U.S. All sea salt was not iodized, and only some of the refined salt was iodized.

WHO's salt iodine concentration recommendations were also used to divide salt into 4 categories based on iodine concentration levels; "zero", "low" (0-15 mg/kg), "adequate" (16-40 mg/kg), and "high" (>40 mg/kg). No CSB salt samples fell in the "adequate" levels (16-40 mg/kg iodine), compared to 15% of SJU samples. No SJU salt samples were low (≤15 mg/kg iodine) compared to one CSB sample, and 50% of CSB and 20% SJU samples were high (≥40 mg/kg iodine), see Figure 8.

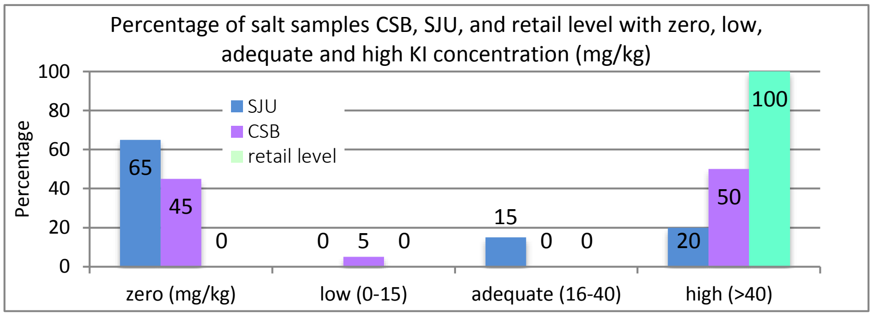


Figure 8. KI concentration levels of CSB (n=20) and SJU (n=20), and newly purchased retail samples (n=2) categorized as zero, low, adequate or high. Iodine concentration categories are consistent with WHO's salt iodization recommendations, to permit comparisons with data from Mexico.

Only 18 of the 40 collected samples were analyzed for KI concentration, because 22 were labeled non-iodized, see Figure 9. Average KI concentration of iodized samples at SJU (n=20) was 50.15 ± 16.7 mg/kg, lower than CSB (n=20) 58.15 ± 25.4 mg/kg. Individual salt sample values ranged from 0 to 116.5 mg/kg at CSB and from 0-74.7 mg/kg at SJU, see Figure 10. The brands Morton (42%) and Food Club (22.5%) were the main brands purchased. The Food Club newly purchased salt sample had a higher KI concentration (58.1 mg/kg) than Morton (43.5 mg/kg), see Figure 11. Tables 9-11 in the appendix provide the raw data of CSB/SJU and newly purchased salt.

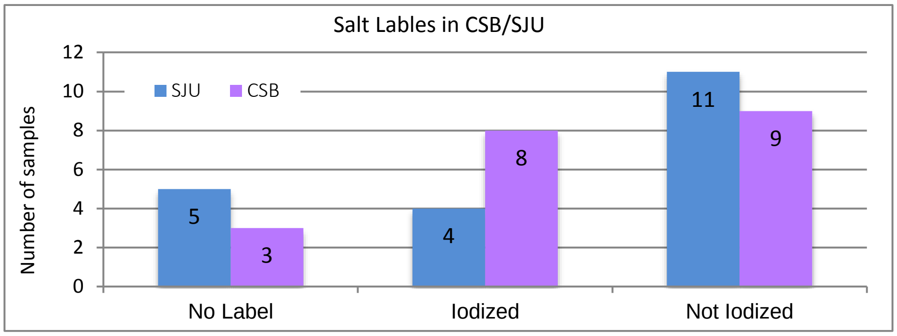


Figure 9. Salt labeling of 40 samples collected at the College of Saint Benedict (CSB) and Saint John's University (SJU) in Minnesota, U.S.

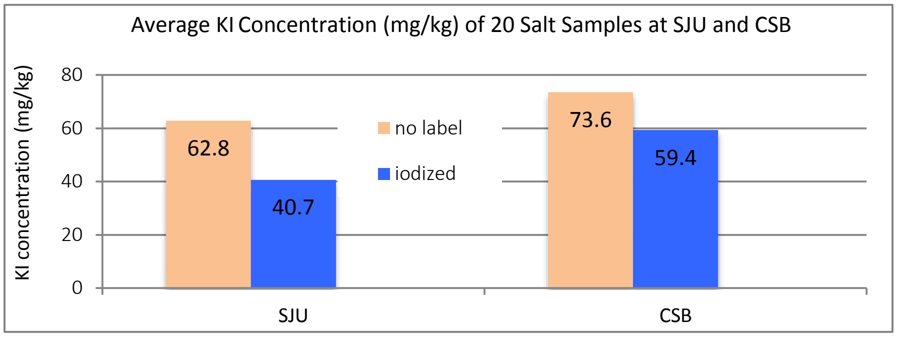


Figure 10. Potassium Iodide (KI mg/kg) concentration of samples collected (n=40) at the College of Saint Benedict (CSB) and Saint John's University (SJU) in Minnesota, U.S. Samples labeled "Not Iodized" were not analyzed and, are not represented on this graph.

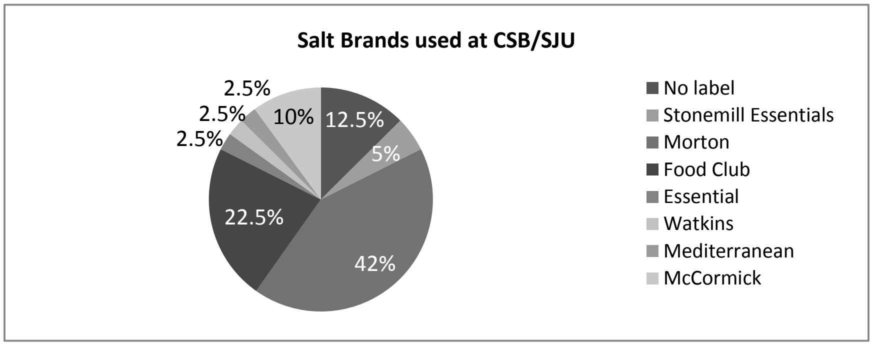


Figure 11. Salt brands collected at the College of Saint Benedict (CSB) and Saint John's University (SJU) in Minnesota, U.S (n=40). Starting at the 12:00 position is "No label", and continues clockwise to "Stonemill Essentials"(5%)

Comparison of Mexico and United States

KIO_3 concentration values (mg/kg) of salt samples from Mexico were converted to KI (mg/kg) to compare salt analysis results from Mexico and United States. Average KI concentration for rural salt samples was 23.33 ± 20.34 (mg/kg), 25.59 ± 18.19 (mg/kg) for urban salt samples, and 26.43 ± 18.96 (mg/kg) for newly purchased salt samples. Average KI concentration for CSB salt samples was 69.56 ± 28.42 (mg/kg), 50.15 ± 16.7 (mg/kg) for SJU, and 66.52 ± 9.58 (mg/kg) for newly purchased salt samples, see Figure 12.

