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On the Presence of Inulin and Oligofructose as Natural Ingredients in the Western Diet

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ABSTRACT: The classic definitions of inulin and oligofructose are constructively criticized. It is observed that inulin cannot unequivocally be described as a polydisperse 1-kestose-based (GF_n) $\beta(2 \rightarrow 1)$ linear fructan chain, but that inulin always contains small amounts of F_m and branched molecules. This review article describes the presence of inulin and oligofructose in common foodstuffs. Historical data on human consumption add an extra dimension.

Modern analytical techniques (HPLC, LGC, HPAEC-PAD) are used to check the variety of data mentioned in the literature throughout the past century. Methods to determine inulin and oligofructose in natural foodstuffs (cereals, fruit, and vegetables) are optimized and used to determine the loss of inulin during storage and during preparation of the food.

These findings allow quantification of the amount of inulin and oligofructose in the average daily western diet. The daily per capita intake is estimated to range from 1 to 10 g, depending on geographic, demographic, and other related parameters (age, sex, season, etc.).

Inulin and oligofructose are not measured by classic methods of dietary fiber analysis and consequently are often not mentioned in food tables. Their significant contribution (1 to 10 g/d/per capita) to the dietary fiber fraction (recommended at 25 g/d/per capita) is not taken into account in any nutritional recommendations. In view of this, inulin and oligofructose deserve more attention, both in food composition tables and in diet or nutrition studies.

KEY WORDS: inulin, oligofructose, analysis, consumption, dietary fiber, fructan, inulo oligosaccharide, food plant, ingredient.

I. INTRODUCTION

Inulin and oligofructose are plant $\beta(2 \rightarrow 1)$-fructans that are polydisperse (degree of polymerization [DP] ranging from 2 to 60 or more for inulin or, by definition, from 2 to 20 for oligofructose). The basis of the nutritional properties of these fructans, and more specifically their indigestibility in the human tract, was discovered several decades ago. It is only recently that there has been a pronounced market need for inulin or oligofructose as new food ingredients. This development has led to the recent commercialization of inulin and oligofructose, and renewed interest in further in-depth nutritional research, which is reflected in the many articles that have been published on this topic during the past 3 years.

This article intends to describe the presence of inulin and oligofructose in the Western daily diet. Inulin is a widespread plant carbohydrate. It also is present in many food plants. Literature data on the inulin content of several food plants are summarized. These figures were generated by different authors over a time period of more than a century. The reliability of these data was checked with such modern techniques as HPLC, GC and HPAEC.

The degradation of inulin during common food preparation procedures (cooking, baking, roasting) was determined for some food plants

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and extrapolated. As a result, an input table containing upper and lower bound levels of the inulin content of most of the inulin-containing food plants was generated. Based on this input table, the daily per capita intake in the U.S. and Europe has been estimated.

The nutritional implications of these observations are illustrated.

II. MATERIALS AND METHODS

A. Materials

Onions were sampled regularly from a farmer's stockpile in Steenbergen, the Netherlands, during the period between November 1988 and February 1989. Chicory roots were collected in mid-November 1992 from the fields in the vicinity of Tienen, Belgium. The other vegetables, as well as roasted chicory and instant chicory powder, were bought at a local grocery store. Inulin from dahlia and from Jerusalem artichoke was obtained from the Sigma Chemical Co. Chicory inulin was obtained from the Sigma Chemical Company and from the Tiense Suikerraffinaderij, Tienen, Belgium. The same company provided Raftilose®, which is an oligofructose syrup.

B. Methods

1. Analytical Sample Preparation

In order to avoid interference from other cellular plant components, inulin or oligofructose were extracted at neutral pH (5.5 to 8.5) to avoid hydrolysis of the $\beta(2 \rightarrow 1)$ fructose bonds. To prevent hydrolysis by plant enzymes released during the extraction process, boiling distilled water was added to a known amount (±25 g) of a macerated sample. The volume of the water should be at least five times the volume of the sample. After a 1-h extraction in a water bath at 75°C under continuous shaking, the solution was accurately weighed and subsequently centrifuged. The supernatant was analyzed after addition of 100 ppm NaN_3. A known amount of the sample was dried to constant weight to determine the DS content.

2. HPLC for Determination of Low-DP Inulin (Oligofructose)

Prior to analysis, the sample was treated with mixed bed resins in order to remove interfering ions. The injector of the HPLC apparatus was a WISP 710B, the pump was Waters 590, and the RI-detector was Waters 410. An aliquot (100 μl) of a 0.1% solution of the sample was injected. The separation was performed on two columns in series packed with Aminex HPX87K (K+ form) with a particle size of 9 μm, eluting at 0.55 ml/min with H_2O at pH 9.5 (KOH) maintained at 85°C. The results were expressed on a 100 g-sample basis or on a 100% sugar basis. This rapid method can be used for quantification of fructose, glucose, sucrose, F_2, F_3, $GF_2 + F_4$, $GF_3 + F_5$, and DP5+ (i.e., the total of all oligosaccharides with a DP higher than GF_3 and F_5). These "higher" DP fractions could not be separated into their individual components, but the integrated DP5+ peak gave a fairly reasonable quantification of their combined content.

3. Quantitative CGC Determination of Oligofructose with DP2 to DP10

Every component in the range DP2 to DP10 (which covers the whole DP range of the partial inulin hydrolysate Raftilose®) can be quantitatively determined by means of CGC. A quantity of aqueous extract, containing at most 500 mg sugar, was weighed accurately, and phenyl-β-D-glucopyranoside (20 mg) as internal standard was added. The volume was brought to 50 ml with water. An aliquot (200 μl) was transferred to a glass test tube with screw cap and dried in a vacuum desiccator containing P_2O_5 or silica gel. To the dried sample, 400 μl hydroxyl-amine-HCl solution (2.5 g $NH_2OH \cdot HCl$ in 100 ml dry pyridine) was added. The oximation was conducted prior to the silylation step in order to produce just one peak for nonreducing sugars: sugars with a reducing group gave two peaks (cis and anti). The solution was vortex-mixed for 10 min and maintained at 60°C over 15 min in a heating block. After cooling and drying under N_2, 200 µl trimethylsilylimidazole (TSIM) was added and the mixture was allowed to react for 10 min at room temperature with vortex mixing. Water (1 ml) was added to neutralize the excess TSIM, until the contents were clear. Isooctane (2 ml) was added and the silylated sugars were extracted by vortex mixing over 3 min. After centrifugation, 1.0 µl of the supernatant was injected onto a Carlo Erba gas chromatograph, type HRGC 5300 HT, equipped with an air-cooled on-column injector, a capillary column (all clad OV1 from Alltech, length 6 m, diameter of 0.53 mm ID, film thickness of 0.1 µm) and a flame-ionization detector. The carrier gas was He at a constant flow of 9 ml/min. The flame ionization detector was fed with H_2 at 60 kPa and air at 110 kPa. N_2 at 60 kPa was used as make-up gas. The detector temperature was 460°C. The initial column temperature was 105°C, and was increased at 10°C per minute to 440°C. The secondary cooling started at the cooling of the oven and stopped 10 s after pulling back the injection needle. The results were computed with an HP 3396 integrator. Response factors for pure samples of the sugars to be analyzed were determined in the same way.

4. Quantitative Determination of Inulin in Foodstuffs and Plant Material

The quantitative determination of the whole DP range of inulin in foodstuffs was performed after hydrolysis into its component monosaccharides. Fructose is a very fragile molecule, which readily decomposes into formic acid and acetic acid under acid hydrolytic conditions. In order to avoid acid-catalyzed decomposition of fructose, enzymic hydrolysis of inulin was utilized.

After taking a reserve sample for CGC determination of fructose, glucose, and sucrose, the inulin-containing plant extract (20 ml) was transferred into a glass bottle with screw cap, and a 20-ml buffer solution at pH 4.5 (28 ml 0.2 *M* acetic acid and 22 ml 0.2 *M* sodium acetate, diluted to 100 ml with distilled water, and pH adjusted to pH 4.5 with 0.2 *M* acetic acid) was added. Novozym 230 (800 units per gram DS) was added and the hydrolysis was performed at 60°C over 30 min.

