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Boron compounds: Challenges and Applications in food industry

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Abstract

Boron compounds have various industrial applications, including the food industry. The most common boron compounds used in the food industry are boric acid and borax, which are often used as food additives to improve the texture and stability of foods.

There is also another boron compound called calcium fructoborate, which is a naturally occurring form of boron and is found in some fruits such as grapes and apples. Calcium fructoborate is a form of boron that is well absorbed by the body and may have health benefits, for instance to protect bones and to improve cognitive function. In the food industry, calcium fructoborate may be used as an ingredient in some food products to provide these health benefits.

Food products containing calcium fructoborate may include beverages, dietary supplements, and functional foods such as protein foods and baked goods. There are also dietary supplements containing calcium fructoborate that are marketed as dietary supplements to support bone and joint health.

The use of boron compounds in foods is established by regulatory agencies such as the Food and Drug Administration (FDA) in the United States and the European Food Safety Authority (EFSA) in Europe. These agencies set dosage limits and strict requirements for the safety of using boron compounds in foods. In conclusion, it is important to follow these regulations and to use boron compounds only in safe and the approved amounts.

Keywords: boron compounds, food industry applications, fructoborate

1. Introduction

Boron (B) is a non-metal, from the 13th group of the periodic system, with properties similar to those of carbon and silicon. There are two forms of elemental boron, namely amorphous boron (brown powder) and crystalline boron (dark gray powder), which is a semiconductor at room temperature [1]. In nature, boron is not present in elemental form, but it occurs bound to oxygen. The most common inorganic compounds of boron with oxygen are borax, boric acid, colemanite, kernite, ulexite and borates. Meanwhile, organic boron compounds contain bor-oxygen or bor-nitrogen bonds, being most often found in plant, animal and human tissues [2]. Boron is found naturally in drinking water and many plants and foods. The large amounts of this trace mineral are discovered in fruits, vegetables, nuts and legumes. Boron is also involved in human and animal nutrition [3]. Thus, boron has beneficial effects on biological functions in humans and animals, such as reproduction, growth, calcium metabolism, bone formation, energy metabolism, immunity, brain function, and steroid hormones, including vitamin D and estrogen [4]. Therefore, the World Health Organization considers boron to be essential for both animal and human health. The recommended daily intake of boron is between 1-3 mg daily for most adults.

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This intake depends on the type of food consumed and the amount of boron in the water used [5]. The European Union (EU) has set the standard level of boron in safe drinking water to be 1.0 mg B/liter [6].The richest sources of boron are the following foods: plum juice, avocado, raisins, peaches, grape juice, apples and pears. Most people in the United States and Europe get most of their boron intake from coffee, milk, apples, beans, and potatoes because they tend to eat large amounts of them [1,5,6].

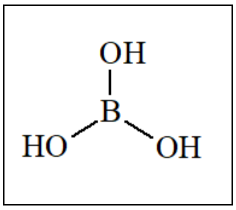
Boron-based compounds have numerous applications in the food industry. The most common compounds in the food industry are boric acid and borax, which are used as additives to improve the texture and stability of food products [7]. Recently, in the food industry, a class of organic boron compounds are considered, namely mono- or di-sugar-borate esters (especially, calcium fructoborate), which have a number of benefits in human health, for instance to protect bones and to improve cognitive function [8]. Food products containing calcium fructoborate may include beverages, dietary supplements, and functional foods such as protein foods and baked goods.

Regulatory agencies, such as the Food and Drug Administration (FDA) in the United States and the European Food Safety Authority (EFSA) in Europe set dosage limits and strict requirements for the safety of using boron compounds in various foods. In conclusion, it is essential to follow these regulations and to use boron-based compounds only in safe and the approved amounts.

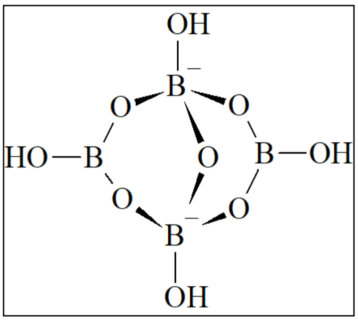
2. Boron compounds used in food industry

2.1. Inorganic boron compounds

The most used inorganic boron compounds in the food industry are boric acid and borax, respectively. Usually, these inorganic boron compounds have various commercial applications due to specific properties, such as, pH buffering and antiseptic or preservative properties. Boric acid (H_3BO_3) (Figure 1 (a)) is a white, crystalline and odorless solid, having certain industrial applications, such as textiles manufactures, fiberglass and ceramic lasers [9]. Borax (sodium tetraborate, or disodium tetraborate) (Figure 1 (b)) is the mineral form with specific household and industrial applications [10].



