# Fructans and Mineral Nutrition

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**Abstract:** Fructan molecules have a history of more than 150 years and ancient peoples used fructans containing plants as food, feed or medicine. The modern history of fructans began with their discovery by Rose (1804) and known at the turn of the $20^{th}$ century considerable development with Edelman's proposal concerning their metabolism in higher plant. At present time, fructans are considered food not food ingredients, and are found in more than 500 food products resulting in significant daily consumption. Because the science of nutrition itself has changed, fructans are now considered as functional foods and the passionate history of their health benefits continues to arise interest of scientists. Contrary to the fact that non-digestible carbohydrates have been accused of causing an impairment in the small intestine absorption of minerals, research conducted during the last three decades demonstrated that fructans enhanced mineral absorption, and the scientific evidence claiming that fructans enhance mineral absorption is based on both animal and human experiments which are very conclusive. Although different hypotheses have been proposed to explain the roles of fructans in enhancing minerals absorption, the mechanisms behind this enhancement are still unclear, even though investigation have demonstrated that different fructans-related mechanisms may be involved in the increased absorption of minerals due to fructans intake. This review paper aims to report on the recent development and the roles of fructans in enhancing mineral absorption and their deficiencies prevention.

**Keywords:** Fructans, minerals, absorption, deficiency, nutrition.

## HISTORY OF FRUCTANS

Fructan molecules have a history of more than 150 years, and some review articles have reported some historical aspects including little on the general history on fructans research [1-3]. First and prior to the contemporary science of fructans, ancient peoples used fructans containing plants as food, feed or medicine. The modern history of fructans began with their discovery by Rose (1804) and known at the turn of the past century considerable development with Edelman's proposal concerning their metabolism in higher plant. More recently, Fructans research has known a considerable progress, especially with the molecular biology tools, thus the scope of fructans research has expended from basic to applied science. At present time, fructans are considered food and not food ingredients, and are found in more than 500 food products resulting in significant daily consumption. Because the science of nutrition itself has changed, fructans are now considered as functional foods which have been introduced as a new concept [4,5]. This passionate history of fructans concerning their chemistry, biochemistry, enzymology and health benefits continues to arise interest of scientists who discover every day their potentials as foods and ingredients.

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## CHEMISTRY OF FRUCTANS

### Definition

Fructans, poly-fructosylsucroses of varying molecular size build on a sucrose starter unit, are $1^F$ (1-β-D-fructofuranosyl)*n* sucrose oligomers where *n* may vary. Fructans are considered as carbohydrates with varying degree of polymerization (DP) and consequently varying molecular weight [6]. They consist of one sucrose molecule to which other molecules of fructose have been added (Figure **1**). The term of fructans is somewhat ambiguous since the number of fructose moieties added varies. However, major researchers agree that fructans have a polymerized chain of *n* varying from 2 to 60 monosaccharides units. While, according to IUB-IUPAC terminology, the dividing point between oligo- and poly-fructooligosaccharides is 10 [7].

### Structure

Because fructans nomenclature is not simple since their structures are variables, the nomenclatures for fructans proposed by Lewis [8], and, Waterhouse and Chatterton [9] are first used in literature. However from the purely chemical point of view, some controversies were raised in the scientific literature concerning this nomenclature. Yun [6] suggested that fructooligo-saccharides are common names for only fructose oligomers that are mainly composed of 1-kestose [GF2 = 1 kestotriose, $1^F$-β-D-fructofuranosylsucrose], nystose [GF3 = 1,1 kestotetraose, $1^F$ (1-β-D-