Determination of fructose, glucose, and sucrose in the hydrolyzates was achieved by means of CGC. The hydrolyzed sample (200 µg), together with 100 µg of the internal standard (IS = 40 mg rhamnose in 50 ml distilled water) was dried in a glass tube. The oximation/silylation procedure previously described was then applied. The silylated sugars were extracted with isooctane, and after centrifugation, 0.3 µl was injected onto a Carlo Erba gas chromatograph (see previous section) with a flame ionization detector. The carrier gas was He at a pressure of 100 kPa. The temperature of the detector was adjusted to 360°C. The column oven temperature was held at 80°C for 1 min and increased by 10°C per minute up to 285°C, by 2°C per minute up to 301°C, by 10°C per minute up to 335°C, and maintained at this temperature for 2 min.

The results were computed with an HP3396 integrator. Response factors were determined in the same way using standard solutions of the pure sugars.

The increase of the sum of fructose and glucose was divided by a factor f, correcting for the weight gain due to hydrolysis. For chicory inulin, with an average DP of ca. 10, the value for f was approximately 1.1. Inulin originating from other plants may have a different average DP. In these cases, the factor f could be estimated as follows: $f = (\text{av.DP} \times 180)/\{(\text{av.DP} \times 180) - (\text{av.DP}-1) \times 18\}$, where average DP = #F + 1, with #F the (integer) value obtained by calculating the fructose-to-glucose ratio of completely hydrolyzed inulin. At present, more elaborate methods are being developed. For example, in order to eliminate the glucose originating from starchy compounds such as maltodextrins, the sample can be pretreated with amyloglucosidase enzymes.[1]

5. Qualitative Characterization of Inulin

Inulin can be characterized via the description of its DP distribution. This parameter was visualized by use of a DIONEX series 4500i apparatus, equipped with an eluent degas module, a pulsed electrochemical detector, a gradient pump, an auto sampler, and a Shimadzu C-R4AX chromatopac as integrator. The analytical column is carbopac PA1 (4 × 250 mm, P/N 35391, S/N 3963), and was preceded by a protecting ion pac (HPIC AG6A P/N 037141 S/N 2106) column. The injection volume was 50 μl (of a solution containing approximately 1% sugars), and the separation was achieved using a gradient of three eluents: #1 is 100 m*M* NaOH; #2 is 100 m*M* NaOH + 400 m*M* NaOAc; #3 is 1 *M* NaOH.

6. Characterization of Native Inulin

Chicory roots were treated in a domestic fruit juice blender. The extract was immediately (within 30 s) collected in a buffer solution at pH 9 in order to inactivate any carbohydrase activity present in the root cells. The inulin collected in this way was reported to have exactly the same chemical and structural composition as "native" inulin. The extract was analyzed further without delay by means of gas chromatography and HPAEC-PAD.

III. INULIN AND OLIGOFRUCTOSE IN THE WESTERN DIET

A. Inulin and Oligofructose

1. Chemical Analysis and Polydispersity

a. Gas Chromatographic Analysis of Inulin and Oligofructose

In Figure 1, a gas chromatogram of native chicory inulin, which was extracted from freshly (<4 h) harvested roots, of commercially available chicory inulin (Raftiline®), and a partial chicory inulin hydrolysate (Raftilose® containing 85% oligofructose and 15% lower sugars: fructose, glucose, and sucrose) is presented. In order to allow a more quantitative comparison, the integrated values of the peaks from DP2 to DP12 are shown in Table 1.

At higher DPs (10 to 12), the baseline shifts significantly (Figure 1). The corresponding integrated values of DP10 to DP12 therefore are not reliable. Integration of the peaks shows that inulin (Raftiline®) contains 1.5% F_m compounds, and that native inulin extracted from fresh roots contains 0.8% F_m compounds on DS.

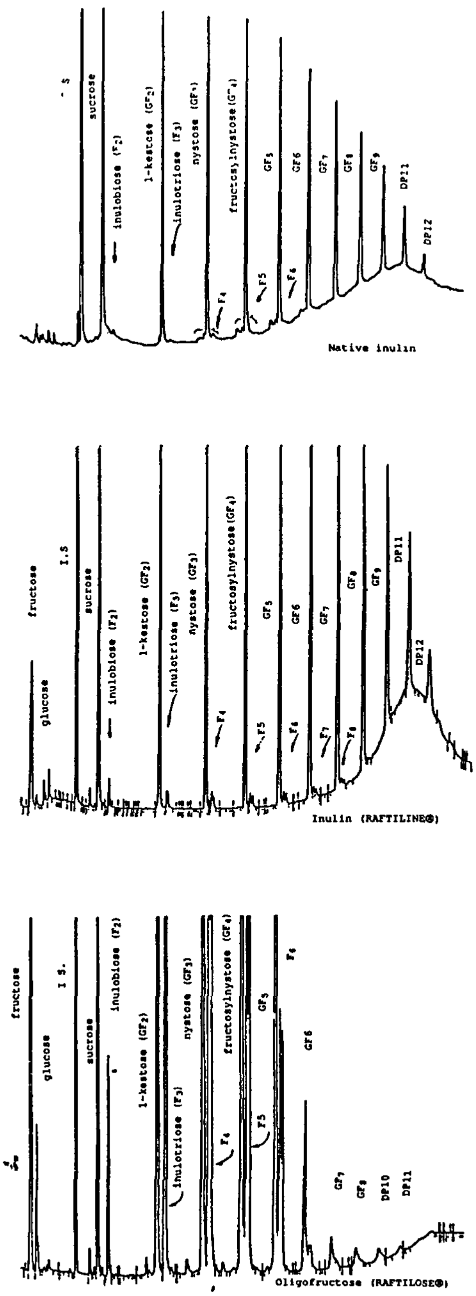

FIGURE 1. Gas chromatogram of native chicory inulin, purified inulin (Raftiline®), and its partial hydrolysate oligofructose (Raftilose®). The GF_n peaks are systematically accompanied by small F_m peaks. The small F_m peaks are double because these inulin compounds have a reducing end, which can be present in two different conformations. I.S. is the internal standard.

The gas chromatographic technique is suitable for the analysis of the whole DP range of oligosaccharides present in Raftilose®, which, due

TABLE 1
Integrated Values of the Gas Chromatographic Analysis of Native and Chicory Inulin (Raftiline®), as well as Its Partial Hydrolysate Oligofructose (Raftilose®)

Total carbohydrates	Native chicory inulin (%)	Raftiline® (%)	Raftilose® (%)
Fructose	0.2	1.1	7.2
Glucose	0.0	0.1	0.8
Saccharose	6.5	5.4	6.3
DFA	0.0	0.1	0.1
F2	0.0	0.2	4.8
GF2	4.1	3.1	6.2
F3	0.2	0.2	16.7
GF3	4.4	3.7	12.9
F4	0.2	0.2	13.3
GF4	4.8	4.0	13.6
F5	0.2	0.2	4.8
GF5	4.6	4.2	9.2
F6	0.2	0.2	2.6
GF6	4.1	4.2	0.9
F7	0.0	0.2	0.3
GF7	3.6	4.0	0.2
F8	0.0	0.2	0.0
GF8	3.1	3.6	0.1
F9	0.0	0.1	0.0
DP10	2.2	3.0	0.0
DP11	1.4	2.2	0.0
DP12	0.5	1.0	0.0
Sum GF_n (in range DP2–DP9)	28.7	26.8	43.1
Sum F_m (in range DP2–DP9)	0.8	1.5	42.5

to controlled partial enzymatic hydrolysis, contains ca. 50% of F_m-type $\beta(2 \rightarrow 1)$ fructans and ca. 50% of GF_n compounds (Table 1).

