Fructooligosaccharides of Edible Alliums: Occurrence, Chemistry and Health Benefits

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Abstract: During the past decade, there has been vast expansion in the research of fructooligosaccharides (FOS), including their chemistry, biochemistry, and enzymology in living organisms, as well as nutritional and health benefits. However, in spite of these considerable advances in FOS science, many other aspects of the mechanisms of FOS behind their involvement in well being have not been fully understood. FOS constitute the major part of the dry matter of edible Alliums, and the knowledge of the mechanisms of their mode of action in human metabolism are of great interest. Important progress has been made in the chemical, nutritional and clinical research areas of Alliums FOS, as well as on other FOS, and in addition to their role as quality attribute, FOS participate in other processes. This paper aims to review the occurrence, chemistry and health benefits of Alliums' FOS including nutritional contribution of FOS in health and well being.

Keywords: Fructooligosaccharides, Alliums, chemistry, nutrition.

1. INTRODUCTION

1.1. History of Edible Alliums

Alliums are supposed to be ones of the world’s oldest cultivated vegetables and large was reported on them. It is presumed that our predecessors discovered and consumed wild Alliums long before farming or writing was invented. Because Alliums are small and leave no archaeologic evidence, the exact origin remains still mysterious. Onion and garlic could probably be the first cultivated crops due to their growing versatility, long storage time, and portability. They could be dried and preserved for times when food was scarce. The Chinese have cultivated Alliums in gardens for 5000 years, and have been referenced in the ancient Vedic writings of India. Alliums can be traced back as far as 3500 B.C. in Egypt, where they served as an object of worship. The onion symbolized eternity to the Egyptians who buried the root vegetable alongside Pharaohs. At the present time, the Allium family has over 500 members, each differing in taste, form and color, but close in biochemical, phytochemical and neutraceutical content. Besides their remarkable medicinal powers, Alliums are generally consumed for their flavors, while their nutritive values have been appreciated only recently [1]. Carbohydrates in Alliums account for a major portion of their dry matter, contributing as much as 65 to 80% of the dry weight. The principle components of the non-structural carbohydrates are glucose, fructose, sucrose and a series of fructooligosaccharides (fructosyl polymers) with degrees of polymerization (DP) up to c.a. 12 [2-5].

1.2. History of Fructooligosaccharides (FOS)

Fructooligosaccharides (FOS), as 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 [6-8]. First and prior to the contemporary science of fructans, ancient peoples used fructans containing plants as food, feed or medicine. One of the most and old vegetable used is onion, which was widely used by Pharaoh civilization in their rituals. However, 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, FOS research has known a considerable progress, especially with the molecular biology tools, thus the scope of FOS research has expended from basic to applied science. At present time, FOS 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, FOS are now considered as functional foods which have been introduced as a new concept [9,10]. In addition, they are nowadays used as feed additive in poultry in USA and Japan. This passionate history of FOS concerning their safety and health benefits continues to arise interest of scientists who discover every day their potentials as food and ingredient.

1.3. Edible Alliums and Diet

Interests in the potential health benefits of edible Alliums, mainly onion and garlic, have origins in antiquity, and are ones of the earliest documented examples of plants used for health maintenance and treatments of diseases [11-14]. Edible Alliums formed an important part of the daily diet of ancient Egypt, and Pharaohs fed working class involved in heavy labor, as in building pyramids [15]. The Jewish slaves...
in Egypt were fed *Alliums*, apparently to them strength and increase their productivity. In ancient Greece, edible *Alliums* were associated with strength and work capacity, and garlic formed an important part of the military diet [15]. By the Romans, *Alliums* were considered as an aid to strength and endurance, and, were fed to both soldiers and sailors and were part of a ship’s manifest when it set out to sea [16]. In ancient Chinese civilization, *Alliums* were evidently and frequently used in combination therapy as medicinal agent [17], and also formed a part of the daily diet particularly when consumed together with raw meat [12].

