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Original Article

Analysis of iodine content in seaweed by GC-ECD and estimation of iodine intake

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ABSTRACT

Edible seaweed products have been consumed in many Asian countries. Edible seaweeds accumulate iodine from seawater, and are therefore a good dietary source of iodine. An adequate consumption of seaweed can eliminate iodine deficiency disorders, but excessive iodine intake is not good for health. The recommended dietary reference intake of 0.15 mg/d and 0.14 mg/d for iodine has been established in the United States and Taiwan, respectively. In this study, 30 samples of seaweed were surveyed for iodine content. The samples included 10 nori (Porphyra), 10 wakame (Undaria), and 10 kombu (Laminaria) products. The iodine in seaweed was derivatized with 3-pentanone and detected by gas chromatography-electron capture detector (GC-ECD). The method detection limit was 0.5 mg/kg. The iodine content surveyed for nori was 29.3–45.8 mg/kg, for wakame 93.9–185.1 mg/kg, and for kombu 241–4921 mg/kg. Kombu has the highest average iodine content 2523.5 mg/kg, followed by wakame (139.7 mg/kg) and nori (36.9 mg/kg). The GC-ECD method developed in this study is a low-cost alternative to inductively coupled plasma-optical emission spectroscopy for iodine detection in seaweeds. The iodine intake from seaweed in the current survey was calculated and compared with the iodine dietary reference intake of Taiwan. The risk and benefit of seaweed consumption is also discussed.

1. Introduction

Marine algae are rich in dietary fiber, vitamins, and minerals, as well as long-chain polyunsaturated fatty acids [1–5]. Because seaweeds are low in calories and full of nutrients, adequate consumption of seaweeds is beneficial to health [6–8]. Marine algae nori (Porphyra), wakame (Undaria), and kombu (Laminaria) are popular food ingredients in Asian countries such as Taiwan, China, Japan, and Korea. Seaweeds are well-known food sources with rich iodine content [9]. Iodine is required throughout life and is related to proper cognition function development for children [10]. Although iodine is essential for proper thyroid function, too much or too little iodine is harmful to health. In recent years, reports of food recall due to excessive iodine content in Australia, Ireland, Singapore, and the European Commission Rapid Alert System for Food and Feed have raised concerns internationally, especially for seaweed and seaweed products. Iodine-induced toxic

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effects through consumption of kelp-containing tea have been reported by Müssig et al [11]. Crawford et al [12] reported serious thyroid dysfunction in those who consume soy milks manufactured with kombu in Australia, and these soy milk products were recalled in Australia, Ireland, and Singapore. A very high iodine content of 22,911 mg/kg in dried seaweed has been reported by the European Commission Rapid Alert System for Food and Feed [13]. However, occasionally food with low iodine content will also cause consumer concern. According to the news released from the Center for Food Safety in Hong Kong, some baby milk powder products had very low iodine content [14]. In Europe, the United States, and Australia, the recommended dietary reference intake (DRI) of 0.15 mg/d for iodine has been established [15,16]. The DRI is set at 0.14 mg/d for adults in Taiwan [17]. For consumer health, the World Health Organization set a provisional maximum tolerable daily intake of 1.0 mg iodine/d (0.017 mg/kg body weight) from all sources [18]. The tolerable upper intake level of iodine is 1.0 mg/d for adults older than 20 years in Taiwan [17]. The upper intake level is 1.1 mg/d for adults in the United States and Australia [16]. According to Zimmermann and Andersson [19], there are 32 countries with iodine deficiency problems, more than half of which are in the industrialized world. Knowledge about iodine content in food will help consumers maintain optimal iodine consumption and protect against excessive intake. Iodine concentration in food needs to be monitored for consumer health, and this is carried out in Japan [20,21], Canada [22], Hong Kong [23], the UK [24], Australia [25], China [26], and in many other countries. Although the European Union has not issued any regulation on maximum permissible iodine levels in algae food products, France has set a limit of 5 mg/kg dry matter for iodine in edible seaweeds [1]. The Federal Institute for Risk Assessment in Germany warned that dry algae food products with more than 20 mg/kg dry weight might damage health [27]. The US Food and Drug Administration has set an upper limit of 5000 ppm for iodine in algal products on dry mass basis [1], whereas Australia has set a maximum tolerable iodine level of 1000 mg/kg dried weight in algal food [25].