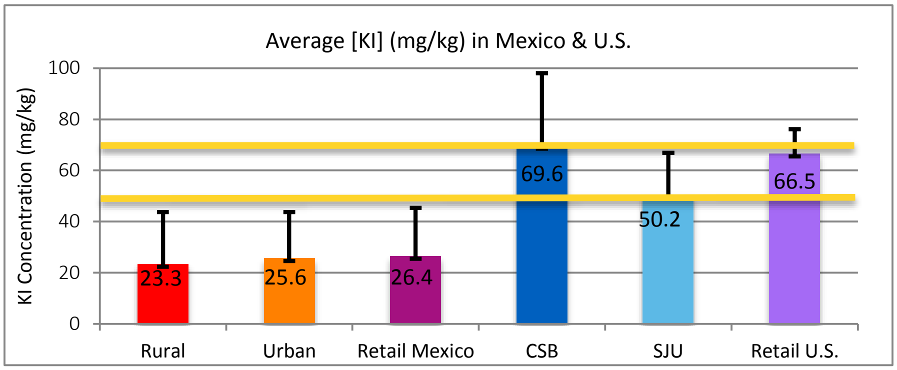


Figure 12. Potassium Iodide (KI) concentration of rural (n=50), urban (n=50), and newly retail salt samples (n=27) in Jalisco, Mexico, and from the College of Saint Benedict (CSB) (n=20) and Saint John's University (SJU) (n=20) in Minnesota, U.S. Lines running across the graph outline the recommended KI concentration levels (44.5 – 75.0 mg/kg) by the World Food Programme.

Survey in Jalisco, Mexico

Rural (88.1%) and urban (81.6%) participants did not know that pregnant women have higher iodine needs. Rural (56.5%) and urban (77.5%) participants agreed that iodine deficiency is an important public health problem worldwide, and 89.8% of rural and 96% or urban residents identified iodine deficiency as a public health problem in Mexico. Rural (54%) and urban (59.2%) participants reported that adding salt to foods is healthy. Only 53% of rural and 56% of urban residents know that a lack of iodine can cause goiter, and only 37.5% of rural and 48% of urban residents know that iodine deficiency can cause mental retardation. Education levels varied between rural and urban areas; however, education did not determine iodine knowledge (p value ≥ 0.5). Tables 12 and 13 list the answers to iodine knowledge and salt use statements.

Table 12. Survey responses to statements regarding iodine knowledge

Statement	More than (R/U)*	Same	Less than	I don't know	
Pregnant women iodine needs are ___than those for non- pregnant women	5/9	2/6	12/5	23/29	
	Strongly agree	Agree	No opinion	Disagree	Strongly Disagree
Iodine deficiency is public health problem worldwide	10/17	17/21	16 /10	4 /2	2 /0
Iodine deficiency is public health problem in Mexico	7 /11	19/27	14/10	5/1	1 /0
Iodine content should be listed in food packaging in Mexico	25/28	19 /20	5 /2	0 /0	0/ 0
Its healthy to add salt to food	10/15	17/14	8 /3	12 /15	3 /2
Iodine deficiency causes goiter	7/14	18/14	17/20	3 /1	2 /1
Iodine deficiency can cause mental retardation in children	5/9	13/15	22/22	6 /2	2 /2

* Values are presented in (rural/urban) format

Table 13. Survey answers to questions regarding salt use

Statement	Price (R/U)*	Brand	Packaging	Iodized / non-iodized	Other
Determining factors for salt choice	7/3	18/20	2/1	5/10	10/7
	Yes	No			
I add salt to foods	45/32	5/18			
	Bulk	Iodized	Granulated		
Type of salt used	0/0	24/18	19/14		

* Values are presented in (rural/urban) format

The average age of rural residents was 37 ±12; this groups consisted of 44 women and 6 men. The average education level achieved was middle school, and ranged from no studies to a college degree. Urban residents were on average 40 ± 16 years old; this group consisted of 38 women and 12 men. The average education level achieved was college degree, ranging from middle school to graduate degree.

One rural participant was diagnosed with goiter, but no participants reported personal or family medical histories of other IDD. Two urban participants were diagnosed with goiter, one with hyperthyroidism, one with hypothyroidism, and one with thyroid nodules. Two urban residents had family members diagnosed with goiter, five with hyperthyroidism, five with hypothyroidism, two with thyroid nodule, and three with thyroid cancer. Smoking, a strong iodine absorption inhibitor, was reported by 6% of rural residents, with an average of 8.67 ± 10.02 cigarettes, and 26% of urban residents, with an average of 3.73 ± 2.87 cigarette

Discussion

A presidential decree began salt iodization in 1942, targeting states in Mexico where more than 20% of population was diagnosed with goiter. In 1963, a decree established the iodization of all the salt produced in all states in Mexico for human consumption or food products (33). Despite the mandatory iodization, the incidence of goiter in the last three years has tripled nationally and in the state of Jalisco. This study explored the recent increases in iodine related deficiencies by examining the actual iodine concentrations of salt samples collected from households in both a rural and urban areas of Jalisco, Mexico. Jalisco was the chosen location for this study as this state is particularly vulnerable to iodine deficiency because non-iodized salt is widely used, and factors like humidity, heat, and light affect the iodine concentration in iodized salt. Jalisco is one of the three states where non-iodized salt, extracted by artisanal methods or intended for industrial use, is available for human consumption (39). Analyzing salt samples acquired directly from families is a more accurate reflection of iodine intake than using data of salt sold at retail level. Fresh salt samples purchased from local stores were also analyzed for comparison.

Mexico mandates that all salt be iodized at 30±10 mg/kg, in the form of KIO_3, but concentrations vary among salt samples. Collected rural salt samples had a slightly lower average KIO_3 concentration compared to urban average, even though the range of average KIO_3 contents were quite similar. The lower rural iodine average is due in part to the higher percentage of non-iodized salt being used in this community. Rural salt samples had the highest percentage of non-iodized samples (32%), which were all granulated. Artisanal extraction of salt and low iodization technology in small salt production plants may explain why granulated samples were mostly non-iodized. Many rural household salt samples were granulated (52%), and most were non-iodized (67%). Similarly, most rural refined samples were also not iodized (67%). Several rural residents reported buying granulated salt in bulk (from small local producers), as granulated salt in bulk was the lowest-cost salt available in local stores. Preference for granulated is also characteristic of other areas in Mexico; for example, 92% (258 of 281) of families in Colima Mexico use granulated salt, which is also mostly non-iodized (9, 693).

Granulated salt was available as iodized or non-iodized. Small local producers use low-technology salt iodization techniques that result in iodization that is less stable than of larger producers that utilize high-technology iodization methods. Major salt producers in Mexico with high-technology equipment reported that 91% to 96% of their salt samples at retail level had >15 ppm of iodine, but only 46% to 48% of salt samples from smaller producers met this level in 2002 (5, 14). Salt from small local producers is also less expensive than salt from major producers with the appropriate iodization technology. Hence, granulated salt from small local producers that may be poorly iodized or not iodized is the only economically viable option for rural residents. In China, people with low socioeconomic status that lived in mountainous or rural areas, also consumed locally produced granulated salt and had lower UIC levels than urban residents (8, 4). Low economic status creates a disadvantage, in rural or urban locations. In India, 37% of the population makes up the lowest economic population group. Salt that is not appropriately iodized in India also has a lower price than well-iodized salt. Thus, as income increases, access to iodized salt does too. Only 50% of the lowest economic population group utilized adequately iodized salt, compared to 86% in the highest economic group (40, 540).

Many urban residents preferred granulated salt from small local producers or major salt companies, not for the price difference, but based on cooking preferences for coarser salt. Salt used by urban residents had higher average KIO_3 concentration levels than salt used by rural residents, but several samples were also not iodized (22%). Urban samples were mostly granulated (78%). Unlike rural samples, urban granulated (74%) and refined (74%) salt samples were mostly iodized. Granulated and refined salt should be equally iodized, yet KIO_3 concentration levels varied greatly. Urban iodized salt samples had better iodization than rural samples, and may explain why even when urban residents mostly consumed granulated salt, iodine concentration levels were still higher in the urban area.