At higher DPs (10 to 12), the baseline shifts significantly (Figure 1). The corresponding integrated values of DP10 to DP12 therefore are not reliable. Integration of the peaks shows that inulin (Raftiline®) contains 1.5% F_m compounds, and that native inulin extracted from fresh roots contains 0.8% F_m compounds on DS.

The gas chromatographic technique is suitable for the analysis of the whole DP range of oligosaccharides present in Raftilose®, which, due to controlled partial enzymatic hydrolysis, contains ca. 50% of F_m-type $\beta(2 \rightarrow 1)$ fructans and ca. 50% of GF_n compounds (Table 1).

Sigma's dahlia inulin is generally considered in the literature to be a reference standard for inulin. In Figure 2, the gas chromatogram of Sigma's chicory inulin is presented. The chromatograms of Sigma's dahlia and normally short-chain Jerusalem artichoke inulin have exactly the same GC profiles in this DP region. It is remarkable that none of Sigma's inulin products contains any DP2 to DP12 oligofructose.

b. HPAEC-PAD Chromatography of Inulin and Oligofructose

This chromatographic technique is a tool that has proven to be useful in characterizing inulin. It separates every DP fraction of inulin into single peaks, but does not separate the GF_n from the F_m fractions over the complete DP range; only in the lower DP region can a distinction be made. This was observed by comparing GC chromatograms and HPAEC-PAD chromatograms of the same sample (Figure 1 — Raftiline® and Figure 5). Nevertheless, a complete profile (fingerprint) of inulin is obtained. In Figure 4, the HPAEC-PAD

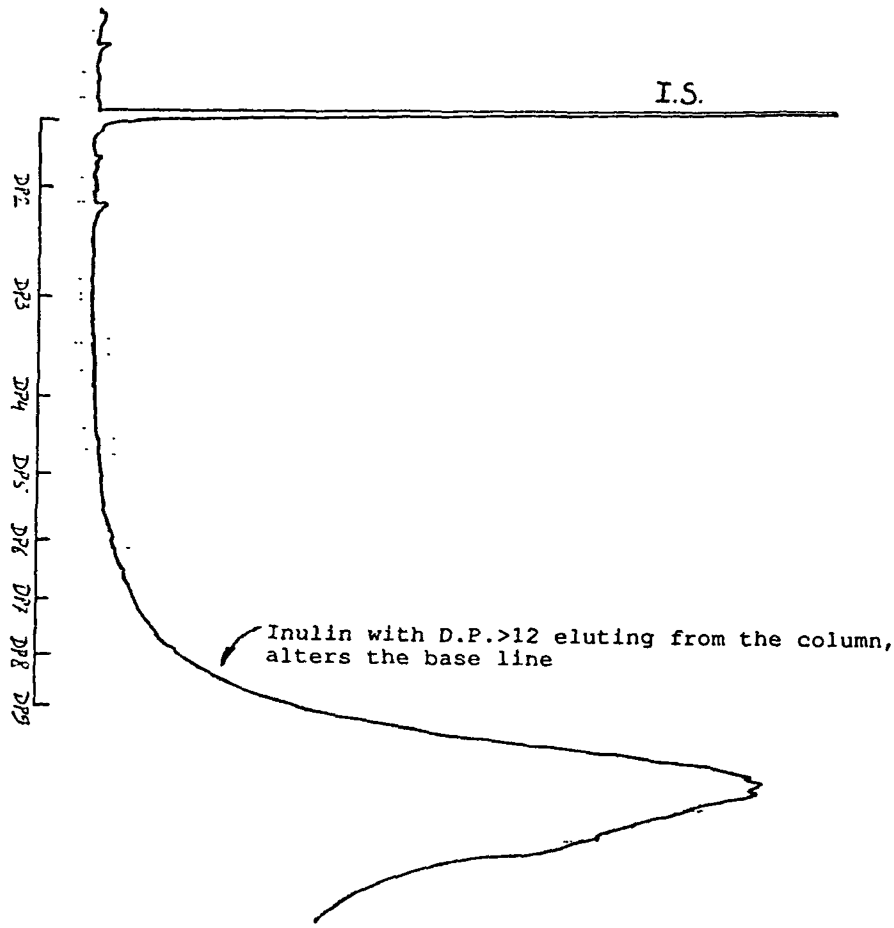

FIGURE 2. The gas chromatograms of Sigma's chicory inulin show that the product has been depleted from its low-molecular-weight fraction. No peaks are observed on the gas chromatographic analysis, which typically quantifies inulin with DP2 to 10. Analogous observations were made with Sigma's dahlia and Jerusalem artichoke inulin (see Figure 4).

chromatograms of Sigma's dahlia, chicory, and Jerusalem artichoke inulin are compared. No fractions with a DP <12 can be observed, which is not observed in native inulin or in inulin samples (Figure 5).

c. Polydispersity of Inulin

In Figure 3, the literature data on the DP distribution of several common vegetables are presented graphically. It can be concluded that 100% of the fructans in onion has a DP <12, whereas for chicory, 50% has a DP <20. Globe artichoke has the inulin with the highest DP; only 10% of the fructans has a DP <40. Data were obtained from publications referenced in Table 2.

Figure 3 demonstrates the large variability of DP distribution among various plant foodstuffs. This variability however could not be detected with the Sigma inulin samples of different origin. Dahlia with typical high DP, chicory with average DP, and Jerusalem artichoke with relatively low average DP all show the same patterns on the HPAEC-PAD chromatograms (Figure 4).

2. Chemical Considerations

The gas chromatograms of inulin (Raftiline®) and of Sigma's dahlia and chicory inulin (Figures

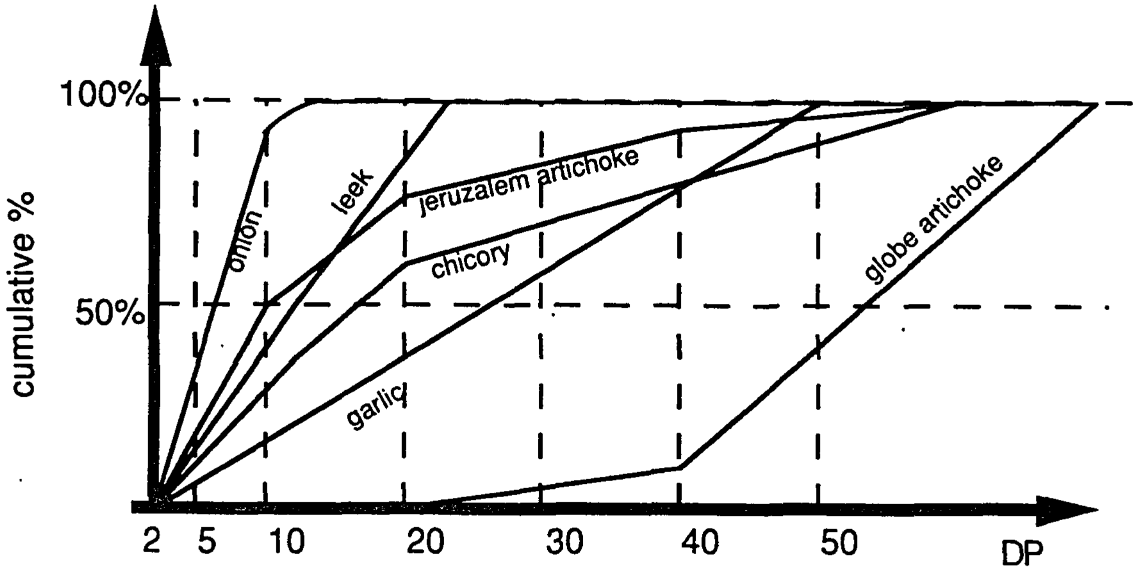

FIGURE 3. Cumulative distribution of polydisperse inulin (of fresh plant material) as a function of degree of polymerization (DP). Globe artichoke and dahlia inulin typically have a high DP, whereas onion or Jerusalem artichoke have low DP inulin, also called oligofructose.

4 and 5; Table 2) illustrate the polydispersity of the $\beta(2 \rightarrow 1)$ fructan.