During the middle age, knowledge of the therapeutic use of plants was gained, and *Alliums* were thought to have medicinal properties and were grown in monasteries [12]. With onset of the renaissance, increasing attention was paid in Europe and America to the medical uses of *Alliums*, such as other aromatic plants. Thus, onion and garlic were one of the major plants and ruling class began to adopt garlic and not to restrict its consumption to the working class. Moreover, contemporary researches are tending, from one part to validate many of the earlier views concerning the efficacy of *Alliums*, from the other part seek to elucidate the mechanisms behind the actions of the major components of onion and garlic such as FOS.

### 2. CHEMISTRY OF ALLIUMS’ FOS

#### 2.1. Definition

The fructooligosaccharides (FOS), also known as fructans, polyfructosylsucroses of varying molecular size built on a sucrose starter unit, are $1^F (\beta-D$-fructo-furanosyl), sucrose oligomers where $n$ may vary. FOS are considered as carbohydrates with low degree of polymerization (DP) and consequently low molecular weight [18]. They consist of sucrose molecule to which other molecules of fructose have been added (Fig. 1). The term of FOS is somewhat ambiguous since the number of fructose moieties added varies. However, major researchers agree that FOS have a polymerized chain if $n$ varying from 1 to c.a. 12 units of fructose, while longer chains are considered as inulin polymers. However, FOS have been variously defined including anything from 2 to 20 monosaccharides units. While, according to IUB-IUPAC terminology, the dividing point between oligo- and poly-fructooligosaccharides is 10.

#### 2.2. Structure

Because *Alliums*’ FOS, as well as fructans, are not simple since their structures are variables, the nomenclatures for FOS proposed by Lewis [19], and, Waterhouse and Chatterton [20] are first used in literature. However from the

**Inulin type**

![Inulin type](image)

**Levan type**

![Levan type](image)

**Mixed type**

![Mixed type](image)

**Inulin neoseries**

![Inulin neoseries](image)

**Levan neoseries**

![Levan neoseries](image)

$1^F, 6^F$-Di-$\beta-D$-fructofuranosylsucrose ($n=1, m=1$)

Fig. (1). Molecular structures of the different types on fructooligosaccharides found in higher plants.
purely chemical point of view, some controversies were raised in the scientific literature concerning this nomenclature. Thus, in a recent paper, Yun [18] has suggested that FOS are a common name for only fructose oligomers that are mainly composed of 1-kestose \([\text{GF}_3 = 1\text{-kestotriose}, 1^3\beta-D-\text{fructofuranosylsucrose}],\) nystose \([\text{GF}_4 = 1,1\text{-kestotetraose}, 1^4 (1\beta-D-\text{fructofuranosyl})_2 \text{sucrose}],\) and \(1^5\text{-fructofuranosyl} \text{nystose \[\text{GF}_4 = 1,1,1\text{-kestopentaose} 1^5 (1\beta-D-\text{fructofuranosyl})_3 \text{sucrose}\]} \right) \text{ (Fig. 2).}

Thus, the simple FOS are “inulin-type” which consist of \(\beta(1-2)\)-linked fructose residues and found in almost all fructan-containing plant. In Liliaceae e.g. onion and garlic, a different type of FOS are present and named the inulin neo-series. These type of FOS have two \(\beta(1-2)\)-linked fructose chains attached to the sucrose starter unit. One chain is linked to the C1 of the fructose residue (as is also the case of inulin-type), and the other to the C6 of the glucose residue (Fig. 2).

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 to deduce high polymerized FOS on one hand, and techniques used for analyses did not allow the separation or identification of higher polymerized FOS on the other hand. Recently, new techniques for separating and determining the structural composition of the different FOS in onions have been developed. Shiomi [21] and Shiomi et al. [22,23] separated the FOS of onion bulbs using the HPAEC-PAD technique, while Stahl et al. [24] used simultaneous MALDI-MS and HPAEC methods and obtained similar results (Table 1).