Only 20% of rural and 36% of urban salt samples contained adequate KIO_3 concentration levels (20-40 mg/kg). Similarly, only 13.6% of salt samples in Colima, Mexico (n=14) had satisfactory iodine levels, 18.84% low levels (<50 ppm) (mg/kg), 90% of sea salt had low iodine levels and 75% of table salt had adequate iodine levels (9, 693). The report of salt analyses of 916 of the household salt samples from 50 localities (76% rural and 24% urban) of Querétaro, Mexico revealed 7.8% contained > 40 ppm, 77% 20-40 ppm and 9.6% < 15 ppm (37, 447). All salt samples gathered from kitchens and storerooms of Tarahumaran boarding schools in Northern Mexico in 2005 were above 25 ppm (mg/kg). Iodine concentration was calculated using kits with a color scale comparison for 25, 50, 75, 100 ppm (±10 ppm) (41, 1214). Most salt sold in Mexico (81%) had adequate iodine concentration levels (20-40 ppm), and almost all (94%) had a concentration above the minimum of 15 ppm (mg/kg) in 2009 (12, 1368).

Improper initial iodization of salt results in low iodine concentration at the retail level, and inadequate storage, greatly decreases, or eliminates the iodine before consumption. New retail samples had the highest average KIO_3 concentration, compared to rural and urban samples, but individual levels varied greatly and some samples were not iodized (11%). Only 19% of newly purchased salt samples contained adequate KIO_3 concentration levels (20-40 mg/kg), demonstrating a discrepancy between recommended and actual KIO_3 concentration levels. Retail samples had the highest percentage of low KIO_3 concentration levels (<20 mg/kg) (33%), compared to rural (8%) and urban (6%). Salt samples that were low at retail level could have lost all or most iodine content, explaining the discrepancy between retail, and urban or rural salt samples with low KIO_3 concentration. High KIO_3 concentration levels (<40 mg/kg) were similar between rural

(40%), urban (36%), and retail (37%) salt samples. KIO_3 concentrations above the recommended levels are not likely to cause iodine toxicity; usual salt consumption levels would not reach toxic levels. Accurate labeling is another important concern in salt at retail level; only 8% of the newly purchased salt samples accurately reflected the iodine content on the label.

The focus of this study included analysis of salt samples from the U.S., a country that has voluntary iodization, to compare the results from Mexico, a country that has mandatory iodization. Mexico utilizes KIO_3 and the U.S. uses KI as forms of iodine for salt iodization. KIO_3 concentration of samples collected in Mexico was converted to KI to have comparable units. The WFP has recommendations for KI concentration in salt, and were used as standards to classify KI concentration as “low”, “adequate”, or “high”. CSB, a women’s college, and SJU, a men’s university, were the selected locations in Minnesota for this study. Based on WFP KI recommendations, samples collected at CSB/SJU were closer to meeting WFP KI recommendations than samples from rural and urban communities in Jalisco, Mexico. The Average KI concentration at SJU was lower than at CSB, and again individual sample values varied greatly. Lower KI concentration at SJU may the larger number of non-iodized samples (65%) than at CSB (45%). All granulated sea salt was not iodized, and refined salt was in both iodized and non-iodized forms. Half of the collected SJU salt samples were granulated sea salt, compared to 15% of CSB salt samples. CSB and SJU participants that used sea salt believe sea salt is more natural than other types, and they prefer coarser salt. Sea salt is not iodized and fails to provide the daily iodine needs.

In the U.S., one serving of iodized salt (¼ teaspoon or 1.5 g) contains 45 mg/kg of iodine or 45% of the daily RDA (150 µg for adults). Irregular iodine concentration within a salt container may vary the amount of iodine in a serving (11, 1318), and iodized salt may therefore fail to supply the estimated 45% of the daily RDA. Salt iodization levels in a country are based on daily salt consumption, form of iodine used, and any environmental factors that may decrease iodine concentration before iodized salt is consumed. If iodized salt is not consumed daily, iodization levels should be adjusted to meet RDA levels. About 77% of salt the U.S. is iodized (24) but a study reports that of 89% participants purchased table salt, only 24% used iodized salt within the last 24 hours (14). Reports may overestimate use of iodized salt if only purchased salt is accounted for, and fail to include salt consumed in households.

Salt iodization is an effective way to provide a steady dietary source of iodine to the general population, but it must also be accompanied by educational components to encourage iodized salt intake. Lack of knowledge is the main barrier to eliminate iodine deficiency in Nigeria, Kazakhstan, India and South Africa (32, 415). This study included an iodine knowledge survey completed by rural and urban residents of Jalisco. Salt iodization is mandatory in Mexico, yet there is a lack of iodine knowledge in the general population. Almost all of rural (90%) and urban (82%) participants did not know that pregnant women have higher iodine needs than non-pregnant women. Slightly more urban (56%)

than rural (50%) participants agreed that iodine deficiency causes goiter, almost the same as Querétaro (54%) (4, 209). More urban (48%) than rural (36%) participants agreed that iodine deficiency can cause mental retardation in children, compared to Querétaro (43.6%) (4, 209). Percentages of participants that agree with iodine knowledge statements include answers marked as "strongly agree" and "agree." Lack of iodine knowledge is deeply concerning, especially in statements regarding the effects of iodine deficiency and iodine needs during pregnancy. Basic iodine knowledge in a population is a key component to adequate iodine intake. A population can easily fail to meet daily iodine needs if individuals do not understand the importance of iodine and the effects of deficiency.

In 2007, Kul Gautam, Deputy Executive Director of the UNICEF stated that of the 38 million babies with IDD, about 30% were born into "the least educated, most isolated and economically disadvantaged" families (25). Demographic factors such as population size, socioeconomic status, education, and gender are determinants of IDD incidence. In this study, the average education level achieved of rural residents in was middle school and for urban residents was college. Education levels varied between rural and urban areas; however, education did not determine iodine knowledge (p value ≥ 0.5). Education level was not a determinant for iodine knowledge in this study, but socioeconomic status was a determinant for other studies. In South Africa, a study reported that low-socioeconomic status groups were less educated on iodine deficiency than those with high-socioeconomic status (42, 346). Education level and socioeconomic status were related to iodine knowledge in a study in Indonesia; a mother's low education level was the strongest indicator for low iodine intake in children from rural regions or urban "slums"-poverty stricken areas. These families were also more likely to have wasted, underweight, or stunted children (Semba). Food insecurity was also reported in 60% of homes in Jalisco, with 10% suffering hunger in the 3 months prior to the survey; affecting rural more than in urban areas (encuesta). Socioeconomic status may be a stronger indicator of iodine knowledge than education levels, and may also determine access to iodized salt.

Daily habits and customs also affect intake. In the U.S., the main source of salt is processed foods, which is generally non-iodized (13, 1743). Families with little time reserved for cooking rely on processed foods. The recent increase in processed food intake worldwide, and inadequate cooking practices are factors that decrease daily iodine intake. Boiling a 5% salt solution for 5 minutes reduces iodine by 21–68% (11, 1318). However, many cultures tend to add salt to food during cooking rather than after increasing the loss of iodine. Cigarettes contain iodine inhibitors that prevent adequate thyroidal absorption of iodine. Smoking exacerbates the risk of iodine deficiency. Cigarette smoking was more prevalent in urban (26%) than rural (6%) Jalisco, yet the average number of cigarettes smoked was higher in rural Jalisco. Even though a small percentage of the rural population reported to smoke cigarettes, the high number of cigarettes smoked hinders adequate iodine intake. Nationally, 19.9% of adults reported having smoked more than 100 cigarettes in their lifetime and currently smoked in Mexico in 2012 (43), compared to 17.8% of adults in the U.S. in 2013 (44). National cigarette smoking statistics in Mexico and the U.S. demonstrate that smoking contributes to risk of IDD for about 20% of the population.