With chicory inulin samples, as well as with inulin samples originating from other plant sources (leeks, onion, Globe artichoke, etc.), it was also consistently observed that for each DP fraction, a large peak was always accompanied by a small peak. In the case of inulin, these small peaks represent 4.3% on inulin DS (Figure 2; Table 1).

Based on literature data[2,20,49] and the results of permethylation analysis,[1,102] it has been concluded that the larger peaks correspond to molecules with the general formula GF_n. Concerning the basic trisaccharide GF_2, no chromatographic (HPLC) distinction could be made between 1-kestose, the major GF_2 compound in chicory roots[40] or Jerusalem artichoke,[2] and neokestose in onion[2] Figure 6). Fructan chains linked to either of these trisaccharides have the $\beta(2 \rightarrow 1)$ configuration. This implies that, with the exception of one glycosidic linkage within the basic trisaccharide, there is no difference between a fructan molecule based on 1-kestose or neokestose.

From recent research on purified DP fractions, it has been shown by means of ^{13}C-NMR that the smaller peaks can be represented chemically as F_m.[51] These compounds may be fragments of high-DP inulin, which are formed by partial hydrolysis (e.g., by endoinulinase activity).

It has been reported that a small fraction of $\beta(2 \rightarrow 6)$ bonds is generally present, even in chicory inulin, implying that inulin is branched.[52] This was confirmed by means of permethylation analysis, showing 1 to 2% branches for inulin (Raftiline®) and 2 to 4% $\beta(2 \rightarrow 6)$ branches for Sigma's dahlia inulins.

3. Conceptual Approach of the Definition of Inulin and Oligofructose

Taking into account all previous information, inulin can be defined for the purposes of this article as a polydisperse set of molecules belonging to the fructan group, with fewer than 150 fructosyl monomers, typically linked by means of $\beta(2 \rightarrow 1)$ fructofuranosyl bonds.

"Oligosaccharides" are currently defined as saccharides with DP 2 to 20.[53] This fraction of inulin is also called oligofructose. The analytical data presented in this article show that inulin from all sources contains significant amounts of oligofructose. These conclusions are summarized in Figure 3.

TABLE 2
Inulin or Oligofructose (=inulin with DP2 to DP20) Content of Fresh and/or Prepared Vegetables, Fruit and Cereals

Foodstuff	Form	Lower bound value (9 inulin/100 g as is)	Upper bound value (9 inulin/100 g as is)	Foodstuff	Form	Lower bound value (9 inulin/100 g as is)	Upper bound value (9 inulin/100 g as is)
Onion				Asparagus			
Dehydrated or dried	Raw Cooked Baked Fried	1.1 0 8 1.3 1.5	7.5 5.3 8.8 10.1		Raw Boiled Fried	2.0 1.4 2.7	3.0 2.0 4.1
Inulin: $\beta(2 \rightarrow 1)$ fructan; 75% 1-kestose based and 25% neokestose based	DP-distribution Range: DP2-12 Modus: DP5 *Content:* 1.1% to 7.5% on fresh weight	Remarks Fructans depolymerise during storage; more than 50% is left 8 months after harvest	Originates from Western Asia; cultivated as vegetable since antiquity; [2], [72], [3]–[11]	Inulin $\beta(2 \rightarrow 1)$ fructan; mostly 1-kestose based; a small fraction is neo-kestose-based [10]	Content (12)		
Jerusalem artichoke				Leek			
	Raw	16.0	20.0		Raw	3.0	
Inulin: $\beta(2 \rightarrow 1)$ fructan is 1-kestose based (121) Content 16% to 20% inulin on fresh weight ([13], [14], [15], [16])	DP-distribution Range: DP2-50 DP <10: 52% DP10–20: 22% DP20–40: 20% DP >40: 6% ([17], [18])	Remarks Per meal advised to diabetics 16–23 g inulin are ingested (50) Additional references ([19] to [23])	Originates from North America (22. 54); cultivated as vegetable since antiquity: ([13], [24], [25], [14], [26], [27])	Inulin $\beta(2 \rightarrow 1)$ *fructan;* 1-kestose and neo-kestose-based Content up to 3% to 10% on fresh weight [72]	DP-distribution DP12 is most frequently occurring chain length [28]	Remarks cfr. onion	
Rye — flour				Garlic			
	Raw	0.5	1.0		Raw	9.8	16.0
Inulin $\beta(2 \rightarrow 1)$ fructan 1-kestose and neokestose based [29]	Content 0.5% to 1% on fresh weight [4]		Remarks The inulin is still present in baked bread [30]	Inulin $\beta(2 \rightarrow 1)$ fructan; *1-kestose and neo-*kestose-based	Content up to 9% to 16% on fresh weight (4)	DP-distribution DP 2 to 50 (28)	
Dandelion — greens				Artichokes — Globe			
	Raw	12.0	15.0		Boiled	2.0	6.8
Inulin $\beta(2 \rightarrow 1)$ fructan ([31], [15], [32])	Content 12% to 15% on fresh weight [13]			Inulin $\beta(2 \rightarrow 1)$ fructan; mostly 1-kestose	Content 2.5% to 9.5% on fresh weight (33)	DP-distribution high DP range: DP <19: 0% DP19–40: 13% DP >40: 87% (18)	Vegetable common ar-*ticle of food in* western countries since centuries (33)
Barley				Bananas			
	Raw	0.5	1.0		Raw	0.3	0.7
Content 0.5–1.5% [34]				Inulin $\beta(2 \rightarrow 1)$ fructan	Content 0.3% to 0.7% on fresh weight (35)		

Wheat			
	Raw	1.0	4.0
	Baked	1.0	3.8
Inulin β(2 → 1) fructan (18. 20); 1-kestose series fructan detected ([29], [36], [37])	Content: 1% to 4% on fresh weight ([34], [38])	DP-distribution Low DP range: 50% has a DP of less than 5 [39]	Remarks The inulin is still present in baked bread [30]

Chicory			
	Roasted root	35.7	47.6
Inulin β(2 → 1) fructan; 100% 1-kestose based Content 15% to 20% on fresh weight [40]	DP-distribution Range: DP2-65 DP <10: 31% DP10–20: 24% DP >20: 45% [18]	Remarks Roasted chicory still contains >70% of its original inulin ([41], [42]) Additional References ([43, [44]–[47])	Vegetable since Greek and Roman antiquity; chicory drink (based on roasted roots) since Middle Ages in Europe [48]