(a)



(b)

Figure 1. Inorganic boron compounds structures. (a) Boric acid, (b) Borax

The excessive use of these boron-based inorganic compounds indicates a toxic level of boron into the human body. From literature it can be seen that most of the boron toxicity data refer to boric acid. Boron in the form of boric acid is easily absorbed in the gastrointestinal tract. Regarding to the genotoxicity and the carcinogenicity, all studies have shown that boron-containing compounds are not genotoxic [3,11].

2.2. Organic boron compounds

Organoboron compounds have at least one carbon-boron bond in their structure and include the following compounds: boranes, borohydrides, boric esters, boronic acids, boronic esters and boramides [12]. The class of organic boron compounds with important applications in the food industry are mono- or di-sugar-borate esters (SBEs). The most important SBE is calcium fructoborate, which can be used as an ingredient in some food products to provide their health benefits or as dietary supplements to support bone and joint health [13]. Calcium fructoborate (Figure 2) is a natural sugar-borate ester found in various fresh fruits and vegetables, containing three forms of borate (diester, monoester, and boric acid) [14].

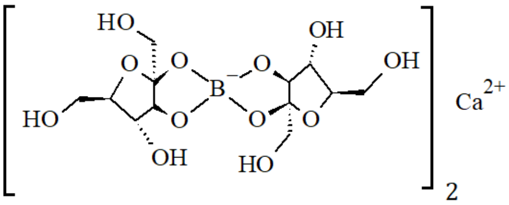


Figure 2. Calcium fructoborate structure

The structure of calcium fructoborate was analyzed and characterized using various spectroscopic methods such as: Fourier-transform infrared (FTIR) spectroscopy, thermogravimetric analysis (TGA), high-performance thin-layer chromatography (HPTLC), nuclear magnetic resonance (NMR), liquid chromatography–multistage accurate mass spectrometry (LC-MSn), X-ray diffraction (XRD), Raman spectroscopy, and inductively coupled plasma (ICP) in non-biological and biological specimens [8,14].

3. Boron food sources

Boron is a trace mineral found naturally in many plant foods such as fruits and vegetables. The main sources of boron for humans are food and drinking water. Boron has multiple benefits, especially for reproduction and development, brain function and immunity. It may also have anti-inflammatory effects [15]. Lately, boron is involved in the optimal functioning of bones, assuring an improvement in the bone formation process and calcium metabolism, respectively. Also, boron has a decisive role in the increasing of the time period in which vitamin D and estrogen remain viable in the body, thus extending their benefits [16,17]. The largest natural exposure to boron for most populations comes from the intake of boron from food. Also, people's daily intake of boron can vary greatly depending on the proportions of various food groups in the diet. Plant-based foods, especially fruits, leafy vegetables, nuts and legumes, are rich in boron, as are wine, cider and beer [18]. National Institutes of Health from US have identified 10 foods with the highest content of boron having multiple health benefits [19,20] as listed in Table 1.

Table 1. List of the 10 foods with the highest content of boron established by National Institutes of Health (US) [19,20]

Foods	Boron content (mg B/100 g)	Supplemetary minerals, fibers or vitamins	Health benefits
Apples	0.66	Potassium, fiber and vitamin C	a high content of various beneficial nutrients and antioxidants
Avocado	1.07	Copper, folate and vitamin K	a great source of healthy fats and dietary fibers
Beans	0.48	Iron, magnesium, phosphorus, potassium, and folate	a full of inexpensive source plant-based protein
Grape juice	0.76	Vitamin C and polyphenols	a great source of antioxidants
Peaches	0.80	Vitamin C and A	a great source of antioxidants
Peanuts	0.48	Phosphorus, copper, niacin and folate	a good source of healthy mono- and polyunsaturated fats
Peanut Butter	0.46	Potassium	a good source of saturated and unsaturated fats
Pears	0.50	Copper, potassium, fiber and vitamin C	a good source of dietary fibers
Prune juice	1.43	Calcium, phosphorus and potassium and dietary fiber	a good functioning of digestive and bone system
Raisins	0.95	Potassium, fiber and small amounts of calcium and iron	a good source of dietary fibers

The boron content of the 10 foods from Table 1 is according to the tolerable upper intake level (UL) for adults (1÷13 mg boron per day) proposed by the World Health Organization [1,21]. Meanwhile, the UL of borron (mg/day) established by the European Food Safety Authority (EFSA) is 10 mg/day for an adult and in the range of 3 mg/day to 9 mg/day for children depending on the age [22].