3. OCCURRENCE AND DISTRIBUTION OF FOS IN EDIBLE ALLIUMS

The occurrence of FOS in some Allium species has been known since 1894 as reported by Archbold [25], and later almost all this investigation carried out focused on onion bulbs, two on garlic while none on leek, shallot, chives or other edible Alliums (Table 2). Their content, distribution, and structure were first investigated during the 1970s by Bacon [26] and Darbyshire and Henry [27,28]. Later, FOS content and distribution were subject of vast investigation [29-33]. Thus, the advanced analytical techniques led to an ideal separation and identification of the different FOS found in onion bulbs [23]. However, this composition varies, although slightly, according to the type of Allium, cultivar, dry matter content and stage of maturity [34], and also the content of the FOS increases from the outer (old) to the inner (young) scales [27]. It has been noted that content of low-DP FOS is correlated to that of dry matter (DM < 10%) [35], while in high dry matter onion bulbs, the maximum degree of polymerization is between 10 and 15 [5,36].

In garlic, few studies investigated the presence of FOS. Das and Das [37] studied the structure of the fructans in garlic bulb and suggested that FOS are linear and have inulin-type structure. Recent results showed that fructans of garlic belongs to the inulin neo-series type, and later Baumgartner et al. [38] isolated a high molecular weigh fructans, and studied their structure by enzymatic, chemical and NMR spectroscopy and confirmed the inulin neo-series structure.

For leek, shallot and other edible Alliums, no data are available regarding the structure of their nonstructural carbohydrates, and the nature of the potential FOS present in their tissues are unknown.

4. HEALTH BENEFITS OF FOS

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 disease prevention. This is fortunate as considerable evidence indicates that adequate fruits and vegetables consumption has a role in preventing many chronic diseases, including heart diseases, stroke and several cancers [39-48]. Because of the great interest of consumers in diet food; and also FOS are not yet being marketed widely throughout the world as food ingredients or additive, cultivated crops remain the main source of FOS such as banana, wheat, barley, asparagus and Jerusalem artichoke [49-51]. In Alliums species, onion and garlic are considered as major source of FOS since FOS constitute 25 to 35% of total non structural carbohydrate [35], while leek and shallot are minor source [29,52]. Thus, FOS 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 [50,53].

Surprisingly, Alliums were consumed mainly for their flavor and used as condiments, while the 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 FOS in the human diet has increased since the initial commercial production of a specific oligofructan (Neosugar\(^{\text{®}}\)) in Japan in 1983. The benefits of adding FOS 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\(^{\text{®}}\) in 1982, 1983 and 1984. The reports given have linked biochemical-nutritional-health changes in human resulting from eating Neosugar\(^{\text{®}}\), and these results were confirmed later by Buddington et al. [54]. Although this history started with Neosugar\(^{\text{®}}\), it has become evident that many of the conclusions could be extended to other FOS [55].

FOS have numerous physiological actions [56] (Fig. 3), and Tomomatsu [53] enumerated 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
Fig. (2). Molecular structures of the different fructooligosaccharides found in onion and other edible *Alliums* [1,23,38].
Table 1. The Structural Composition of the Different Fructooligosaccharides of Onion Bulb Separated by HP AEC

<table>
<thead>
<tr>
<th>Structure</th>
<th>Fructose (3a)</th>
<th>Neokestose (3b)</th>
<th>Nystose (4a)</th>
<th>4b</th>
<th>4c</th>
<th>5a</th>
<th>5b</th>
<th>5c</th>
<th>5d</th>
<th>6a</th>
<th>6b</th>
<th>6c</th>
<th>6d, 6d</th>
<th>6d, 6d</th>
<th>7a</th>
<th>7</th>
<th>8</th>
<th>9x</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-kestose</td>
<td>1'o-β-D-fructofuranosylsucrose</td>
<td>6'o-β-D-fructofuranosylsucrose</td>
<td>1'o-β-D-fructofuranosylsucrose</td>
<td>6'o-β-D-fructofuranosylsucrose</td>
<td>1'o-6'o-di-β-D-fructofuranosyl sucrose</td>
<td>1'o-β-D-fructofuranosylsucrose</td>
<td>6'o-β-D-fructofuranosylsucrose</td>
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<td>1'o-β-D-fructofuranosylsucrose</td>
</tr>
</tbody>
</table>