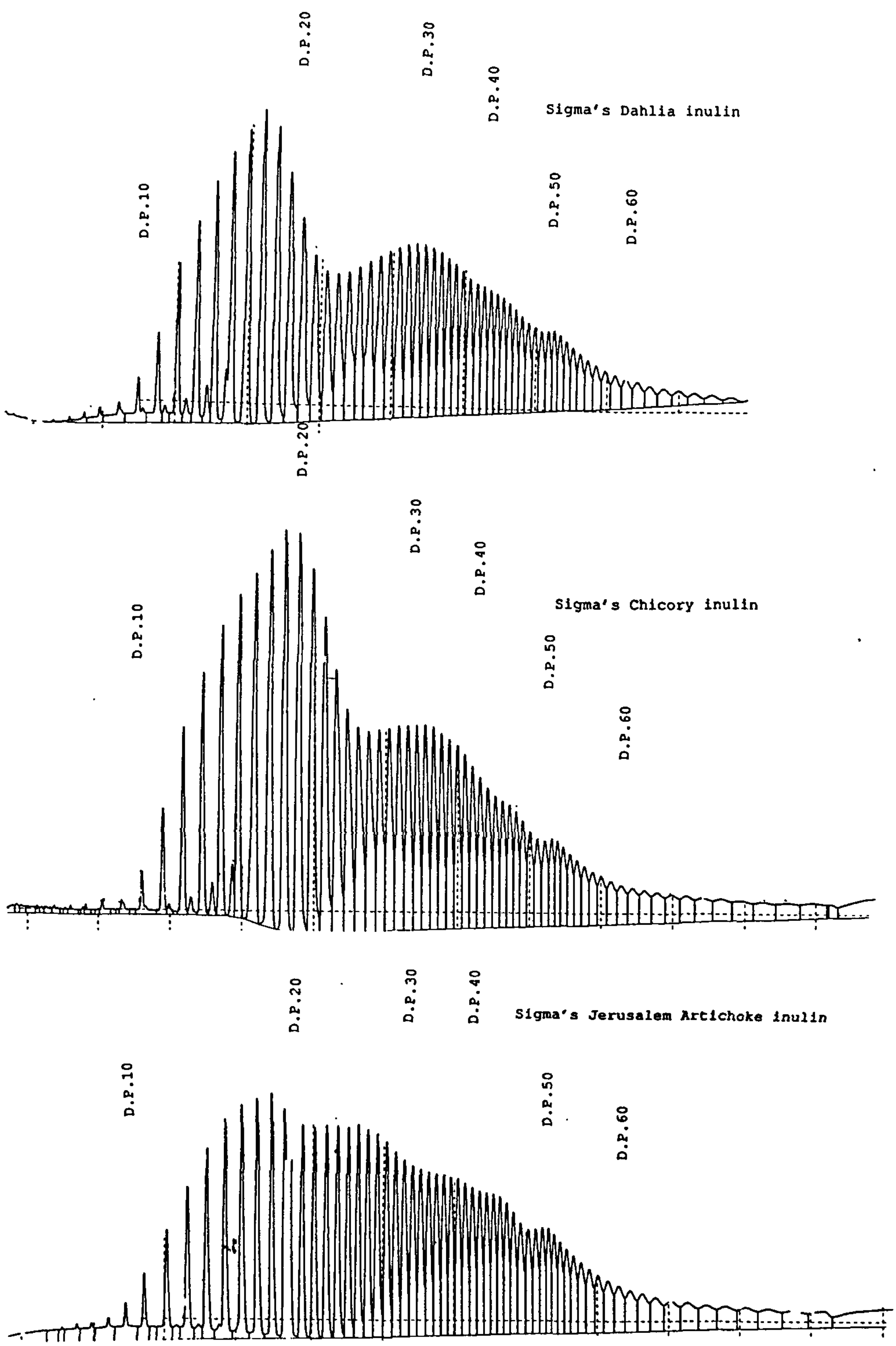

FIGURE 4. HPAEC-PAD chromatograms of Sigma's dahlia, chicory, and Jerusalem artichoke inulin showing the polydispersity of inulin over its whole DP range. It is observed that the DP range of the three types of inulin has been uniformalized by removal of the lower-molecular-weight (DP2 to 10) fractions.

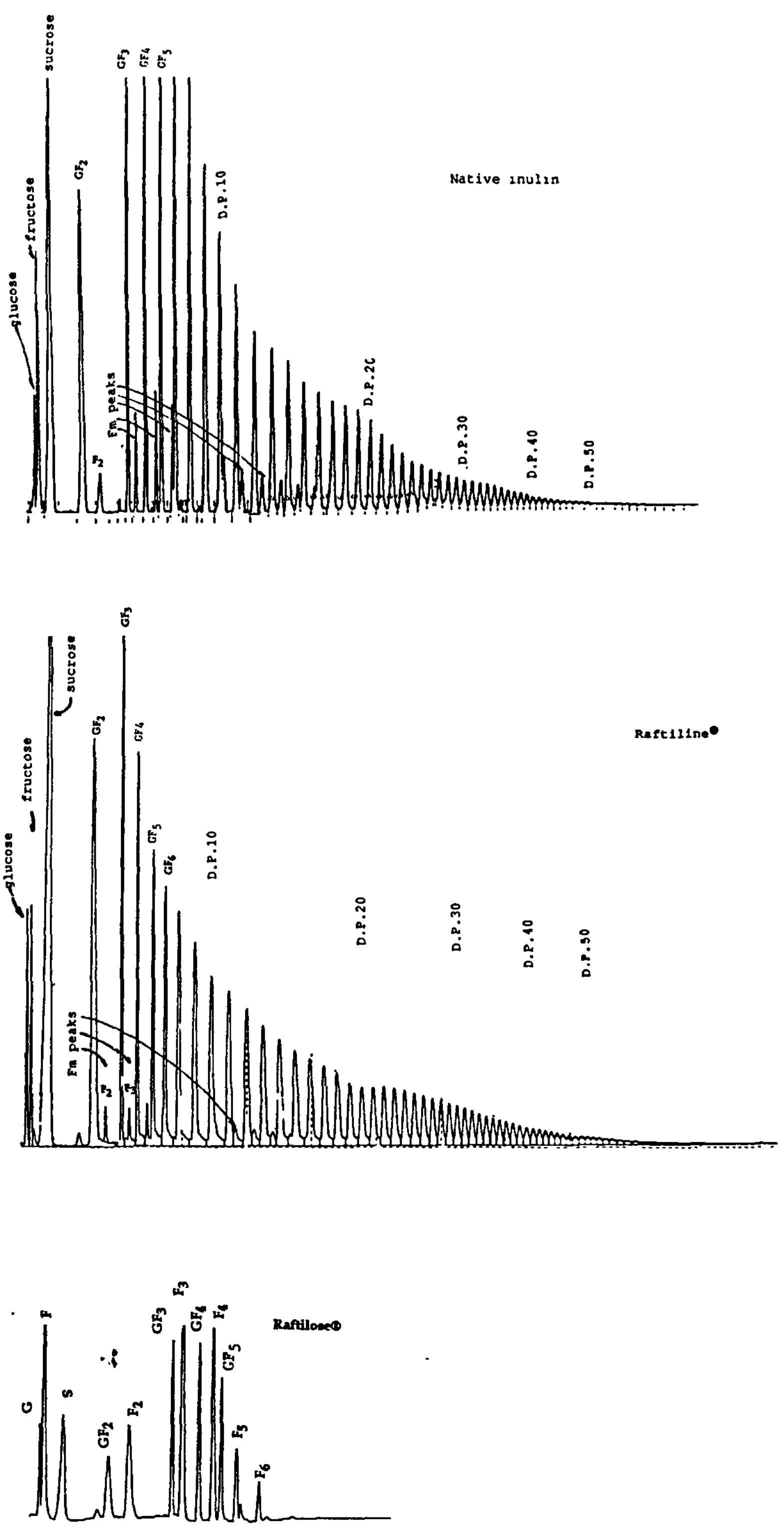

FIGURE 5. HPAEC-PAD chromatograms of native and commercial chicory inulin (Raftiline®) showing the importance of the lower-DP oligofructose fraction. Raftilose® contains oligofructose, which was obtained by enzymatic hydrolysis of chicory inulin.

