BIOFORTIFIED WITH IODINE POTATO (SOLANUM TUBEROSUM L.) AND KALE (BRASSICA OLERACEA L. VAR. SABELLICA L.) - REVIEW ARTICLE

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ABSTRACT

The article discusses the consequences of iodine deficiency observed in most countries in the World. Iodine deficiency can cause birth defects, permanent mental and physical disabilities and increase the risk of premature death. Biofortification is the production of micronutrient-rich crops. It is an alternative approach to combat mineral malnutrition. Biofortified crops will be low-energy-dense products high consumption will further prevent an increasingly overweight and obesity among people. Potato may be a good carrier of iodine due to the high consumption of this vegetable among people throughout the year. This publication focuses on collecting information on the biofortification effectiveness of potato - the most consumed vegetable in Poland, and kale which is not very popular among these consumers. Due to its high nutrient content, it is worth promoting the increased consumption of kale among people. Biofortification with iodine of kale will further improve its nutritional value.

KEYWORDS

Biofortification, Potato, Kale, Iodine, Nutritional value.

1. INTRODUCTION

There is a continuous growth of the population on earth, whose adequate nutrition is now becoming a priority task for the agri-food sector nutritionists, food technologists and physicians [1]. In countries with low levels of economic development, the consequences of insufficient intake of essential nutrients are observed. The deficiency of nutrients in diet may contribute to the development of nutrition-dependent diseases [2]. The consequences of such nutritional policies may be more dangerous than the health consequences resulting from hunger, i.e. insufficient energy intake [3].

Iodine is a microelement. This element is responsible for the normal growth, development and physiology of the human body [2]. The deficiency of this element can cause permanent mental and physical impairments and birth defects. In addition to increasing the risk of premature death [4]. Iodine deficiency disorders have been defined as IDD - Iodine Deficiency Disorders. They occur in almost every country in the World [5]. It is estimated that the human body, to function properly, needs about 60 components, of which at least 40 are classified as so-called essential [6]. Despite this, there is currently a global increase in the number of overweight or obese people with a concomitant deficiency of selected macro-and micro-nutrients [1]. Therefore, promoting the importance of a well-balanced diet in the context of human health and ensuring that the population is adequately fed is important in both the prevention and treatment of many diseases. According to WHO, at the turn of the 20th and 21st centuries more than 2 billion people were at risk of iron deficiency (half of them had anemia). More than 250 million children were affected by vitamin A deficiency (40 million had visual impairment). Almost 2 billion people living in areas far from the sea were at risk of iodine deficiency (200 million of them had thyroid goiter) [1, 3].

2. WHAT IS BIOFORTIFICATION?

Biofortification of food crops, is the production of micronutrient-rich crops for human consumption. It is a new approach to combat mineral malnutrition, especially in poor countries. Biofortified crops may contain higher amounts of specific micronutrients, due to their better uptake and accumulation capacity or by their lower content of anti-nutritional compounds. These crops can be obtained by selecting better genotypes, using traditional breeding or modern biotechnology. Alternatively, improved agronomic approaches can be developed and applied [7]. Furthermore, biofortified food crops will have low energy density and high consumption will prevent the increase in overweight and obesity in humans [2]. Biofortification of plant crops with iodine may therefore become a viable strategy for increasing iodine levels in plant-based foods while improving human nutritional status. It is commonly known that, fruits and vegetables are poor sources of iodine, although there are large variations due to different iodine content in soil [8]. Nevertheless, many studies indicate that plants can accumulate iodine and there is a positive correlation between soil applications and the final accumulation of this element in plants [7].

2.1. Top candidates for biofortification with iodine

Several methods of enriching plants with iodine have already been proposed, but none of them can be considered the best. Unfortunately, each species requires careful and detailed evaluation. However, numerous studies have shown that some leafy vegetables (spinach, lettuce) confirm, especially in hydroponic crops, that vegetables are good candidates for iodine biofortification programs, as enhancement of other crop types seems to be more difficult [7, 9, 10, 11, 12].