4. Applications of boron compounds in food industry

Based on the safety analysis developed by The Scientific Panel on Food Additives, Flavourings, Processing Aids and Materials in Contact with Food (AFC) (2005), boric acid and sodium borate can be used as for certain nutritional applications and food supplements [23].

The Panel on Food Additives and Nutrient Sources added to Food (ANS) (2013) concluded that these two food additives: boric acid (E 284) and sodium tetraborate (borax) (E 285) are suitable as preservatives of sturgeon eggs (caviar) up to a maximum concentration of 4 g boric acid/kg in UE [24].

Currently, boric acid is used in the development of the absorbing packaging systems being a proper moisture absorber [25,26]. Argin et al. (2019) have developed new biodegradable antimicrobial packaging films from gelatin with various inorganic boron compounds (boric acid, disodium octaborate tetrahydrate and sodium pentaborate as antimicrobial agents [27]. Another challenging inorganic boron compound with potential applications in the development of the food packaging is hexagonal boron nitride with a similar structure as graphite [28,29] (Figure 3) which can improve the strength and ductility of foods packaging films. Nguyen et al. (2018) have proposed a boron nitride nanosheet (BNNS)-reinforced cellulose nanofiber (CNF) film with good oxygen-barrier properties, being suitable as a packaging material for meat and cheese [30].

Recently, there were synthetized carbon quantum dots (CQDs) based on glucose and certain heteroatoms (boron, sulfur and nitrogen atoms). These CQDs doped with boron are involved in the development of active packaging for food films as functional fillers as a result their antibacterial properties and antioxidant activity [31].

There are a number of dietary supplements that contain only boron and others with boron in combination with several nutrients, often minerals. Usually, in dietary supplements, we can identify various organic boron compounds, such as sodium borate, sodium tetraborate, boron amino acid chelate, boron ascorbate, boron aspartate, boron citrate, boron gluconate, boron glycinate, boron picolinate and calcium fructoborate [33].

The EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA) (2021) have concluded that the chemical synthetized calcium fructoborate can be used as a novel food (NF). The content of the calcium fructoborate obtained by chemical synthesis is the following 2,9% boron, 4,7% calcium and 84,2% fructose [34].

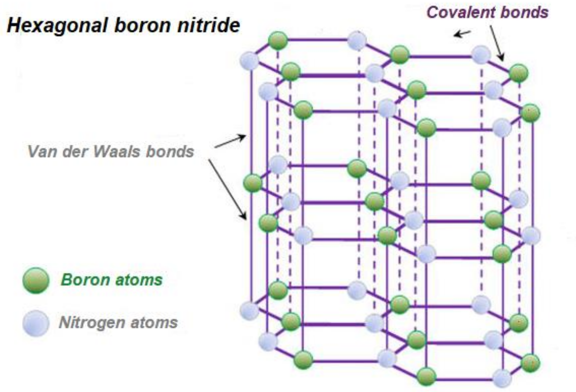


Figure 3. Hexagonal boron nitride structure. Adapted from [32]

5. Conclusions

Boron is a non-metal having beneficial effects on animal and human health. The natural sources of boron are drinking water, various plants and foods. The most significant amount of boron is found in fruits, vegetables, nuts and legumes. The World Health Organization established that the standard daily dose of boron for adults to be 1-13 mg boron/day. Boron-based compounds have many industrial applications, such as: the chemical industry, the pharmaceutical industry and the food industry. The most used inorganic compounds in the food industry are borax and boric acid as food additives or in combination with other compounds to obtain biodegradable food packaging materials.

Organic boron compounds, such as calcium fructoborate, which are naturally found in grapes and apples, are also used in the food industry. Calcium fructoborates can be used as an ingredient in various food products to protect bones and to improve cognitive function. Food products containing calcium fructoborate may include beverages, dietary supplements, and functional foods such as protein foods and baked goods. Nowadays, there are various dietary supplements containing calcium fructoborate that are marketed as dietary supplements to support bone and joint health.

The use and marketing of foods with boron-based compounds is regulated by the Food and Drug Administration (FDA) in the United States and the European Food Safety Authority (EFSA) in Europe. These agencies established dosage limits and strict requirements for the safety of using boron compounds in food products. So, it is mandatory to follow these regulations and to use boron compounds in the approved amounts.

Conflict of Interest. Author has declared that no competing interests exist.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human / or animal subjects (if exist) respect the specific regulation and standards.

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