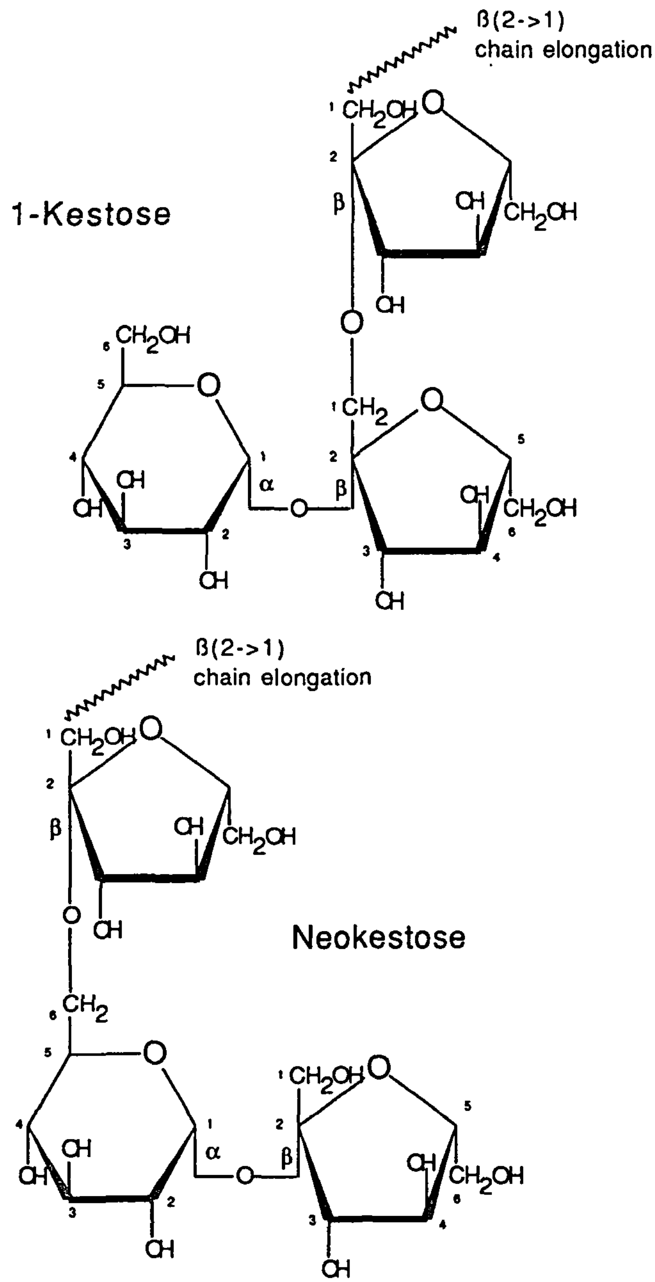

FIGURE 6. Structural formula of the basic trisaccharides of β(2 → 1) fructans.

B. Common Food Plants and their Inulin Content

*1. Onion (*Allium cepa*)*

a. History of Its Human Consumption

Onion (*Allium cepa* cv) is a commonly cultivated crop. It originates from western Asia and has been cultivated as a vegetable since antiquity in the European region. The bulb of this plant is an important ingredient of the daily nutrition in Europe,[5] as well as in the U.S. and many other parts of the world.

b. Carbohydrate Content

i. Literature Data

The nonstructural carbohydrates in onions include glucose, fructose, and sucrose together with a series of oligosaccharides, the fructans. In the USDA Manual on the composition of Foods (1984), an average value of 7.32% carbohydrates fresh is mentioned for onion (NDB No. = 11282). Hanley and Fenwick[5] found a total carbohydrate content of 5.2 to 8.7%. These carbohydrates may account for 65% or more of the dry weight.[6] Randle[54] mentions a range of 41 to 88% of nonstructural carbohydrates on a dry weight basis. Suzuki and Cutcliffe[3] determined that the oligofructose content ranges from 27.1 to 41.5% on DS, and hence the oligofructose content varies between 1.8 and 4.4% on a fresh weight basis. Asami et al.[4] found 2.8% on a fresh weight basis.

ii. Experimental Control

The oligofructose content of several onion samples, analyzed by means of standardized methods of analysis (Section II.B.2), ranged between 1.1 and 7.1% oligofructose on a fresh weight basis (Table 3), which confirmed the literature findings (see Table 4).

TABLE 3
The Inulin or Oligofructose Content of Different Commercial Onion Types, Determined by Means of a Standardized HPLC Method

Onion type	Oligofructose content (g/100 g as is)
Hiton	1.6
Jumbo	1.1
Type 1	7.1
Type 2	2.2
Type 3	3.9

TABLE 4
Summary Table Describing the Inulin in Onion (*Allium cepa*)

Composition

Item	Range	Average (%)
DS content	6.5–11.5	9.7
%Fructan on fresh	1.1–7.5	3.6

DP-Distribution

Range	Remark
1–12	Most frequently occurring DP is 5

c. Influence of Storage Time on the Fructan Content of Onion Bulbs

i. Literature Data

The fructan content of onion bulbs diminishes during cold storage.[7] Onions (*A. cepa* cv Robusta) stored at 4°C and 70% RH and originally containing 4.3% (on a fresh weight basis) fructans still contained 4.4% (on a fresh weight basis) fructans after 2 months. The fructan content dropped to 3.3% after 4 months, and finally to 2.5% after 8 months of storage.[7]

Darbyshire[8] demonstrated on *A. cepa* cv Golden Brown Lockyer an increase in fructose content with time. He also observed that the fructose content increased with decreasing temperature, which indirectly indicates that more fructan hydrolysis occurs at lower temperatures (a temperature range of 4 to 37°C was considered). A higher trisaccharide content at 37 than at 4°C confirmed these results.

ii. Experimental Control

Two types of onion (Hiton and Jumbo) were stockpiled in a conditioned silo. A sample of five randomly selected onions was used for chemical analysis. The analysis was repeated after 28 and 73 d of storage. Additionally, the analysis of the Hiton type was undertaken on a sample that was kept on a laboratory shelf at room temperature for 68 d. The results are presented in Table 5. As long as the environmental temperature was higher than 8°C (up to 25°C), no significant change in the inulin or in the DS content was observed over 28 d. After this initial period, the storage temperature dropped to 2°C, and after 73 d of storage both the inulin and DS contents were reduced significantly.

*2. Jerusalem Artichoke (*Helianthus tuberosus *L.) and Jerusalem Artichoke Flour*

a. History of Its Human Consumption

Yanovski and Kingsbury[13] reported that the tuber of Jerusalem artichoke was eaten by the Indian populations of Columbia. Kuppers-

TABLE 5
Evolution of the Oligofructose Content of Two Types of Onion (Jumbo and Hiton) as a Function of Storage Time

Jumbo

Date	No. days	Storage temperature	DP5+	DP4	DP3	DS	DS (%)	Fresh (%)
21/Nov.	0	>8°C	2.7	5.0	12.2	9.1	11.9	1.08
19/Dec.	28	>8°C	2.0	4.6	11.9	10.3	13.3	1.37
01/Feb.	73	Temperature dropped to 2°C	<0.1	3.3	9.5	9.0	7.0	0.70

Hiton

Date	No. days	Storage temperature	DP5+	DP4	DP3	DS	DS (%)	Fresh (%)
21/Nov.	0	>8°C	3.8	7.8	17.5	11.8	13.5	1.6
19/Dec.	28	>8°C	3.1	7.0	14.7	11.2	14.5	1.6
0.1/Feb.	73	Temperature dropped to 2°C	3.2	3.7	9.8	9.9	8.0	0.8
Stored in lab	68	20°C to 25°C	2.5	4.4	11.2	9.6	11.2	1.1

Note: DP3, DP4, and DP5 = inulin with a degree of polymerization of 3, 4, or 5 expressed as a percentage of total extracted carbohydrate content. DS = the dry solids content of the onion. DS (%) = the inulin content of the onions, being the sum of DP3 + DP4 + $DP5^+$ and expressed as a percentage of DS. Fresh (%) = the inulin content expressed as a percentage of fresh weight.

Sonnenberg[16] states that Canadian Indian populations have been eating the grilled tuber since before 1613. Routley[19] studied historic travel reports and states that Jerusalem artichoke is one of the oldest cultivated crops in North America. Written data from 1585 and 1602 give evidence that the tubers were eaten by Indians and the early settlers of Canada.[24] The crop came to Europe via Rome (1616) and became commonly known in Spain and the Mediterranean around 1650. During the seventeenth century,[14] when the potato was hardly known, Jerusalem artichoke was considered a common food component in countries like England (pastry), Germany, and France. The plant was commonly consumed by the French in 1910[14] and in the Netherlands, especially Zeeland, where it was a common compound of the daily food.[24] In 1920, more than 100,000 ha of Jerusalem artichoke was cultivated in France.[26]

Diabetics are advised to eat Jerusalem artichoke as an alternative source of energy.[16,55] The inulin-containing tubers are presented as a substitute for starch-containing vegetables.[20] Balzli[31] and Dallimonti[27] recommend Jerusalem artichoke to diabetics and point out several preparation methods.