2.2. Consequences of biofortification

Biofortification in micronutrients can affect not only the content of major components (ascorbic acid, sugars, free amino acids or phenolic compounds) in the plant but also the content of other elements [13]. By enriching plants with a particular element, we can obtain increased or decreased amounts of the other micronutrients contained in the raw material. An example is a research conducted by the Agricultural University in Krakow on the biofortification of carrots. Biofortification with iodine may influence the content of other mineral components. These changes may not only be positive but also negative, as they may reduce the nutrition of plants in other important micro-and macro-elements, thus reducing the abundance of plant food products [7].

2.3. Which vegetables and fruits have so far been successfully biofortified with iodine

Several techniques have been developed worldwide to biofortified plants with iodine. These include hydroponics, pot, and field experiments. Iodine accumulation demonstrated in lettuce, spinach, beans, pakchoi, cabbage, Chinese cabbage, tomato, rice, strawberry, cucumber, kohlrabi, celery, radish, potato and carrot [14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33].

2.4. Why produce biofortified with iodine vegetables and fruit?

Nowadays, considering the increasing number of people who are overweight or obese, comprehensive methods should be developed to provide better nourishment for the human population. High consumption of plant-based foods prevents the development of overweight and obesity and nutrition-dependent diseases among people [2]. Continuously promoting the consumption of those products will influence consumers' nutritional choices and inhibit the ever-increasing percentage of people suffering from obesity. Moreover, enrichment of plant-based foods, through biofortification of vegetables with iodine, can simultaneously prevent the development of goiter and thyroid diseases and reduce the prevalence of overweight and obesity among the human population.

3. THE IMPORTANCE OF IODINE FOR HUMAN HEALTH

Iodine is part of the thyroid hormones and therefore it is important for maintaining their normal production process. Like iodine deficiency, iodine excess can cause impaired thyroid function. Deficiency can lead to thyroid goiter, while excess can cause the Wolff-Chainkoff effect [2].

3.1. Why should the iodization of table salt be changed?

In a study including more than 1,400 children, iodization of table salt was shown to increase urinary iodine concentrations while reducing the incidence of goiter in children. Some studies have also shown that mandatory enrichment of food, such as in Denmark table salt and that used in bread baking, increased the incidence of autoimmune diseases of the thyroid gland. In contrast, another study conducted with a female Hashimoto patient showed that more than one-third of those included in the study did not consume sufficient iodine in their diet [34, 35].

Current iodine prophylaxis is based on the mandatory use of iodized table salt, using inorganic iodine compounds in the form of potassium iodide [5]. Although this effectively reduces the iodine deficit in the body and prevents the development of goiter and thyroid disease, it is associated with a very high salt intake (12.6-16.0 g NaCl/day in many countries) In comparison, the recommendations by the WHO of 5 g NaCl/day [1]. This excessive salt intake is a factor that increases the risk of cardiovascular disease [2] and may be involved in the increased incidence of Hashimoto's lymphocytic chronic thyroiditis [34]. Thus, biofortification of plants with iodine can be an effective and low-cost method of iodine prophylaxis and a safe alternative to the iodization of table salt.

3.2. Is salt iodization with inorganic forms of iodine (potassium iodide) the safest method?

The results of a study conducted at the University of Agriculture in Krakow showed that iodine (depending on the chemical form) had different effects on the viability of Caco2 colon cancer cells. It was shown that the addition of KI (potassium iodide), compared to lettuce extract not enriched in iodine, did not affect on cancer cell proliferation, while lettuce extract enriched in organic iodine markedly reduced it. Furthermore, multiple genes under different regulations were identified, suggesting divergent mechanisms of action between iodine introduced during biofortification and iodine added as KI salt to unfortified lettuce. Further analyses showed that iodine biofortified lettuce significantly regulates the transcription of genes related to the cell cycle and apoptosis process [36].