E-ISSN: 1929-5634/16 

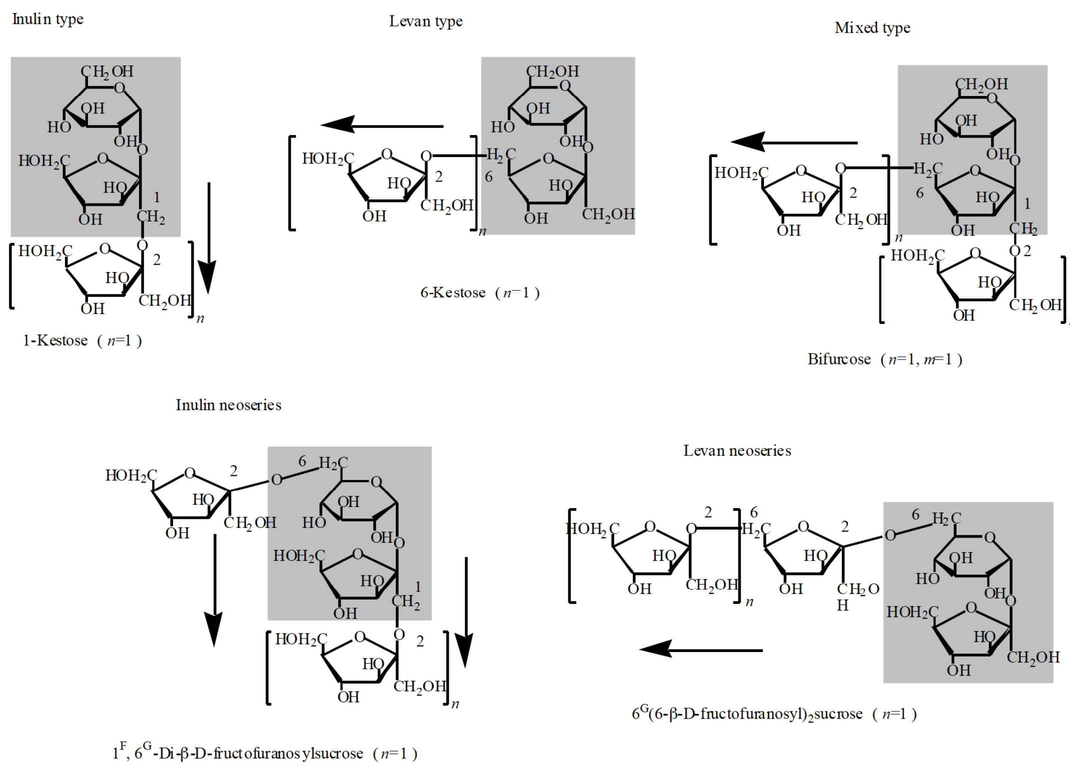


**Figure 1:** Molecular structures of the different types on fructooligosaccharides found in higher plants.

fructofuranosyl)$_2$ sucrose], and $1^F$-fructofuranosyl nystose [GF4 = 1,1,1- kestopentaose $1^F$ (1-β-D-fructofuranosyl)$_3$ sucrose]. Therefore, the simple fructans are "inulin-type' which are linear and consist of β(1-2)-linked fructose residues and found in almost all fructan-containing plant (Figure **1**).

Furthermore, the analytical studies carried out on their structures were characterized by a relative lack of data because chemical and/or enzymatic methods were used to assess and deduce high polymerized fructans on one hand, and techniques used for analyses did not allow the separation or identification of higher polymerized fructans on the other hand. Recently, new techniques for separating and determining the structural composition of the different short chain fructans have been developed. Shiomi [10] and Shiomi *et al*. [11,12] separated short FOS of onion bulbs using HPAEC–PAD technique, while Stahl *et al*. [13] used simultaneous MALDI–MS and HPAEC methods and obtained similar results.

## HEALTH BENEFITS OF FRUCTANS

Generally, it is recommended to eat an average of 400 g of fruits and vegetables per day, and scientific advances linking diet and health have fostered unprecedented attention on the role of nutrition in health promotion and diseases prevention. This is fortunate as considerable evidences are indicating that adequate fruits and vegetables consumption has a role in preventing many chronic diseases, including heart diseases, stroke and several cancers [14-23]. Because of the great interest of consumers in diet food; and also fructans are not yet being well marketed widely throughout the world as food ingredients or additive, cultivated crops remain the main source of fructans such as banana, wheat, barley, asparagus, onion, garlic, chicory and Jerusalem artichoke [24-26]. Thus, fructans are presently produced industrially and used as food ingredients, while in Japan they are considered as food and are found in more than 500 food products including soft drinks, cookies, cereals and candies, resulting in significant daily consumption [25,27].

Fructan-containing foods have been consumed because availability, low cost, and personal preference rather than for any specific effect on nutrition and health. In fact, the use of fructans in the human diet has increased since the initial commercial production of a specific oligofructan (Neosugar®) in Japan in 1983. The benefits of adding fructans to the human diet has been first reported by the NSG (Neosugar Study Group) at a series of conferences held in Japan to highlight research with Neosugar® in 1982, 1983 and

1984. The reports given have linked biochemical-nutritional-health changes in human resulting from eating Neosugar®, and these results were confirmed later by Buddington *et al*. [28]. Although this history started with Neosugar®, it has become evident that many of the conclusions could be extended to other fructans [29].

Fructans also have numerous physiological actions [30], and Tomomatsu [27] enumerated the following health benefits attributed to oligosaccharides:

- Encourage proliferation of bifidobacteria and reduce detrimental bacteria
- Reduce toxic metabolites and detrimental enzymes
- Prevent pathogenic and autogenous diarrhea
- Prevent constipation
- Protect liver function
- Reduce serum cholesterol
- Reduce blood pressure
- Have an anticancer effect
- Produce nutrients

Thus, these physiological effects are the basis for associating fructans intake with reduced diseases and prevention.