Jerusalem artichoke flour has been produced for many years as an ingredient for food preparations, for example, added to wheat flour, the latter becomes a low-calorie flour.[56] Jerusalem artichoke flour is also used in the production of several pasta products.[57]

b. Carbohydrate Content

The earliest publication of Jerusalem artichoke as a source of inulin dates from 1870.[50,58] As early as 1918, Colin[21] determined the inulin content of Jerusalem artichoke. He found a value of 7.4% on a fresh weight basis, which he confirmed in 1919 (6.3% fresh). Jumelle[14] mentions values between 12.4 and 14.3%;[59] Yanovski and Kingsbury,[13] determined 20.5% inulin on a fresh weight basis, a figure that was confirmed by Melnik.[60] Yet, in 1938, Balzli[31] published that the "inulin and the like substances" mount up to 30% of this fresh tuber. Bacon and Edelman[15] confirmed in 1951 that the most abundant carbohydrate in Jerusalem artichoke was inulin.[61] Kuppers-Sonnenberg[16] mentioned an inulin content of 17% on a fresh weight basis. Van den Hil and Mesken[62] found an inulin content of 16%. These data are confirmed by the USDA (1984), where a total carbohydrate content of 17.44% fresh is mentioned (NDB No. = 11226). Heyraud et al.[22] showed by means of ^{13}C-NMR the presence of 1-kestose-based oligofructoses with a DP up to 7.

In 1965, Phelps[49] demonstrated globally that inulin is polydisperse. Heyraud et al.[22] mentioned the presence of inulobiose (F_2) in fresh Jerusalem artichoke juice. Praznik et al.[63] detected inulin fractions with a DP up to 30 in Jerusalem artichoke tuber aqueous extracts. Praznik and Beck[18] detected that 74% of the Jerusalem artichoke inulin had a DP <19, that 20% is situated between DP 19 to 40, and that 6% had a DP >40. Praznik and Beck[23] confirmed these data (30% had DP >20). In 1986, the same authors[64] refined their findings: 26% of the inulin had a DP >20, 22% had a DP between 10 and 20, and 52% had a DP <10. They remarked, however, that DP decreased as the harvesting time is postponed (Table 6).[23]

TABLE 6
Summary Table Describing the Inulin in Jerusalem Artichoke (*Helianthus tuberosus*)

Item	Composition Range
DS content (%)	19–23
%Fructan on fresh	17–20.5
%Inulin on fructan	100

DP-Distribution

DP2–19	DP19–40	DP >4
74%	20%	6%
DP <10	DP 10–20	DP >20
52%	22%	26%

3. Chicory (Cichorium intybus)

a. History of Its Human Consumption

Chicory has been a food for man probably ever since humans have existed. Old Egyptian (the Ebers Papyrus, 4000 BC), Greek (Aristphane, 450 BC; Threophaste, 371 BC), and Roman (Horatius, Ovidius) sources indicate chicory as a vegetable. It was consumed raw, cooked, or roasted (Egyptians made coffee with it). It was also considered a cure for diseases.[48,65]

Since the Middle Ages, torrified chicory has been used to prepare a drink, even before "coffee" was known. A certain Dr. Hueppe of Prague wrote that the first "industrial" production of torrified chicory was performed in the Netherlands, and dates from 1650.[65] Since the end of the eighteenth century, coffee chicory has been prepared on a vast industrial scale.[44,48,65]

b. The Inulin Content of Chicory

i. Literature Data

In 1919, Colin[47] published that the root of this plant contained inulin. Praznik and Beck[18] demonstrated that 55% of inulin had a DP of 2 to 19, that 28% had a DP between 19 and 40, and that 17% of the inulin had a DP >40. In 1986, the same authors[18] specified the lower DP fraction: the fraction with DP 2 to 10 constituted 31% of the inulin, the fraction with DP 10 to 20, 24%, and the remaining 45% had a DP >20. Douglas and Poll[40] determined the DS content and the sugar content of *C. intybus* cv. Reine Bon. They harvested the roots in October and concluded that the dry matter content of the roots was 24.4 (±0.25)% fresh and that the fresh sugar content was 16.2 (±0.61)%. The inulin content of several other cultivars examined ranged from 15.2 to 20.5% fresh. USDA (1984) mentions a value of 20% DS and 17.51% total carbohydrates (NDB No. = 11154).

Fitters et al.[66] followed the evolution of inulin accumulation in chicory (witlof) roots, as well as the evolution in time of the DP. Van den Ende and Van Laere[67] purified and characterized the chicory SST-enzyme (sucrose:sucrose fructosyltransferase), the enzyme that is the basis of the inulin formation in this plant.

ii. Experimental Control

In Table 7, the inulin content (Section II.B.4), its average DP (the ratio of fructose to glucose originating from inulin hydrolysis), and the DS content of chicory roots from the period September to December 1992 are presented. The results confirm the literature data. It is also observed that the inulin content fluctuates slightly as a function of time, and that the average DP of inulin decreases as the weather conditions become colder (see Table 8).

c. The Influence of Roasting on the Inulin Content of Chicory

i. Literature Data

Pazola and Cieslak[41] described the influence of the roasting process on the inulin content of coffee chicory. Depending on the intensity of the roasting process, more inulin is converted to fructose: coffee chicory that was roasted "dark" still contained 29% inulin (i.e., 48% degradation) and a "normal" roasted product contained 44% (i.e., 21.4% degradation). The remaining inulin is extracted during the coffee preparation process.

TABLE 7
Inulin Content and Its Average DP of Chicory Roots as a Function of Time

Date	Inulin content	Average DP
August 1993	16.2	13.6
September 1993	17.0	14.0
October 1993	16.1	12.0
November 5, 1993	14.7	10.9
November 16, 1993	14.5	9.5

TABLE 8
Summary Table Describing the Inulin in Chicory (*Cichorium intybus*)

	Composition	
Chicory roots	**Range**	**Average**
DS content (%)	—	24.4
% Inulin on fresh	15.2–20.5	16.2
	DP-Distribution	
DP 2–19	**DP 19–40**	**DP >40**
55%	28%	17%
DP <10	**DP 10–20**	**DP >20**
31%	24%	45%

ii. Experimental Control

In Table 9, the inulin of commercially available roasted chicory (Pacha) is compared with inulin as it is present in the chicory root. The roasting process to some extent depolymerized the inulin. The roasted inulin is richer in smaller-DP fractions and has less inulin, with DP ≥ 10. Comparison of the total inulin content on DS of both samples shows that the degradation of inulin into nonsugar degradation products is of the order of magnitude of 10%. These results compare with literature data.

*4. Asparagus (**Asparagus officinalis L.**)*

a. History of Its Human Consumption

The shoots of asparagus are a precious vegetable that is cultivated in many countries of the world. In many European countries and the U.S., it is a delicacy that has been served in spring for centuries.

b. Carbohydrate Content

i. Literature Data

Shiomi and co-workers[10,68,69] and Fiala and Jolivet[12] detected 1-kestose, nystose, fructosylnystose, and neokestose in asparagus roots.

TABLE 9
Influence of Food Processing Actions (e.g., Cooking and Roasting) on the Inulin and Oligofructose Content of Foodstuffs

	Salsify		Globe artichoke	
	Fresh	**Cooked**	**Fresh**	**Cooked**
Dry solids (%)	19.6	10.6	75.7	74.6
Sugar spectrum (in % on total sugars)				
DP5+	47.9	37.5	75.7	74.6
DP4	8.5	10.4	1.2	0.6
DP3	8.1	11.5	1.5	2.4
F3	0.9	7.3	—	—
Sucrose	12.8	9.4	8.5	8.9
F2	1.4	0.7	—	—
Glucose	0.5	1.0	1.8	1.8
Fructose	7.1	8.3	11.1	11.6
Inulin on DS	21.2	19.2	—	—
Inulin on fresh	—	—	1.8	1.7
Average degradation	9.4%		6.4%	

Carbohydrate spectrum (in % on total sugars): a correction for non-carbohydrates DS has been made	**Roasted chicory granules[a]**	**Native inulin**
Fructose	12.1	0.2
Glucose	4.4	0.0
Sucrose	4.1	6.5
DP2	14.2	0.0
DP3	5.3	4.3
DP4	3.5	4.6
DP5	2.5	4.9
DP6	2.0	4.8
DP7	1.4	4.1
DP8	0.8	3.6
DP9	0.3	3.1
DP10	49.5	63.8
% Inulin on DS	56.6	64.2
% Degradation[b]	(7.6%)	
Reference 41	21%	

[a] Commercial product (Pacha coffee chicory).
[b] The figures are not directly comparable but give a fairly good idea of the order of magnitude.