Table 2. The Distribution of Fructooligosaccharides in Edible Alliums

<table>
<thead>
<tr>
<th>FOS (mg g⁻¹ FW)</th>
<th>DP³</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunching onion</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chinese chive</td>
<td>&lt;0.1</td>
<td>-</td>
</tr>
<tr>
<td>Garlic</td>
<td>3.9⁴</td>
<td>3-5</td>
</tr>
<tr>
<td>Garlic, powder</td>
<td>1.7⁴</td>
<td>3-5</td>
</tr>
<tr>
<td>Leek</td>
<td>0.9⁴</td>
<td>2-4</td>
</tr>
<tr>
<td>Onion, welsh</td>
<td>1.1⁴</td>
<td>3-5</td>
</tr>
<tr>
<td>Onion, white</td>
<td>3.1⁴</td>
<td>3-5</td>
</tr>
<tr>
<td>Onion, yellow</td>
<td>26.3³</td>
<td>3-12</td>
</tr>
<tr>
<td>Onion, red</td>
<td>27.1³</td>
<td>3-12</td>
</tr>
<tr>
<td>Onion, powder</td>
<td>47.7³</td>
<td>3-5</td>
</tr>
<tr>
<td>Shallot</td>
<td>8.5⁴</td>
<td>-</td>
</tr>
</tbody>
</table>

³ Degree of polymerization.
⁴ values are total of DP 3 to 5.
⁵ values are total of DP 3 to up to 12.
⁶ values are total of DP 3 to 5 estimated on dry weight basis.

- Have an anticancer effect
- Produce nutrients

Thus, these physiological effects are the basis for associating FOS intake with reduced diseases and prevention. However, only some predominant effects will be developed in the paragraphs below.

4.1. Prebiotic Effects

The large bowel is by far the most colonized region of the gastrointestinal tract, with c.a. 10¹² bacteria per gram of gut content. Through the fermentation process, colonic bacteria, most of which are anaerobes, produce a wide variety of compounds that may affect gut as well as systemic physiology. Thus, fermentation of carbohydrates reaching the large bowel produces short-chain carboxylic acids mainly acetate, propionate and butyrate and lactate which allow the host to salvage part of the energy of nondigestible oligosaccharides and that may play a role in regulating both cell division and cellular metabolism. In addition to their selective effects on bifidobacteria and lactobacilli, FOS influence many aspects of bowel function through fermentation, and are mildly laxative [57]. Indeed, FOS constitute a carbon source for microbial flora of bowel and the ability of bifidobacteria to utilize FOS was well demonstrated [58-63]. These works reported also that the majority of Bifidobacterium strains fermented all FOS and even low polymerized inulin. Biedrzycka and Bielecka [62] claimed that the results of in vitro studies indicate the specificity of Bifidobacterium except B. bifidum to utilize short-chain FOS and oligofructose, but not HP-inulin. However, according to Van Laere et al. [64], the main factors affecting the susceptibility of FOS to fermentation are: chemical structure, degree of polymerization, and possible linear or branched structure, as well as solubility in water. Generally, FOS with short chain length, unbranched nature and high solubility in water are well and preferentially fermented. Nevertheless, discrepancies in the capability of different Bifidobacterium species to metabolize FOS may be due to the differences in the expression of fructan-
Effects of FOS

- Satiety
- Gastric emptying
- Glucose absorption
- Fat metabolism
- Nitrogen fixation
- FOS fermentation
- SCFA production
- Prebiotic effects, e.g. bifidogenesis
- Fecal bulking

Possible health benefits

- 'Metabolic syndrome'
- Obesity?
- Diabetes?
- Hyperlipidaemia?
- Hypertension?
- Hepatic encephalopathy?
- Bacterial translocation?
- Distinct forms of colitis?
- Colonic carcinogenesis?
- Constipation?
- Symptoms of diverticulosis?
- Irritable bowel syndrome?