Possible solutions

Constant population monitoring is a proposed solution to decrease IDD incidence. The WHO, UNICEF, and IGN recommended measuring national iodine urinary excretion levels every three years. Cost and complexity of urinary iodine testing may impede proper monitoring of iodine status. Mexico has failed to complete periodic surveillance of the population's iodine status, leaving a gap of more than 15 years. The National Nutrition Survey in 1999, the latest effort to monitor iodine status in Mexico, reported women (12-49 years, non-pregnant) had an adequate median UIC of 281 μg/L (12, 1369). National median UIC values are not available after 1999, and important changes may have occurred since.

Small salt producers formed the Mexican Association of the Salt Industry (AMISAC) in 1945, a body that offered representation of similar interests and unity between salt production, packaging, and distribution entities in Mexico (33). Such organizations help ensure that governmental salt producers meet regulations, and remain consistent among salt producers. Salt iodization technology is accessible and relatively low-cost, yet not all salt producers have adequate salt manufacturing and packaging technologies (25). Iodine loss in salt can also be related to packaging methods and materials utilized. Packaging improvement may be an effective way for salt producers to improve iodine concentration at retail level.

The U.S. has monitored urinary iodine since 1971 using the National Health and Nutrition Examination Survey. Urinary iodine levels decreased more than 50% from 1971-1974 to 1988-1994, but the general population is iodine sufficient. Milk producers reduced the use of iodophor agents (containing iodine) to sanitize equipment and iodine feed supplements, and together cause a decrease in milk iodine levels. The bread industry also reduced the use of iodate dough conditioners. The use of erythrosine, a food dye that contains iodine usually used in fruit-flavored cereals, decreased as well, but this change might not have had a significant effect. If urinary iodine levels continue to decrease at this rate, the U.S. population could be at risk of iodine deficiency. UIC levels in pregnant women continue to be a concern in the U.S., as data from 2009-2010 NHANES reports median UIC in pregnant women was significantly lower (144 μg/L) than in 2007–2008 (164 μg /L) (45). Lower UIC levels may be explained to the recommendation to limit salt intake during pregnancy, a main source of iodine, and increased iodine needs due to metabolic changes and lactation (46). Pregnant women are considered a population with increased risk of IDD, as iodine needs are higher than other age groups.

Monitoring a population's iodine status should review current iodization programs. Vulnerable groups such as pregnant women and newborns, and the quality of salt at industrial and retail levels should be monitored to ensure that iodization programs are effective (26, 9). China reviewed iodine nutritional status 16 years after the introduction of the USI policy through a questionnaire regarding gender, age, residence, information of diet habits, and other categories as well spot urine samples. As a result, China adjusted standard salt iodine concentration from 35 ± 15 mg/kg in 2000 to 20-30 mg/kg in 2012 (8, 3). Constant monitoring of a population's iodine status allows for corrective measures. Iodine concentration testing kits and dried urine strip testing can accommodate the analysis of samples from remote areas. Appropriate iodine status monitoring must be representative of all age groups and regions in the country, and comprehensively include urinary iodine concentration data, salt iodine concentration at household and retail level, and surveys that assess iodine dietary intake and overall knowledge.

The sooner an iodine deficiency during pregnancy is corrected, the greater the likelihood that long term harmful neurodevelopmental consequences in infants can be reduced (18, 1959). Salt iodization has helped ameliorate iodine deficiency, but maintaining adequate iodine levels is challenging. Single iodized oil injections can provide adequate iodine for 2 to 3 years, yet the cost and increased risk of transmitting communicable diseases are possible disadvantages. Iodized oil in oral capsules is an alternative, but the frequency and dosage are not well established. Iodized oil's fatty acid composition is a determinant of it is efficacy (28, 1208). The WHO has adopted a yearly dose of slow-released iodized oil in some countries, especially for children, and recommends a yearly dose of 400 mg for lactating women and 200 mg to weaning infants (10, 534).

In Spain, tablets containing 200 µg of iodine are made available to pregnant and lactating women through the national health system (11, 1319). In Indonesia, iodine from iodized peanut oil was retained 3 times more than from iodized poppy seed oil, and provided twice the duration of iodine deficiency protection than iodized poppy seed oil (28, 1213). Peanut oil is 41% oleic acid and 39% linoleic acid, compared to 14% oleic acid and 73% linoleic acid in poppy seed oil. Interestingly, iodized oleic acid released more iodine than iodized linoleic acid (28, 1212). Peanut oil offers a desirable medium of for iodization, as it is rich in oleic acid and is cheaper than poppy seed oil (28, 1208).

Iodine-rich foods are another potential source of iodine supplementation to populations. Iodine-rich celery retains 93 and 86 % of iodine after cooking for 2 and 5 minutes, while celery cooked for 5 minutes with iodized salt absorbed only 1.6% of the iodine and the salt had lost 69% of its iodine. Iodine-rich foods are a promising solution, yet food insecurity and food preferences are factors that would impede national consumption. Increasing national iodine concentration in salt recommendations is a possible solution, but should be carefully revised before implementation. China set a high iodine concentration in salt of 60 mg/kg, resulting in iodine excess. China later modified the iodine concentration in salt to 30 mg/kg (27, 816). Worldwide salt iodization should be more consistent and cover the needs of each country's population. In Mexico, a solution would be guarantee the appropriate iodization of salt by ensuring that small and large salt producers have the necessary iodization technology.

Limitations

A major limitation of the salt analysis in Jalisco, Mexico is that many participants did not have the original salt container. Therefore collected salt samples could not be grouped by brand or labeled specifications such as "iodized" or "sea salt". Date of purchase data was not always known, for this reason the brand and date of purchase information were not included in salt analysis results.

This study attempted to include men in the population sample, because most of the current iodine deficiency studies focus on women and children and fail to include men. However, it was difficult to recruit men. The selected churches were mostly attended by women, and intrinsically reduced men participation. For this reason the methodology of this study was modified to attempt to include more men, and participants were also recruited by visiting homes door to door. However, the limited times that men answered the door, men referred to women to answer the survey as men expressed not knowing much about the salt consumed at home and that women were responsible of cooking and purchasing foods at home. Ultimately men represented only 12% of the rural and 24% of the urban population studied. Urban residents were more reluctant to participate in the study than rural residents. About 2 of every 3 visited urban homes refused to participate in the study did not agree to participate in the study as they expressed safety concerns when opening their doors to strangers or did not have time available. Almost all visited rural homes agreed to be part of the study, with exception of 2 or 3 that expressed not having time.

Both population samples in rural and urban areas of Jalisco, Mexico and CSB/SJU in Minnesota, USA were convenience samples and may not be representative of the entire population. Salt analysis in Mexico utilized "Kit para la determinación de yodatos en sal", which provided acceptable KIO3 concentration data but was not as accurate as the inductively coupled plasma mass spectrometry used to determine KI concentration of U.S. salt samples. Salt samples collected at CSB/SJU were small in number, and a larger population sample would have provided more representative data.