3.3. Other dietary sources of iodine and their absorption from the gastrointestinal tract

The iodine content of food depends on the origin, such as groundwater and soil abundance of this element. Products rich in iodine include foods of marine origin (fish, crustaceans, molluscs). Halibut and cod are particularly rich in iodine, Baltic herring less so. Other dietary sources of iodine are eggs, milk, milk products, iodized salt and water enriched with this micronutrient, which is increasingly common on the market [2, 35].

Iodine in the gastrointestinal tract is absorbed almost 90% from food, although the absorption of iodine by the thyroid gland is about 25-30% of the amount consumed.

Iodine absorption is hindered by sulphonamides, glycosides containing cyano groups (mainly in cabbage, peanuts, and cauliflower), rhodamines, soy flour (found in food), and fluoride, nitrate, magnesium, calcium, and iron found in water [2].

4. WHY SHOULD WE ENRICH POTATOES

4.1. History of cultivation and consumption of the potato (*Solanum tuberosum L.*)

The potato (*Solanum tuberosum L.*) belongs to the Solanaceae family. It is native to South America, in what is now Peru, Chile and Bolivia. Traces of potato cultivation in these areas date back to 4,000 BC. It was brought to Europe in the second half of the 16th century but at first, it was an unusual specimen of a new plant found mainly in botanical gardens. Later it was included among medicinal, ornamental and horticultural plants [37].

In Poland, it is said that the earliest people to know and cultivate the potato were apothecaries from Wrocław. As early as 1569, it was growing in the botanical gardens and later in the gardens of the pharmacists of Wrocław as a medicinal plant. As reported by many researchers [38, 39, 40], the year 1683 is considered the beginning of potato cultivation in Poland.

4.2. Why the potato in Poland is a good product for biofortification with iodine?

In the 19th century, the potato was used as a raw material for alcohol distillation, as basic feed for pigs, and starch production. However, the potato played its greatest role as a valuable nutrition source. It improved the quality of nutrition of the rural and urban population in the developing industrial centres and increased the intake of vitamin C, which had a considerable effect on the general health of Poles. For this reason, the potato was considered at that time a symbol of modernity and progress in plant cultivation [41, 42].

Potato is a major product in the diet of most Poles due to its high nutritional and culinary value. Despite lower potato production, its consumption is quite high, with 116-130 kg in the last ten years and 112 kg per capita per year in the last season (2010/2011) [37]. Moreover, it is "one of nature's best-designed products" - it is born in a first-class package and, stored well, maintains its freshness for a long time [38]. It is also valuable that for the consumer the potato is available all year round [43]. The rich varietal assortment also deserves to be highlighted. In 2011, the National Register included as many as 137 varieties, of which 108 were edible creations and 29 were starchy [37].

Although lettuce and spinach are better candidates for iodine biofortification [7, 14, 20, 22] due to their highest bioavailability, the potato seems to be an easier product for the consumer to include in their diet. Potatoes are consumed by Poles practically every day of the year in contrast to lettuce and spinach, which are seasonal vegetables. Moreover, the amount of lettuce or spinach can be very large in volume and difficult for a consumer to consume to cover the daily iodine requirement (150 ug/day) [2]. If iodine biofortification of the potato were effective and ensured that the daily iodine requirement was met, the potato would be easier for the consumer to consume.

4.3. Nutrition value of the potato *Solanum tuberosum L.*

The nutritional value of potato results from its chemical composition such as: (starch, total and reducing sugars, protein, dietary fiber, vitamins, minerals). In addition it has a low content of harmful compounds (glycoalkaloids, nitrates, pesticide residues) [37-45]. Contrary to prevailing opinion, potato tubers are low in calories and they do not cause obesity. The caloric value of a potato is low (50-90 kcal) and it is comparable to apples or milk [2].