## FRUCTANS AND MINERAL NUTRITION

### Fructans and Calcium Nutrition

Altough it was always thought that non-digestible carbohydrates cause an impairment in the small intestine absorption of minerals [31], studies conducted by van den Heuvel *et al*. [32,33] showed that the amount of calcium ions recovered in the ileostomate over a period of three days was significantly modified after supplementing the diet with 15 g per day of these fructans. Later, additional investigations were conducted on the effects of fructans and minerals (see review of Scholz-Ahrens *et al*. [34] and Scholz-Ahrens and Schrezenmeir [35]). However. Most of scientific evidences claiming that fructans enhance mineral absorption are mainly based on animal experiments [36-39], and only few on human ones [40-42]. Coudray *et al*. [38] studied the effects of different chain length and type of branched fructans on intestinal absorption and balance of calcium in rats and their results showed that all tested fructans studied seem to have similar activity by increasing absorption and/or balance of calcium. Lobo *et al*. [43] reported similar results when they supplemented diet with yacon flour and noted a significant positive balance of calcium leading to higher values of bone mineral retention. On human studies, Tahiri *et al.* [42] studied the effect of short-chain fructans and also noted these polymers may influence positively calcium absorption in the late postmenopausal phase. Additional experiments were conducted on the effects of oligofructose-enriched inulin absorption of calcium in postmenopausal women, and results were in agreement with those reported on animals regarding the positive effect of fructans on calcium absorption [44]. These data were confirmed by Jackman *et al*. [45] who noted that a daily intake of 50 mg per day of short chain fructans increased bone calcium retention in postmenopausal women.

Interestingly, the combination of oligofructose and highly polymerized-inulin (HP-inulin) showed synergetic effects on intestinal calcium absorption and balance. In thir studies conducted on humans, van Heuvel *et al*. [32] reported that 15 g of mixed oligofructose polymers per day stimulate fractional calcium absorption in male adolescents. Similar results also reported the increase of calcium absorption by combination of oligofructose + inulin in girl at or near menarche [41] and young adolescents as well [46].

On the other hand, other studies did not found consistent evidence between fructans intake and calcium absorption. Jamieson *et al*. [47] investigated the effect of long chain inulin on bone mineralization and density. In their conclusion, these authors reported that fructans did affect neither the bone mineral density (BMD) nor the whole body (WB) of the growing female rats. Experiment carried out on human by López-Huertas *et al*. [48] also showed that milk with added fructooligosaccharides did not significantly increase calcium absorption.

Indeed, the mechanisms of calcium absorption are not fully understood yet, but it seems that different factors such as enhanced pools of soluble and ionized calcium, an increase in the absorptive surface in caecum, higher SCFAs (short chain fatty acids) concentrations, and by direct interaction with the intestinal tissue [49]. However, this retention and accumulation of calcium, as well as other minerals, in bone is enhanced only when the basic diet for the control group do not contain fructans and when the mineral demand is particularly high for example during growth [50].

## Fructans and Magnesium Nutrition

Magnesium plays a central a role in many metabolic functions in humans, and all enzymatic reactions involving adenosine triphosphate have an absolute requirement for magnesium. Its metabolism appears to be very closely linked to calcium, potassium, and sodium, and its level is controlled by the kidneys and gastrointestinal tract [51,52]. van den Heuvel *et al*. [32,33] indicated in their study that the amount magnesium ions recovering in the ileostomate over a period of three days was significantly modified by fructans supplemented diet. In their study, Coudray *et al*. [38] also reported that different fructans types seem to have similar activity by increasing absorption and/or balance of magnesium. Lobo *et al*. [43] reported similar observations and noted a positive balance of magnesium leading to higher values of bone mineral retention in rats resulting from a supplementation of the diet with yacon flour. Recent studies also confirmed these data by reporting similar effects when animals are fed, and a positive correlation was found between fructans consumption and magnesium absorption [53-55].

Experiments carried out on humans showed similar results to those observed on animals. Supplementation of diet with oligofructose-enriched inulin and a daily intake of short chain fructans increased bone magnesium retention in postmenopausal women [44,45] and improved its absorption in adolescent girls with a low calcium intake [56].