Future research studies in Mexico should analyze iodine concentration of newly purchased salt samples after exposing salt to controlled environments with varying heat, light, and humidity through an extended period of time. Several samples from the same salt brands should be analyzed to have comprehensive results, as iodine is not uniform in a salt container. Iodine concentration of samples taken from the top, middle, and bottom of a container can vary greatly.

Conclusion

Most salt samples in the selected rural and urban locations of Jalisco, Mexico did not meet the national recommended KIO_3 concentration levels, even though Mexico mandates the iodization of salt for human consumption. Numerous salt samples had no KIO_3 present. Rural salt samples had a lower average KIO_3 concentration and more were non-iodized than urban samples. Humidity, heat, light and time are factors that decrease iodine concentration in salt, and could help explain why so many salt samples were not iodized since Jalisco is a state subject to high humidity and heat levels. Low KIO_3 concentration levels in new salt containers, along with environmental factors that decrease iodine concentration, further increase a population's risk of consuming non-iodized salt.

KIO_3 concentration levels varied greatly among newly purchased retail salt samples, demonstrating that salt iodization quality standards and techniques should be improved and consistent among all salt producers. Rural and urban residents preferred granulated salt, which is often not iodized, based on lower price or habit to consume coarser salt. Trends to decrease sodium intake and to consume non-iodized granulated salt, and variation in KIO_3 concentration in salt may explain the recent rise in goiter incidence. Lack of iodine knowledge in both rural and urban locations of Jalisco is also a threat to adequate intake of iodine; individuals that don't understand the importance of iodine will not seek iodized salt. This study was the first to examine iodine concentration in salt and iodine knowledge in the state of Jalisco, and will hopefully call attention to the iodine status of this vulnerable region. Jalisco is vulnerable to IDD as it is a mountainous region, and artisanal non-iodized salt is readily available. The results of this study will also add to Mexico's national data pool to monitor the population's iodine status, by providing data on salt iodine concentration and iodine knowledge of an unstudied region. Results and data collected will be provided to Dr. Solis, and if feasible, presented to AMISAC or a governmental entity that could make use of the data collected in this study.

Mexico and the U.S. have varying salt iodization regulations; Mexico's salt iodization regulation calls for the use of KIO_3 while the U.S utilizes KI. KIO_3 is more stable than KI, but KI contains more iodine per molecule and is less expensive. Most CSB/SJU salt samples were non-iodized, despite American iodized salt meeting the recommended iodine levels. The number of iodized salt samples from CSB was double the number from SJU, and both student populations utilized non-iodized salt. KI concentration of newly purchased salt samples did not vary greatly, but the sample size was small. Several CSB/SJU students reported preferring granulated sea salt, as a coarser salt and based on the belief that sea salt is more natural. Since all granulated sea salt is not iodized, the population at CSBSJU is at risk of iodine deficiency.

Iodizing all granulated sea salt in Mexico might be an acceptable solution to end IDD. In the U.S., iodized granulated sea salt should also be available, an action that would still maintain ~~s~~ voluntary iodization. The cost of iodized and non-iodized should also be the same, ensuring that salt cost is not a factor that reduces access to iodized salt. Iodized oil and iodine-rich foods are additional forms of iodine supplementation that could be considered as an additional form of iodine supplementation. Iodized oil is a valuable source of iodine for pregnant women and children, as well as other populations at risk.

In 1978 UNICEF director Henry Labouisse stated “iodine deficiency is so easy to prevent that it is a crime to let a single child be born mentally handicapped for this reason" (Martinez, 2012). Iodine deficiency continues to threaten children’s development and the general population more than 50 years after salt iodization was implemented in Mexico. Periodic, detailed, and comprehensive iodine status monitoring of salt iodization and population intake of iodized salt is the most important step to reduce IDD incidence. Effective monitoring will allow a country to implement corrective measures and make the necessary changes to iodine supplementation programs and regulations. Immediate and sustainable actions are vital to the eliminate IDD, particularly in vulnerable populations, in order to improve the population’s health and nation’s overall development.

Appendix A

Table 1. Median Urinary Iodine Concentrations (UIC) to assess iodine status in different target groups

Median urinary iodine (µg/L)	Iodine intake	Iodine status
Pregnant Women		
<150	Insufficient	
150-249	Adequate	
250-499	Above requirements	
≥500	Excessive	
Lactating women and children aged less than 2 years		
<100	Insufficient	
≥100	Adequate	
School-age children (6 years or older - also applies to adults)		
<20	Insufficient	Severe iodine deficiency
20-49	Insufficient	Moderate iodine deficiency
50-99	Insufficient	Mild iodine deficiency
100-199	Adequate	Adequate iodine nutrition
200-299	Above requirements	May pose a slight risk of more than adequate iodine intake in these populations
≥300	Excessive	Risk of adverse health consequences (iodine-induced hyperthyroidism, autoimmune thyroid disease)

Source: WHO. *Urinary iodine concentrations for determining iodine status deficiency in populations*. Vitamin and Mineral Nutrition Information System. Geneva: World Health Organization; 2013 (http://www.who.int/nutrition/vmnis/ indicators/urinaryiodine, accessed [January 18, 2015]).

Appendix B

Table 3. Selected Food Sources of Iodine

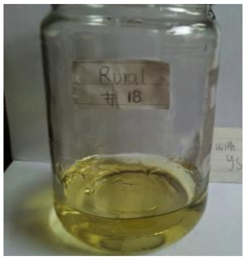
Food	Approximate Micrograms (mcg) per serving	Percent DV*
Seaweed, whole or sheet, 1 g	16 to 2,984	11% to 1,989%
Cod, baked, 3 ounces	99	66%
Yogurt, plain, low-fat, 1 cup	75	50%
Iodized salt, 1.5 (approx. ¼ teaspoon)	71	47%
Milk, reduced fat, 1 cup	56	37%
Fish sticks, 3 ounces	54	36%
Bread, white, enriched, 2 slices	45	30%
Fruit cocktail in heavy syrup, canned, ½ cup	42	28%
Shrimp, 3 ounces	35	23%
Ice cream, chocolate, ½ cup	30	20%
Macaroni, enriched, boiled, 1 cup	27	18%
Egg, 1 large	24	16%
Tuna, canned in oil, drained, 3 ounces	17	11%
Corn, cream style, canned, ½ cup	14	9%
Prunes, dried, 5 prunes	13	9%
Cheese, cheddar, 1 ounce	12	8%
Raisin bran cereal, 1 cup	11	7%
Lima beans, mature, boiled, ½ cup	8	5%
Apple juice, 1 cup	7	5%
Green peas, frozen, boiled, ½ cup	3	2%
Banana, 1 medium	3	2%

* DV = Daily Value. DVs were developed in the U.S. Food and Drug Administration (FDA) to help consumers compare the nutrient contents of products within the context of a total diet. The DV for iodine is 150 mcg for adults and children aged 4 and older. However, the FDA does not require food labels to list iodine content unless a food has been fortified with this nutrient. Foods providing 20% or more of the DV are considered high sources of a nutrient.