Table 1. Nutrient content of the raw potato (*Solanum tuberosum L.*) tubers [43-45]

Ingredients	Content	Ingredients	Content
Starch	11,0-18,3%	Iron	0,5 mg/100 g
Total sugars	0,3-0,6%	Zinc	0,1 mg/100 g
Total protein	1,7-2,3%	Copper	0,08 mg/100 g
Dietary fibres	2,0-2,5%	Vitamin C	11-28 mg/100 g
Fats	0,1-0,12%	Vitamin B1	0,12 mg/100 g
Total minerals	1,0-1,2%	Vitamin B2	0,04 mg/100 g
Potassium	450 mg/100 g	Vitamin B6	0,3 mg/100 g
Phosphorus	60 mg/100 g	Nicotinic acid	1,2 mg/100 g
Magnesium	22 mg/100 g	Phenolic compounds	15-30 mg/100 g
Calcium	15 mg/100 g	Glycoalkaloids	1,2-12,9 mg/100 g
Sodium	2 mg/100 g	Nitrates	10-30 mg/100 g

Table 1. shows the chemical composition of the raw potato. It is difficult to obtain information about the composition of biofortified potatoes in literature. It would be worthwhile to extend the study of iodine biofortified potatoes to include basic composition, antioxidant potential and other macro-and micro-nutrients. This would make it possible to assess whether biofortification influences other bioactive components.

Péter Dobosy et all. showed that the biofortification of potatoes was not effective. The amount of accumulated iodine was too low to cover the daily iodine requirement of an adult (150 ug/day) [46]. The lack of a positive iodine accumulation in the potato in these authors could have been due to the use of an inappropriate chemical analysis procedure. The method used could result in iodine loss during mineralization in nitric acid. The use of alkaline extraction in TMAH (Tetramethylammonium hydroxide), according to the European Union analytical standard, should have a positive effect on the accumulation of iodine in potatoes. Ledwożyw-Smoleń et al. from the University of Agricultural in Krakow, Poland evaluated the effectiveness of iodine biofortification of potato tubers. Soil application of KI and foliar application of KIO_3 were tested in a three-year field experiment. Both soil and foliar application of iodine resulted in potato tubers with increased content of this element without a decrease in starch and sugar content. The highest efficiency of iodine biofortification was recorded for foliar spraying of KIO_3. The obtained iodine level in 100 g of potatoes could be sufficient to cover up to 25% of the recommended daily intake of this element [47].

The results indicate that iodine biofortified potatoes could become an additional source of iodine in the daily diet. Though more research needs to be done. At this point, there is not a sufficient amount of scientific data to conclude that biofortification of the potato is not effective.

5. WHY SHOULD WE ENRICH KALE

5.1. Frequency of kale consumption in Poland

Kale (*Brassica oleracea L. var. sabellica L.*) is a vegetable whose nutritional value and health properties have been appreciated since ancient times. In Poland, it is still used more commonly for decorating platters than for eating [48]. Kale prevents many dangerous diseases such as cardiovascular diseases and cancer. Kale is a variety of cabbage with long, wrinkled leaves whose health properties are appreciated in Scandinavia. In Poland, few people know the nutritional value of kale, so it is treated more as an ornamental plant. Meanwhile, the colourful leaves of kale (in various shades of green, purple-green and purple-brown) are a treasury of protein, fiber, vitamins-especially vitamin C and K, and mineral salts - especially calcium and potassium, as well as sulforaphane [48, 49].

5.2. Kale - valuable vegetable with anti-cancer properties

Of the brassicas, it is this species that contains the most: potassium, calcium, iron, vitamin A, β-carotene, vitamins: B1, PP and C [48]. Kale, like broccoli and other brassica vegetables, is rich in sulforaphane, an antioxidant that has potent anti-cancer effects [49].