Fig. (3). Potential physiological effects of FOS (left column) and possibly related health benefits (right column). (SCFA, short-chain fatty acids) [56].

hydrolyzing enzymes, since these later have not been extensively investigated.

4.2. FOS and Mineral Absorption

Contrary to the fact that nondigestible carbohydrates have been accused of causing an impairment in the small intestine absorption of minerals [65], van den Heuvel et al. [66] and van den Heuvel et al. [67] demonstrated that the amount of Ca, Mg and Fe ions recovered in the ileostomate over a period of 3 days is significantly modified after supplementing the diet with 15 g per day of these fructans. Later, a vast number of studies were carried out on the effects of FOS and mineral absorption and reviewed by Scholz-Ahrens et al. [68] and Scholz-Ahrens and Schrezenmeir [69], and the scientific evidence claiming that FOS enhance mineral absorption is based on both animal [70-73] and human experiments [74-76]. Coudray et al. [72] studied the effects of different chain length and type of branching on intestinal absorption and balance of calcium and magnesium in rats and their results showed that all tested fructans seem to have similar activity by increasing absorption and/or balance of Ca and Mg. However, the combination of oligofructose and HP-inulin showed synergetic effects on intestinal calcium absorption and balance. In humans, van Heuvel et al. [67] reported that 15 g of oligofructose per day stimulates fractional calcium absorption in male adolescents. Tahiri et al. [76] noted that short-chain FOS may influence positively calcium absorption in the late postmenopausal phase in women. Moreover, Griffin et al. [75] noted also that calcium absorption is increased by combination of oligofructose + inulin in girl at or near menarche.

In fact, the hypotheses most frequently proposed to explain the enhancing effect of FOS on mineral absorption are the osmotic effect, acidification of the colonic content due to fermentation and production of short-chain carboxylic acids, formation of calcium and magnesium salts of these acids and hypertrophy of the colon wall [74,77]. However, according to Ohta et al. [70], 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.

4.3. FOS and Lipid Metabolism

Many attempts have been made in control of triacylglycerol concentrations through the modification of dietary habits [78,79]. The hypotriglyceridemic effect of FOS, as well as other nondigestible carbohydrates, has been described both in humans [80-83] and animals [84-87]. In fact, almost all studies were carried out on inulin or HP-inulin, and none concerned short-chain FOS and lipid metabolism in healthy men. On the other hand, the daily addition of 10 g inulin to the diet significantly resulted in lower plasma triacylglycerol (TAG) levels, supporting that fructans influence the formation and/or degradation of TAG-rich lipoprotein [83]. Letexier et al. [83] also reported that addition of HP-inulin has a beneficial effect on plasma lipids by decreasing hepatic lipogenesis and plasma TAG concentrations. Indeed, this effect is likely to result from a
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Unfortunately, the mechanisms behind the serum-lipid lowering effects of FOS remain still unclear and have to be elucidated [88] (Fig. 4). In fact, liver plays a key role in triacylglycerol-rich lipoprotein homeostasis and because newly synthesized fatty acids are preferentially channeled into VLDL, the lipogenic activity of the liver is a key factor for the hepatic triacylglycerol-VLDL output [89]. Fatty acid synthase (FAS), among the key enzymes that control lipogenesis, is the most sensitive to nutrients and hormones [90]. Thus, it is supposed that decreased lipogenesis in liver is a key event in the reduction of VLDL-triglyceride secretion in fructan-fed rats, and the activities of many enzymes e.g. acetyl CoA carbyxylase, FAS, malic enzyme, ATP citrate lyase and G-6-P 1-deshydrogenase, are decreased by 50% [78].