Source: NIH (National Institutes of Health). Office of Dietary Supplements. Iodine – Fact Sheet for Health Professionals. http://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/

Appendix C

Table 5. Description of methods used in kit “Kit para la determinación de yodatos en sal” supplied by Boiteccsa Laboratorios in Sonora, Mexico

Step	Description
Step 1	Weigh 10 grams of salt (M) and dissolve in 100 ml of distilled water 
Step 2	Add 20 drops of reactant YS1 and mix well  
Step 3	Add 0.5 grams of reactant YS2. After mixing, if the obtained color is yellow, the sample contained iodine and the reaction can continue to determine the iodine concentration  
Step 4	Add 15-20 drops of reactant YS3, which will produces blue coloration  
Step 5	The last and most important step is to add reactant YS4, one drop at a time and mixing after each addition, until the blue coloration becomes colorless. The number of reactant YS4 drops will determine the iodine concentration by using the following formula: $\text{KIO3 (MG/KG)} = \frac{(\text{\# of YS4 drops})\ (14.73)}{M}$  

Appendix D

Table 6 - KIO_3 and KI concentration, type, and brand of rural salt samples in Jalisco, Mexico

RURAL				
Sample #	[KIO3] (mg/kg)	[KI] mg/kg	Type of salt	Brand
1	0.0000	0.0000	granulated	Other
2	58.9200	45.6630	granulated	Other
3	66.2850	51.3709	granulated	Other
4	82.4880	63.9282	refined	La Fina
5	0.0000	0.0000	granulated	Other
6	30.9330	23.9731	granulated	Other
7	85.4340	66.2114	refined	La Fina
8	0.0000	0.0000	granulated	Other
9	47.1360	36.5304	refined	El Cisne
10	33.8790	26.2562	refined	El Cisne
11	10.3110	7.9910	granulated	
12	10.3110	7.9910	refined	La Fina
13	51.5550	39.9551	refined	El Cisne
14	0.0000	0.0000	granulated	Other
15	20.6220	15.9821	granulated	Other
16	0.0000	0.0000	granulated	Other
17	0.0000	0.0000	granulated	Other
18	53.0280	41.0967	refined	La Fina
19	33.4427	25.9181	refined	El Cisne
20	41.2440	31.9641	refined	Other
21	0.0000	0.0000	granulated	Other
22	86.9070	67.3529	refined	La Fina
23	0.0000	0.0000	granulated	
24	23.5680	18.2652	refined	Other
25	30.9330	23.9731	refined	Other

26	47.1360	36.5304	refined	Other
27	41.2440	31.9641	granulated	Elefante
28	54.5010	42.2383	refined	Other
29	17.6760	13.6989	granulated	
30	25.0410	19.4068	granulated	La Fina
31	61.8660	47.9462	refined	El Cisne
32	70.7040	54.7956	refined	La Fina
33	0.0000	0.0000	granulated	Pegaso
34	0.0000	0.0000	granulated	Colima
35	45.6630	35.3888	refined	El Cisne
36	38.2980	29.6810	refined	Other
37	36.8250	28.5394	refined	Other
38	0.0000	0.0000	granulated	Pegaso
39	57.4470	44.5214	refined	Other
40	51.5550	39.9551	refined	Pegaso
41	0.0000	0.0000	granulated	Other
42	0.0000	0.0000	granulated	Colima
43	16.2030	12.5573	refined	El Cisne
44	51.5550	39.9551	granulated	Pegaso
45	0.0000	0.0000	granulated	Other
46	41.2440	31.9641	refined	El Cisne
47	0.0000	0.0000	granulated	
48	44.1900	34.2473	refined	El Cisne
49	36.8250	28.5394	refined	
50	0.0000	0.0000	granulated	Pegaso
AVERAGE	30.10	23.33		
STDV	26.25	20.34		

Appendix E

Table 7 - KIO_3 and KI concentration, type, and brand of urban salt samples in Jalisco, Mexico

URBAN				
sample #	[KIO3] (mg/kg)	[KI] mg/kg	Type of salt	Brand
1	42.7170	33.1057	refined	
2	37.4492	29.0231	refined	
3	29.4600	22.8315	granulated	
4	27.9870	21.6899	granulated	
5	25.0410	19.4068	granulated	
6	26.5140	20.5484	granulated	Pegaso
7	31.3961	24.3320	refined	
8	10.3110	7.9910	granulated	
9	32.4060	25.1147	granulated	
10	35.3520	27.3978	granulated	
11	36.8250	28.5394	refined	
12	47.1360	36.5304	granulated	
13	73.6500	57.0788	granulated	
14	36.8250	28.5394	granulated	
15	0.0000	0.0000	granulated	
16	25.0410	19.4068	granulated	
17	0.0000	0.0000	granulated	
18	63.3390	49.0877	granulated	
19	61.8660	47.9462	granulated	
20	0.0000	0.0000	granulated	
21	29.4600	22.8315	granulated	
22	32.4060	25.1147	granulated	
23	0.0000	0.0000	refined	
24	53.0280	41.0967	granulated	
25	0.0000	0.0000	granulated	

26	19.1490	14.8405	granulated	La Fina
27	55.9740	43.3799	granulated	La Fina
28	57.4470	44.5214	granulated	Salvatierra de Coyutlan Colima
29	0.0000	0.0000	granulated	Pegaso
30	70.7040	54.7956	granulated	
31	0.0000	0.0000	granulated	
32	22.0950	17.1236	refined	
33	39.7710	30.8225	granulated	
34	54.5010	42.2383	granulated	
35	57.4470	44.5214	refined	
36	0.0000	0.0000	granulated	
37	0.0000	0.0000	granulated	
38	36.8250	28.5394	granulated	
39	55.9740	43.3799	refined	
40	0.0000	0.0000	granulated	
41	72.1770	55.9372	granulated	Colima
42	29.4600	22.8315	refined	Pegaso
43	14.7300	11.4158	granulated	Salvatierra de Coyutlan Colima
44	47.1360	36.5304	granulated	Colima
45	86.9070	67.3529	refined	La Fina
46	55.9740	43.3799	granulated	Pegaso
47	0.0000	0.0000	granulated	Colima
48	20.6220	15.9821	refined	
49	42.7170	33.1057	granulated	Pegaso
50	53.0280	41.0967	granulated	Pegaso
AVERAGE	33.02	25.59		
STDV	23.47	18.19		

Appendix F

Table 8 - KIO_3 and KI concentration, type and brand of newly purchased salt samples at retail level in Jalisco, Mexico

RETAIL LEVEL				
Sample	Labeled (mg/kg)	[KIO3] (mg/kg)	[KI] mg/kg	Type of salt
URBAN				
La Fina (750g)	40	42.7170	33.1057	refined
La Fina (650g)	40	48.6090	37.6720	refined
La Fina (1kg)	40	76.5960	59.3619	refined
La Fina (220g) *light*	26.8	30.9330	23.9731	refined
Pegaso (1kg)	50	38.2980	29.6810	refined
Pegaso (1kg)	50	61.8660	47.9462	granulated
Pegaso (1kg)	50	66.2850	51.3709	granulated
Pegaso (160g) *light*	34	57.4470	44.5214	refined
Elefante (1kg)	34-68	58.9200	45.6630	granulated
Elefante (1kg)	34-68	25.0410	19.4068	granulated
Elefante (750g) *gourmet*	34-68	67.7580	52.5125	granulated
Great Value (1kg)	34-68	0.0000	0.0000	refined
Great Value (1kg) *fluorinated*	34-68	17.6760	13.6989	refined
Great Value (1kg)	34-68	16.2030	12.5573	refined
Great Value (220g) *low sodium*	34-68	16.2030	12.5573	refined
Biosal (125g) *light*	20-40	17.6760	13.6989	refined
Biosal (125g) *fine herbs*	20-60	10.3110	7.9910	refined
Novoxal (450g) *light*	34-68	13.2570	10.2742	refined
Novoxal (110g) light	34-68	30.9330	23.9731	refined
Soriana (1kg)	34-68	75.1230	58.2203	refined
Soriana (1kg)	34-68	33.8790	26.2562	refined
Cisne (1kg)	40	10.3110	7.9910	granulated
Cisne (1kg)	40	70.7040	54.7956	refined