Sulforaphane has the potential to minimalize the risk of prostate, lung and colon cancer, among others. However, for kale to retain as much of its anti-cancer properties as possible, it should be cooked similarly to broccoli, i.e. steamed for a maximum of 3-4 minutes [48]. Otherwise, it will lose its health-promoting effects. Besides, kale contains carotenoids (β-carotene, lutein, zeaxanthin) - antioxidants, which also inhibit harmful oxidative processes and thus may prevent the development of cancer [48, 49].

Carotenoids in kale have been shown to have antioxidant properties. Due to its properties, it is widely used in the pharmaceutical, cosmetic and medical industries. Carotenoids are high activity against free radicals. Chlorophyll (green pigment) in kale masks the colour given by carotenoids (yellow, orange or red). Chlorophyll has antioxidant properties and supports the body's detoxication process. It forms strong bonds with many toxic compounds (including some carcinogens), allowing fewer harmful compounds to reach the body's tissues [48, 49].

Moreover, kale is a source of vitamin K. It is a substance with anti-cancer properties. Vitamin K is believed to inhibit the development of certain cancers, including breast, ovarian, colon, gallbladder, and liver [39]. Kale may also protect against gastric and duodenal ulcers. The sulforaphane contained in this vegetable destroys Helicobacter pylori [48].

Kale contains large amounts of β-carotene, from which the body produces vitamin A, a compound involved in maintaining proper eye sight. It prevents the occurrence of the so-called "night blindness" problems with vision at dusk, and dry eye syndrome. In addition, kale contains other antioxidants such as lutein and zeaxanthin, which are the main components of macular pigment. Their antioxidant activity protects the retina from free radical damage and the damaging effects of excess light energy [49].

5.3. Nutrition value of the kale *Brassica oleracea L. var. sabellica L.*

The health benefits of kale are mainly due to its high content of antioxidant compounds, rarely found in other vegetables. Kale does not contain harmful oxalic acid. This respect is more recommended for children than spinach, which is many times not favoured by them [50-52].

Table 2. Nutrient content of the kale leaf (*Brassica oleracea L. var. sabellica L.*) - fresh weight [50, 51, 52]

Ingredients	Content	Ingredients	Content
Protein (%)	11,67	β-carotene	6,4 mg/100 g
Energy	58,46 kcal/100 g	Hydroxycinnamic acids	204 mg RE/100 g
Ash (%)	1,33		
Fat (%)	0,26	Vitamin C	62,27 mg/100 g
Carbohydrates (%)	2,36	Potassium	440,2 mg /100 g
Dietary fiber (%)	3	Magnesium	34,9 mg/100 g
Moisture (%)	81,38	Calcium	384,8 mg/100 g
Total flavonoids	646 mg/100 g	Sodium	38,5 mg/100 g
Quercetin	44 mg/100 g	Manganese	0,86 mg/100 g
Kaempferol	58 mg/100 g	Zinc	0,83 mg/100 g
Total phenols	384 mg GAE/ 100 g	Copper	0,05 mg/100 g

Table 2. presents the basic chemical composition of kale leaves, total flavonoid, quercetin, kaempferol, total phenol, hydroxycinnamic acids, β-carotene, and selected minerals. There is a lack of information in the literature on the chemical composition of biofortified kale. It would be worthwhile to carry out additional research in this area. This research would enrich the scientific discipline of the food and nutrition field.

5.4. Why kale should be tested for biofortification with iodine?

Due to the high content of health-promoting components in kale, scientists should consider the possibility of biofortifying this vegetable with iodine. Although its popularity in Poland is not high, it is worth promoting the increased consumption of this vegetable. In the future, effective biofortification could additionally enrich this vegetable with another microelement such as iodine. The iodine content per 100 grams of fresh weight in kale is insignificant [2, 53]. It is commonly accepted that, vegetables and fruit are a poor sources of this microelement [36].
Kale is structurally and physically similar to lettuce and spinach, which are among the best iodine-accumulating vegetables during the biofortification process [7, 14, 20, 22]. Kale may prove to be just as much of an accumulating vegetable, or perhaps even better. Its consumption in adequate portions could cover the daily iodine requirement of 150 ug/day for an adult [2]. However, so far researchers have not included this 'anti-cancer' vegetable in their studies. Moreover, the biofortification of kale may increase the content of other macro-and micro-nutrients, as studied [21]. Then kale would become an even better product, from which the consumer would derive even more health benefits when consuming it.