## Fructans and Phosphorus Nutrition

Alike calcium and magnesium, phosphorus is essential to human life, and during the process of bone hardening or aging, the Ca:P ratio gradually increases from 1:1 to 1.67. Hydroxyapatite is the predominant mineral of the bone with smaller quantities of intermediate calcium phosphates and some calcium carbonate. However, unlike calcium, phosphorus (and magnesium) requirements of adults are relatively low [57-59]. Comparatively, the number of studies on fructans and phosphorus absorption is much less than that conducted on calcium and magnesium. In his study, Scholz-Ahrens *et al*. [37] noted that oligofructans affected significantly magnesium when dietary calcium was high, and similar observation was reported by Pérez-Conesa *et al*. [60] showing an increase in phosphorus bioavailability in rats fed with prebiotics supplemented diet.

## Fructans and other Minerals Nutrition

The effects of fructans on the absorption of minerals is quite well documented in animals, however, results of studies on humans are questionable. Although fructans and calcium and magnesium absorption has been the most studied, the ability of fructans to enhance absorption of other minerals, such as iron, zinc, and copper, has been also studied, but not all these studies have shown increased mineral absorption in animals when fed by non-digestible oligosaccharides.

For living organisms, iron (Fe) is essential and involved in numerous metabolic processes such as oxygen transport, deoxyribonucleic acid (DNA) synthesis, and electron transport. Nevertheless, its level requires a controlled regulation because excessive amounts might cause tissue damages [61]. In controversial studies, iron status in rats was not affected by inulin-type fructans (ITF) supplementation [62], while later the same authors observed that ITF increased iron bioavailability and its level in liver [63]. Human experiment showed no evidence between fructans intake and iron absorption, and even showing prebiotic effects, inulin did not improve iron absorption in women having low iron status [64].

Zinc is another essential mineral although at low doses, and its deficiency is now known to be an important malnutrition problem. In nutrition, zinc bioavailability plays a crucial role in its absorption, and phytates are the main known inhibitor of zinc, decreasing its availability, thus prevailing its high deficiency in large cereal proteins consumers [65,66].

As for zinc, little is known on the biochemical defects, physiological dysfunction, and clinical manifestations of copper and its metabolism, and studies to determine human copper status are limited. However, copper-dependent functions can be affected by intracellular distribution as well as total-body depletion of this mineral nutrient, and concerted effort to improve status assessment through the use of functional indices are becoming a high priority [67-69]

Studies investigating how fructans can affect zinc and copper availability and absorption are very scarce. Coudray *et al*. [70] investigated the effect of inulin intake on zinc and copper absorption, and any correlation with the age of animals and the absorption of these two minerals. Their results showed that dietary inulin intake affected significantly intestinal absorption of zinc and copper in rats, and this absorption was much higher in older than younger animals. Similar and positive effects of fructoligosaccharides on zinc and copper absorption were reported by Lopez *et al*. [71]. In contrary, Vaz *et al*. [53] did not find any change in zinc status of iron-deficient rats fed with inulin-type fructans supplemented diet, while copper was negatively affected.

## COMMENTARIES AND CONCLUSION

From the literature and beside the progress done on understanding the roles of fructans in mineral nutrition, the results reported by these investigation are sometimes consistent and sometimes not. In fact, what makes the issue complex is the understanding of the mechanisms behind minerals availability and absorption. On these mechanisms, different hypotheses have been suggested and some of them are making a good consensus. The hypotheses most frequently proposed to explain the enhancing effects of fructans on mineral absorption are: (i) the osmotic effect, (ii) acidification of the colonic content due to fermentation and production of short-chain carboxylic acids (SCFAs), (iii) formation of calcium and magnesium salts of these acids, and (iv) hypertrophy of the colon wall [72,73]. However, according to Ohta *et al*. [36] and Raschka and Daniel [49], other and different mechanisms may be involved in the increased absorption of calcium and magnesium, the former being absorbed mostly in the cecum and the later mostly in the colon. Other issues are the discrepancies between animal and human studies, and most of these results have been observed in animals, and few were conducted on human. Even though the beneficial effects of fructans on mineral absorption (and other metabolic functions as well) do not suffer from any ambiguity, still further work needs to be done and the mechanisms are yet to be determined in order to clarify how and what regulate fructans and minerals interactions, including their promoters and inhibitors. Indeed, numerous and complex reactions occur in the intestine and might interfere with the mechanisms of fructans-minerals absorption. In the future and to further clarify the roles of fructans in mineral nutrition, two main approaches could be adopted. Firstly, we need to understand the mechanisms of how fructans increase the absorption of some minerals and why not most of the essential ones. Secondly, we need to extend findings in animal models to human, with a particular emphasis on young and elderly persons.

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Received on 19-08-2016 Accepted on 19-09-2016 Published on 07-10-2016

DOI: http://dx.doi.org/10.6000/1929-5634.2016.05.03.2