Krisal (1kg)	20-40	17.6760	13.6989	granulated
Granulated (1kg)		0.0000	0.0000	granulated
RURAL				
Aurrera (500g)	34-68	16.2030	12.5573	refined
Diamante Azul (1kg)		0.0000	0.0000	granulated
AVERAGE		34.10	26.43	
STDV		24.46	18.96	

Appendix G

Table 9 – KI concentration, type, and brand of CSB salt samples

CSB				
sample #	Labeling	[KI] (mg/kg)	Type of salt	Brand
1	none	4.5869	refined	none
2	iodized	46.2449	refined	Morton
3	not iodized	0	refined	Morton
4	not iodized	0	refined	Morton
5	not iodized	0	sea salt	McCormick
6	not iodized	0	refined	Morton
7	iodized	68.7822	refined	Morton
8	iodized	45.7645	refined	Stonemill Essentials
9	not iodized	0	refined	Morton
10	iodized	72.8179	refined	Morton
11	not iodized	0	Kosher coarse	Morton
12	not iodized	0	sea salt	Food Club
13	not iodized	0	sea salt	Morton
14	iodized	59.8197	refined	Morton
15	none	99.7053	refined	none
16	none	116.4597	refined	Morton
17	iodized	47.8872	refined	Morton
18	not iodized	0	refined	Food Club
19	iodized	54.6746	refined	Stonemill Essentials
20	iodized	78.8278	refined	Food Club
AVERAGE		69.56		
STDV		28.42		

Appendix H

Table 10 - KI concentration, type, and brand of SJU salt samples

SJU				
sample #	Labeling	[KI] (mg/kg)	Type of salt	Brand
1	not iodized	0	refined	Food Club
2	none	74.6698	refined	N/A
3	not iodized	0	sea salt	Essential
4	not iodized	0	sea salt	McCormick
5	not iodized	0	sea salt	Morton
6	none	0	sea salt	Watkins
7	not iodized	0	refined	Food Club
8	iodized	28.2676	refined	Food Club
9	none	0	sea salt	Mediterranean
10	not iodized	0	refined	Morton
11	not iodized	0	sea salt	Food Club
12	none	73.0712	refined	N/A
13	iodized	55.4607	refined	Food Club
14	iodized	39.0558	refined	Food Club
15	not iodized	0	sea salt	McCormick
16	not iodized	0	sea salt	Morton
17	none	40.6893	sea salt	N/A
18	iodized	39.8332	refined	Morton
19	not iodized	0	sea salt	McCormick
20	not iodized	0	refined	Morton
AVERAGE		50.15		
STDV		16.70		

Appendix I

Table 11 - KI concentration, type, and brand of newly purchased samples at local stores near CSB/SJU

RETAIL U.S.				
sample #	Labeling	[KI] (mg/kg)	Type of salt	Brand
1	iodized	76.1024	refined	Food Club
2	iodized	56.9458	refined	Morton
AVERAGE		66.52		
STDV		9.58		

Acknowledgements

— Dr. Amy Olson for being my thesis advisor and for her mentorship over the past 2 years and assistance in the design, implementation, and execution of this project.
— Dr. Jayne Byrne and Dr. Emily Heying for their willingness to be committee members and taking the time to read and edit my thesis.
— Dr. Richard Wielkiewicz for his statistical assistance in the analysis of the data.
— Dr. Brian Johnson for his assistance understanding and interpreting chemical analysis of iodine, and the conversion of units.
— Dr. Pablo Garcia Solis (Autonomous University of Queretaro, Mexico) for his guidance and endless help to learn about iodine in Mexico.
— Dr. Purnendu Dasgupta (University of Texas at Arlington) for his advice on iodine testing techniques and kind offer to ask Dr. Charles Shelor to complete the salt analysis of samples collected at CSB/SJU.
— Dr. Charles Shelor (University of Texas at Arlington) for his hard work to complete the salt analysis of samples collected at CSB/SJU, and detailed report of data collected.

I would like to thank the College of Saint Benedict and Saint John’s University Undergraduate Research Program and the Honors Thesis Fellowship Program for funding this research.

Bibliography

1. Secretaria de Salud. Notificacion Semanal. Casos nuevos de enfermedades (September, 2013) http://www.facmed.unam.mx/deptos/microbiologia/pdf/Reporte_septiembre_2013_Casos_Nuevos_Enfermedades_Mexico.pdf

2. Secretaria de Salud. Notificacion Semanal. Casos nuevos de enfermedades (March, 2013) http://www.ddic.com.mx/investigacion/wp-content/uploads/2014/01/Casos_nuevos_enfermedades_2013.pdf

3. Secretaria de Salud. Notificacion Semana. Casos nuevos de enfermedades (June, 2014) http://www.epidemiologia.salud.gob.mx/doctos/infoepid/inf_morbilidad/2014/morbi_jun_2014.pdf

4. Zimmmerman, Michael B. (2009). Iodine Deficiency. *Endocrine Reviews*, 30(4), 376-408. doi: 10.1210/er.2009-0011

5. International Council of Control of Iodine Deficiency Disorders. (2004). *Optimal iodine nutrition in the Americas*. Lima, Peru: Eduardo A. Pretell

6. Martinez, A. H., & Perez, E. J. (2012). *Iodine: Characteristics, sources, and health implications*. New York: Nova Biomedical Books.

7. Méndez-Villa, L., Elton-Puente, J., Solís-S, J., Sampson-Zaldívar, E., García-G, C., Villalobos, P., García-Solís, P. (2014). Iodine nutrition and thyroid function assessment in childbearing age women from Queretaro, Mexico. *Nutricion Hospitalaria*, 29(1), 204-211. doi:10.3305/nh.2014.29.1.6996

8. Zou Y, Lou X, Ding G, et al. (2014) A cross- sectional comparison study on the iodine nutritional status between rural and urban residents in Zhejiang Province, China. *BMJ Open*, 4:e005484. doi:10.1136/bmjopen-2014- 005484

9. Pineda-Lucatero, A., Avila-Jiménez, L., Ramos-Hernández, R., Magos, C., & Martínez, H. (2008). Iodine deficiency and its association with intelligence quotient in schoolchildren from Colima, Mexico. *Public Health Nutrition*, 11(7), 690-698.

10. Swanson, C. A., & Pearce, E. N. (2013). Iodine insufficiency: a global health problem?. *Advances In Nutrition*, *4*(5), 533-535. doi:10.3945/an.113.004192

11. Dasgupta, P. K., Yining, L., & Dyke, J. V. (2008). Iodine Nutrition: Iodine Content of Iodized Salt in the United States. *Environmental Science & Technology*, 42(4), 1315-1323.

12. García-Solís, P., Solís-S, J., García-Gaytán, A., Reyes-Mendoza, V., Robles-Osorio, L., Hernández-Montiel, H., & Leo-Amador, G. (2011). Iodine Nutrition Status in Pregnant Women in Mexico. *Thyroid*, 21(12), 1367-1371. doi:10.1089/thy.2011.0197l

13. Leung, A. M., Braverman, L. E., & Pearce, E. N. (2012). History of U.S. Iodine Fortification and Supplementation. *Nutrients*, *4*(11), 1740-1746. doi:10.3390/nu4111740

14. NIH (National Institutes of Health). Office of Dietary Supplements. Iodine – Fact Sheet for Health Professionals. http://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/

15. Branson, H. M. (2013). Normal myelination: a practical pictorial review. *Neuroimaging Clinics Of North America*, *23*(2), 183-195. doi:10.1016/j.nic.2012.12.001

16. Yarrington, C., & Pearce, E. N. (2011). Iodine and Pregnancy. Journal Of Thyroid Research, 1-8. doi:10.4061/2011/934104

17. WHO. *Urinary iodine concentrations for determining iodine status deficiency in populations*. Vitamin and Mineral Nutrition Information System. Geneva: World Health Organization; 2013 (http://www.who.int/nutrition/vmnis/ indicators/urinaryiodine, accessed [January 18, 2015]).