6. CONCLUSIONS

In this review, we focus on the benefits that plant biofortification can provide and why this research is worth continuing. Increasing essential nutrients should be implemented using all biofortification techniques and strategies developed to date. It is most important to achieve this goal with limitations or strengths for each of them.

Of the conventional methods, breeding techniques require a long time to select specific genetic traits of interest and introgress them into crop varieties. Agronomic practices can affect both crop yield and quality. Each method has its advantages and disadvantages [8, 16, 21, 22, 29].

Nonetheless, food producers should take constant care to improve food production to fully nourish the ever-growing population. Vegetables used must be consumed by the majority of the population and are relatively common among consumers. Potato would seem to be the best candidate for obligatory biofortification with iodine in Poland and worldwide. The results of this study may be of great importance to consider potato and kale cultivation as an excellent target for agronomic iodine biofortification and its usefulness as an additional source of iodine in daily diet [46, 47]. Kale is a vegetable that should be recommended more due to its low popularity among consumers. It has highly valuable nutritional values and, in addition, enriching it with iodine can bring even more benefits to its consumption [48, 50, 52]. The issue of kale biofortification is poorly explored. New studies on the effectiveness of iodine enrichment in kale would be useful.

It is worth noting that there is a lack of data on the direct human consumption of biofortified vegetables and the degree of iodine absorption from the gastrointestinal tract. Biofortified vegetables should be evaluated *in vivo* studies. These studies will allow the assessment of the bioavailability of iodine from vegetables biofortified with iodine compounds. Additionally, analyses of selected biochemical parameters of thyroid-regulated processes should be performed in the context of their safety or the risk of excessive or uncontrolled iodine intake. There are is no data on this subject in the literature. Therefore, the results obtained would be of high scientific value and beneficial for the discipline of food and nutrition technology.

Research in this area is being carried out at the University of Agriculture in Krakow, Poland. Research on the effectiveness of iodine biofortification of potato and kale will be undertaken in the near future. The research will involve both organic and inorganic forms of iodine. Based on results from the biofortification of lettuce (*Lactuca sativa L.*), it can be concluded that organic (iodosalicylates) forms of iodine are better than inorganic (KI) [54]. Investigation of the effect of biofortification with different iodine compounds of potato and kale will yield new results. It is noteworthy that additional research is being carried out at the University of Agriculture in Krakow to produce a food supplement from lettuce *Lactuca sativa L.* biofortified with organic iodine compounds (iodosalicylates). The effective biofortification of potato and kale may also give rise to research into the production of supplements from these vegetables.

In the studies, apart from the effectiveness of biofortification and determination of iodine concentration in plants, analyses of the basic composition, polyphenol content, free radicals - ABTS, carotenoids, nitrates, vitamin C, B, and minerals will be carried out. All this is to fully assess the nutritional value of vegetables subjected to biofortification and assess whether the effect is positive or negative. The research can be extended to *in vitro*. We can try to analyze of assessments cytotoxicity, viability and proliferation of cells exposed to extracts with biofortified with iodine kale and potato (organic and inorganic form).

Biofortification in the light of science seems to be a very interesting issue. Nevertheless, if it were to prove successful, the introduction of cultivation on a wider scale could be very problematic. Cultivation of potatoes or kale would probably have to take place in special greenhouses and foil tunnels, where conditions would be constant and would ensure effective biofortification. Introducing this process among farmers may be difficult. The size and quality of the crop being influenced by weather conditions such as water and soil, and by fertilization. This is a distant prospect, until which time prior research must be done on the safety of eating iodine biofortified vegetables and absorption from the digestive tract.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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