4.4. FOS and Short-Chain Carboxylic Acids Production

The colonic fermentation of FOS produces short-chain carboxylic acids, lactate and gases. However, only part of these carbohydrates energy is salvaged, and consequently, they are classified as low energy food ingredients [91,92]. Indeed, the available energy content of FOS is only 40 to 50% that of digestible carbohydrates, giving them a caloric value of 1.5 to 2 kcal/g [91]. Castiglia-Delavaud et al. [93] studied the net energy of soluble and insoluble polysaccharides and found that sugarbeet fibers and inulin digestible energy values averaged 2.65 and 3.22 kcal/g respectively, while metabolizable energy values averaged 2.55 and 3.10 kcal/g, respectively.

Concerning the pattern of production of short-chain carboxylic acids, unless very sophisticated studies are performed in humans to measure them in situ and/or in portal

Fig. (4). Putative mechanisms involved in the modulation of lipid metabolism by dietary fructooligosaccharides in rats, including effects on gastric emptying and glucose absorption, production of short-chain carboxylic acids (acetate, butyrate, propionate), secretion of incretins, and subsequent actions on liver, adipose tissue, and pancreatic insulin output [88].
blood, remains still unclear and almost unknown. Because what is excreted in the feces does not represent the in situ situation since more than 90% of the acids produced in the colon are probably absorbed in the ascending part of the colon, and data reported in human could be not relevant [94]. Thus, experiments carried out on animal showed that supplementing diet with FOS decreases the cecal pH, increases the size of the cecal pool of short-chain carboxylic acids, with acetate being primary acid, and butyrate and propionate as secondary acids [95,96]. The increase in the pool of short-chain carboxylic acids could probably due to the effects of FOS on intestinal tissue [96], on either microbial [54] or intestinal [97] enzymes, or effects on the concentrations of metabolites [98]. Furthermore, possibly related to this increase in the effect in the pool of short chain carboxylic acids is the effect of some nondigestible oligosaccharides on the intestinal tissue leading to hyperplasia of the mucosa and increased wall thickness both in the small intestine and the cecum [96]. Moreover, because of the stimulation of bacterial growth leading to an increase in bacterial biomass, oligofructose have been shown to increase fresh fecal mass either in rats or in humans.

4.5. Effects of FOS on Glycemia and Insulinemia

The effects of FOS on glycemia and insulinaemia are not yet fully understood, and the nondigestible oligosaccharides for which published data are available on the effect related to glucose are inulin-type fructans [99,100]. Beside that available data on the effects of FOS on glucose and insulin concentrations are sometimes contradictory; these effects also may depend on physiological (fasting compared to postprandial or disease (diabetes) conditions [78,94,101]. Moreover, other nondigestible carbohydrates are known to modify the kinetics of absorption of carbohydrates, thus decreasing the incidence of glycemia and insulinaemia [102]. The effects of inulin type fructans on glycemia and insulinaemia are not fully understood, and available data are sometimes contradictory, indicating that these effects may depend on physiological or disease conditions. Luo et al. [103] reported that chronic ingestion of short-chain fructooligosaccharides (20 g per day for 4 weeks) did not modify fasting plasma glucose and insulin in healthy humans, even if it lowers basal hepatic glucose production. However, in diabetic subjects taking 8 g per day of short-chain fructooligosaccharides for 14 days leads to a decrease in fasting blood glucose [99].

4.6. FOS and Nitrogen/Urea Disposal

Almost all studies carried out on the effects of nondigestible carbohydrates were performed on animals, and results showed that FOS decrease uremia [104], enhance fecal nitrogen excretion and reduce renal excretion of nitrogen, and feeding rats a diet supplemented with oligofructose (10%) for a few weeks decreased uremia [104]. Dietary short-chain fructooligosaccharides effectively enhanced fecal nitrogen excretion and reduced renal excretion of nitrogen in rats [105]. This occurs because these fermentable carbohydrates serve as energy source for the intestinal bacteria, which during growth, also require a source of nitrogen for their protein synthesis. In addition, their osmotic effect in the small intestine accelerates the transfer of urea into distal ileum and the large intestine where highly ureolytic microflora may proliferate [105]. Propionate, an important end product of the bacterial fermentations of inulin-type FOS, also inhibits ureagenesis in the liver in the presence of ammonia and amino acids [106].