Iodine is volatile and can be reduced or oxidized easily, which makes analyzing iodine content in foodstuff a challenging task. Many analytical methods have been developed for the determination of iodine content in food, including neutron activation analysis, inductively coupled plasma-optical emission spectroscopy (ICP-OES), ICP-mass spectrometry (ICP-MS) and gas chromatography-electron capture detector (GC-ECD) [28–31]. Neutron activation analysis can analyze very low iodine concentrations but is costly and requires special equipment. The sensitivity of iodine measurement by ICP-OES is not very good because of the vacuum UV emission of iodine and the interference from phosphorous emission. ICP-MS tends to have poor signal stability and memory effects for iodine detection [30]. Sample deposition on the sampler and skimmer cones and sample material buildup in the plasma torch and spray chamber could happen in ICP-MS and cause serious memory effects. Several GC-ECD methods such as pentafluoro derivatives [32] and ketone derivatives [20,21,33–35] have been developed for iodine determination. The pentafluoro derivatization reagent, however, is expensive and is not cost-effective compared to the ketone reagent. Kikuchi et al [20] analyzed 139 kinds of food and beverages by GC-ECD via derivatization with 2-butanone. The detection limit in the study of Kikuchi et al [20] was 0.5 mg/kg. Derivatization with 2-butanone will produce two isomers. Mitsuhashi and Kaneda [33] determined iodine content in milk, wheat flour, and beef using GC-ECD via derivatization with 3-pentanone. Gu et al [34] determined iodine content in milk and oyster tissue samples by GC-ECD via derivatization with 3-pentanone. Akhoundzadeh et al [35] improved the 3-pentanone derivatization GC-ECD method with head-space single drop microextraction procedure and achieved a detection limit of 250 ng/L in infant formula.

There have been relatively few studies in relation to the iodine content of seaweeds in Taiwan, and only one study specifically reported on the iodine content of seaweeds in Taiwan [32]. The study using GC-ECD was very limited in seaweed samples. The iodine contents of three popular seaweed products in Taiwan—nori, wakame, and kombu—were thus investigated using the GC-ECD method in the present study. The seaweed samples consisted of 10 nori products, 10 wakame products, and 10 kombu products. The method presented here requires relatively low-cost GC equipment and is also suitable for other food matrices. The iodine intake from seaweed in the current survey was calculated and compared with the iodine DRI of Taiwan. The benefits of seaweed consumption are also discussed.

2. Materials and methods

2.1. Reagents and chemicals

KI (potassium iodide; puriss. p.a., reag. ISO, reag. Ph. Eur., ≥99.5%), 3-pentanone (ReagentPlus, ≥99.0%), and $K_2Cr_2O_7$ (ReagentPlus, ≥99.5%) were purchased from Sigma-Aldrich (Sigma-Aldrich, St. Louis, MO, USA). NaOH (ACS, Reag. Ph. Eur) was obtained from Merck (Darmstadt, Germany). H_2SO_4 (Extra Pure Reagent) was from Union Chemical Works Ltd. (Hsinchu, Taiwan). *n*-Hexane (≥99%, HPLC grade) was from Tedia (Fairfield, OH, USA). Seaweed samples were purchased from local convenient stores and supermarkets. All seaweed samples were dried seaweeds. The place of origin for all seaweed samples is listed in Table 1.

2.2. Instrumentations

The Agilent 7890A gas chromatograph equipped with an ECD detector was used for the detection of derivatized product 2-iodo-3-pentanone. The HP-5MS capillary column (Agilent Technologies, Santa Clara, CA, USA) was used for chromatographic separation. The Mettler Toledo AL204 balance was used for weighing of samples. The sample ashing and carbonation were carried in the Nabertherm E4/11/R6 ashing furnace. The Corning PC620D hot plate was used for heating. Delta ultrasonic bath DC400H (Taipei, Taiwan) was used for sample dissolution. The shaker was a funnel shaker FS-12 obtained from Shin Kwang Co. (Taipei, Taiwan).