18. Hynes, K. L., Otahal, P., Hay, I., & Burgess, J. R. (2013). Mild Iodine Deficiency During Pregnancy Is Associated With Reduced Educational Outcomes in the Offspring: 9-Year Follow-up of the Gestational Iodine Cohort. *Journal Of Clinical Endocrinology & Metabolism*, *98*(5), 1954-1962. doi:10.1210/jc.2012-4249

19. Zava, T. T., Kapur, S., & Zava, D. T. (2013). Iodine and creatinine testing in urine dried on filter paper. *Analytica Chimica Acta*, *764*64-69. doi:10.1016/j.aca.2012.12.021

20. Charlton, K., Yeatman, H., Brock, E., Lucas, C., Gemming, L., Goodfellow, A., & Ma, G. (2013). Improvement in iodine status of pregnant Australian women 3 years after introduction of a mandatory iodine fortification programme. *Preventive Medicine*, *57*(1), 26-30. doi:10.1016/j.ypmed.2013.03.007

21. Pearce, E. N., Andersson, M., & Zimmermann, M. B. (2013). Global iodine nutrition: where do we stand in 2013? *Thyroid*, 23(5), 523-528. doi:10.1089/thy.2013.0128

22. IGN (Iodine Global Network), McNeil Donald. (2006). In Raising the World's I.Q., the Secret's in the Salt. http://www.ign.org/p142000392.html

23. Gushurst, C. A., Mueller, J. A., Green, J. A., & Sedor, F. (1984). Breast Milk Iodide: Reassessment in the 1980s. Pediatrics, 73(3), 354.

24. Azizi, F., & Smyth, P. (2009). Breastfeeding and maternal and infant iodine nutrition. *Clinical Endocrinology*, *70*(5), 803-809. doi:10.1111/j.1365-2265.2008.03442.x

25. The Salt Institute. (2013). Iodized Salt. http://www.saltinstitute.org/news-articles/iodized-salt/

26. Andersson et al. (2010). Epidemiology of iodine deficiency: Salt iodisation and iodine status. *Best Practice & Research Clinical Endocrinology & Metabolism*, 24, 1–11. doi:10.1016/j.beem.2009.08.005

27. Weng, H.X., Liu, H.P., Li D.W., Ye M., Pan L., Xia T.H. (2014). An innovative approach for iodine supplementation using iodine-rich phytogenic food. *Environ Geochem Health*, 36, 815–828. DOI 10.1007/s10653-014-9597-4

28. Untoro, J., Schultink, W., West, C., Gross, R., & Hautvast, J. (2006). Efficacy of oral iodized peanut oil is greater than that of iodized poppy seed oil among Indonesian schoolchildren. *American Journal Of Clinical Nutrition*, *84*(5), 1208-1214

29. IGN (Iodine Global Network). Iodate or iodide? http://ign.org/p142000383.html

30. VMR https://us.vwr.com

31. World Food Programme. Technical Specifications for Iodized Salt. (2013). http://home.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp228072~4.pdf

32. Mirmiran, P., Nazeri, P., Amiri, P., Mehran, L., Shakeri, N., & Azizi, F. (2013). Iodine Nutrition Status and Knowledge, Attitude, and Behavior in Tehranian Women Following 2 Decades Without Public Education. Journal Of Nutrition Education & Behavior, 45(5), 412-419.

33. AMISAC Asociación Mexicana de la Industria Salinera A.C. Evolución normativa de la Yodación de sal en México http://www.amisac.org.mx/index_archivos/24.htm

34. Secretaría de Salud. Norma Oficial Mexicana NOM-040-SSA1-1993, Bienes y Servicios. Sal yodada y sal fluorurada. Especificaciones sanitarias. (1993). http://www.salud.gob.mx/unidades/cdi/nom/040ssa13.html

35. Secretaría de Salud. Modificación a la Norma Oficial Mexicana NOM-040-SSA1-1993, Productos y Servicios. Sal yodada y sal fluorurada. Especificaciones sanitarias. (2003). http://www.salud.gob.mx/unidades/cdi/nom/m040ssa193.html

36. COFEPRIS, Proyecto: Sal Yodada y Fluorurada http://www.cofepris.gob.mx/Paginas/Temas%20Interes/Programas%20y%20Proyectos/Alimentos/SalYodadaFluorurada.aspx

37. García-Solís P., Solís-S J.C., García-Gaytán A.C., Reyes-Mendoza V.A., Robles-Osorio L., Villarreal-Ríos E., Leal-García L., Hernández-Montiel H.L. (2013). Iodine nutrition in elementary state schools of Queretaro, Mexico: correlations between urinary iodine concentration with global nutrition status and social gap index. *Arq Bras Endocriol Metab*, 57(6), 473-82.

38. Shelor, C. P., & Dasgupta, P. K. (2011). Review of analytical methods for the quantification of iodine in complex matrices. *Analytica Chimica Acta*, *702*(1), 16-36. doi:10.1016/j.aca.2011.05.039

39. Secretaria de Salud. Programa de Acción: Protección Contra Riesgos Sanitarios. *Sistema Federal de Protección Sanitaria. (2003)*

40. Rah, J. H., Garg, A., Naidu, B. G., Agrawal, D. D., Pandey, R. S., & Aguayo, V. M. (2013). Reaching the poor with adequately iodized salt through the Supplementary Nutrition Programme and Midday Meal Scheme in Madhya Pradesh, India. *Bulletin Of The World Health Organization*, *91*(7), 540-544. doi:10.2471/BLT.12.110833

41. Monárrez-Espino, J. J., & Greiner, T. T. (2005). Iodine nutrition among indigenous Tarahumara schoolchildren in Mexico. *European journal of clinical Nutrition*, 59(10), 1213-1216. doi:10.1038/sj.ejcn.1602214

42. Jooste, P. L. (2003). Assessment of the iodine concentration in table salt at the production stage in South Africa. *Bulletin Of The World Health Organization*, *81*(7), 517.

43. Encuesta Nacional de Salud y Nutricion 2012. Evidencia para la politica publica en salud. 2012 http://ensanut.insp.mx/doctos/analiticos/ConsumoTabaco.pdf

44. CDC Current Cigarette Smoking Among Adults in the United States. 2013. http://www.cdc.gov/tobacco/data_statistics/fact_sheets/adult_data/cig_smoking

45. Caldwell, K. L., Pan, Y., Mortensen, M. E., Makhmudov, A., Merrill, L., & Moye, J. (2013). Iodine Status in Pregnant Women in the National Children's Study and in U.S. Women (15-44 Years), National Health and Nutrition Examination Survey 2005-2010. *Thyroid*, *23*(8), 927-937. doi:10.1089/thy.2013.0012

46. Delange, F. (2007). Iodine requirements during pregnancy, lactation and the neonatal period and indicators of optimal iodine nutrition. *Public Health Nutrition*, *10*(12A), 1571-1580