However, in humans consumption of nondigestible carbohydrates also results in a higher fecal excretion of nitrogen [107], and limits the formation of ammonia and other end products of catabolized proteins which could be risk factor of colonic carcinogenesis in the distal part of the large bowel [108].

4.7. FOS and Cancer

The effect of nutrition on tumor incidence and growth is a subject of priority interest [109,110], and amongst the most frequently investigated dietary compounds, the nondigestible carbohydrates play a major role in nutritional prevention [110,111]. FOS were used in various experimental models to study their cancer risk reducing capacity. Initial researches demonstrated that FOS have anticarcinogenic and tumor growth inhibitory effects [112,113]. However, the most surprising activity of FOS is the capacity to significantly reduce the number of metastases [114]. Moreover, FOS also have potentiation of cancer chemotherapy and have been shown to potentiate the therapeutic effects of all six investigated cytotoxic drugs representatives of the different groups of cytotoxic drugs classically used in human cancer treatment [115]. From the review of the available experimental data, it is concluded that fat has, most probably, no modulating effect but that unbalanced diets rich in lipids could act as a positive modulator of chemically induced carcinogenesis by virtue of their capacity to cause a break in metabolic and proliferative homeostasis. Thus, vegetable carbohydrates and fibers as well as restriction in caloric intake could act as negative modulators of the same process because they could restore this homeostasis. It is thus supposed that to maintain dietary balance either by increasing nondigestible carbohydrates and/or reducing calorie intake is the most effective way to negatively modulate chemically induced carcinogenesis in animals [110]. Beside these encouraging results regarding fructooligosaccharides and inulin in experimental animals, however, to make the same recommendations to humans could most probably help preventing some major cancers.

4.8. Other Insights of FOS and Health

Beside the numerous health benefits described previously, other roles of FOS have been a topic of much research recently and investigation reported other benefits and interesting actions of FOS. Due to their positive action on mineral absorption, FOS have been proposed to enhance bone health in animals. This concept is provocative and some recent finding in animals should be extended to man [116]. Recent data also provide first evidence that FOS modulate function of the immune system especially in the area of the gut-associated lymphoid tissue (GALT) [117].

However, more recently some controversies were reported on FOS and their roles in intestinal disorders. It was reported that FOS dose-dependently impairs the resistance to Salmonella in rats [118]. Later, similar results were reported and it has been shown that FOS inhibit intestinal
colonization but stimulate translocation of Salmonella [119], and increase the intestinal permeability [120,121]. However, results showed that impairment was partially prevented by calcium phosphate [121]. Nevertheless, these investigations were carried out on animal models and they require further studies to be extrapolated to humans.

CONCLUSIONS

In conclusion, and after reviewing their occurrence, chemistry and health benefits, it is presently admitted that *Alliums*’ FOS, as well as other vegetables’ FOS, fit well within the current concept of the class of dietary material and could be labeled as “functional foods” since their vast health benefits are continuously appreciated. Likely due to their specific properties, FOS affect several functions and contribute to reduce the risk of many diseases. Thus, they may contribute in a significant way to a well being by their specific effects on several physiological functions. However, and bearing in mind their superior functional properties, such as the bioavailability of minerals, prebiotic effects and modulation of colonic microflora, improvement of the gastrointestinal physiology, the metabolism of lipids, or prevention of some cancers, further basic researches on their real utilization in the human feeding are needed. Having more and more improved technical tools, such as genetic and molecular biology, the methodology can be reversed, showing the consequences under the administration of FOS.

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