The chain elongation from both fructan precursors (trisaccharides) takes place through $\beta(2 \rightarrow 1)$ fructose bonds.

The $\beta(2 \rightarrow 1)$ fructans amount to 8% of the sugars (4% fresh) detected, which means that asparagus roots contain at least 0.3% inulin (fresh).

Asparagus shoots have a DS of 7.75%, and a total carbohydrate content of 3.69 g fresh (USDA [1984]; NDB No. = 11011).[70] No specific data on DP distribution have been published.

ii. Experimental Control

Our research method (Section II.B.2) revealed that the DS content of the shoots was 6.3%, with a soluble carbohydrate content of 3.7% (fresh), of which 2.6% was inulin, or the inulin content on fresh plant material detected was 0.1%. This is lower than the figures mentioned in the literature, but the order of magnitude is confirmed. The inulin content of vegetables is dependent on the time of harvest.

5. Leek (Allium ampeloprasum)

a. History of its Human Consumption

The widespread use of leek as a domestic crop for centuries is evident.[5]

b. Inulin Content of Leek

i. Literature Data

Bacon[71] found 5 to 10 times more inulin in leek than in onion. As is the case in onion, 1-kestose and neokestose-based fructan were the main nonstructural carbohydrates present. Darbyshire and Henry[28] added to these results that DP 12 is the most frequently occurring chain length. The USDA (1984) manual on food analysis mentions a DS content of 17%, and an average carbohydrate content of 14.2 g fresh (NDB No. = 11246). These data, together with the Bacon findings,[71] indicate that the inulin content of fresh leek, that is, stored for less than 1 month, can be as high as 10%. Valuable literature data on DP distribution are lacking.

ii. Experimental Control

The inulin content of leek was determined by the method in Section II.B.2. An inulin content of 2.9% was detected on fresh leek leaves. The literature data seem to overestimate the inulin content. The present analysis however was performed in August; this means that the leek was stored for at least several months. Some degradation of inulin hence may have occurred in the meantime. The figure, however, can be considered as a lower bound value of the actual inulin content of leek.

6. Garlic (A. sativum)

a. History of Its Human Consumption

The widespread use of garlic as a domestic crop for thousands of years has an abundance of evidence.[5]

b. The Inulin Content of Garlic

i. Literature Data

Darbyshire and Henry[28] have demonstrated the presence of 1-kestose and neokestose-type fructans with a chain length of 2 to 50 monomers. The bulbs contain as much as 25.2% soluble carbohydrate, which is nearly five times higher than that of onion. Asami et al.[4] found a DS content of 42.9% in fresh garlic. In the USDA (NDB No. = 11215) manual on food compositions (1984) a DS of 41.41% is mentioned and a total carbohydrate content of 33.07%.

Based on these data, and on the data of Asami et al.,[4] who mentions a DS content of 42.9%, one can reasonably deduce that the inulin content of garlic can be estimated at 16.1% fresh.

ii. Experimental Control

Garlic obtained in the local grocery store was analyzed as described in Section II.B.1 and 2. The results are summarized in Table 10. Based on these figures, it was calculated that the inulin content of garlic is 12.98%, which confirms the literature data.

It was also remarked that 75% of the inulin had a DP of 5 or higher, which implies that the inulin had a relatively high DP. Determination of the average DP was made by completely hydrolyzing the inulin. A fructose-to-glucose ratio of 14 was found, which means that the average molecular weight is 15 (compared with chicory, where the average DP is 8 to 10). This confirms the statements of Darbyshire and Henry.[28]

TABLE 10
The Inulin Content and the DS Content of Garlic

DS content	34.7%
DP-distribution	% of total extracted carbohydrates
DP5 and higher	74.8
DP4	±1
DP3	±1
DP2 (including sucrose)	9.1
Glucose	0.6
Fructose	13.5

Note: The garlic inulin has a high DP: 75% of the inulin has a DP of 5 or higher.

7. *Globe Artichoke* (Cynara scolymus)

a. *History of Its Human Consumption*

As early as in 1920, Okey and Williams[33] published that artichoke was a common food, especially in California. The same authors mention a reference dating from 1883, wherein the presence of inulin in the flowering head is described. Okey and Williams[33] deduced from a study of Wiley[72] that inulin was present in canned artichoke hearts.

b. *The Inulin Content of Globe Artichoke*

i. Literature Data

Okey and Williams[33] meticulously analyzed artichoke and concluded that the DS content was 14.4%, the inulin content 2.5%, and the total sugar content 6.8% on a fresh weight basis. The USDA (1984; NDB No. = 11007) determined a DS content of 15.62% and a total carbohydrate content of 11.91%.

Praznik and Beck[18] discovered that artichoke inulin had a very high DP; they did not detect inulin with a DP of 2 to 20, but 13% of the inulin had a DP between 19 and 40 and 87% of the inulin had a DP >40.

ii. Experimental Control

In Table 9, the inulin content of Globe artichoke was determined by the methods in Section II.B.1 and 2. The analysis was performed on a fresh sample and a sample that was previously cooked for 15 min, the latter to check how much of the inulin appears as such "on the dish". In the fresh sample, of a total of 2.3% soluble carbohydrates, 1.8% was inulin. These figures are somewhat lower than the values mentioned in the literature. More than 96% of the inulin had a DP >5, which is an indication of a high average DP.

Concerning the inulin content of the prepared sample, only a slight decrease (6.4%) in inulin content was observed, indicating that cooking vegetables does not degrade or leach the inulin to a significant degree.

8. *Salsify* (Scorzonera hispanica)

a. *History of Its Human Consumption*

Salsify is a well-appreciated vegetable in western Europe.[14]

b. *Inulin of Salsify*

i. Literature Data

Van Hee[73] analyzed the roots and found a DS content of 22%, 50% or more of which was inulin.

ii. Experimental Control

It was observed that the DS content of the fresh vegetable was 19.6%, with a total inulin content of 21.2% (or 4.2% fresh). These values confirm the literature data.

Salsify inulin has a lower average DP than Globe artichoke inulin; 75% of the inulin had a DP >5 (compared with onion, where only 3 to 5% of the inulin has a DP >5).

Also, the inulin content was determined after cooking for 15 min. Some depolymerization resulted in higher fructose, and DP2 to DP4 fraction was observed; 9.4% of the inulin was degraded (Table 9).

9. *Banana* (Musa cavendishii *Lamb.*)

a. *History of Its Human Consumption*

Bananas have been used for human consumption probably as long as mankind has existed. Presently, it is consumed throughout the entire world. Bananas provide an example of the occurrence of inulin in fruit.

b. *Inulin Content of Bananas*

i. Literature Data

Henderson et al.[35] observed the conversion of starch into glucose, fructose, and sucrose during the ripening of bananas. The sucrose formation is accompanied by an increase in neokestose. Fructan chain elongation from neokestose occurs via β(2 → 1) bonds, hence the resulting oligosaccharides belong to the inulin group.

Asami et al.[4] found a DS of 24.6%, and an inulin content of 0.3% in fresh fruit.

In USDA (1982), a DS content of 25.74%, and a total carbohydrate content of 23.43% fresh are mentioned (NDB No. = 09040).

ii. Experimental Control

With an observed inulin content of 0.7% on a fresh weight basis, the literature data were confirmed. From the HPLC chromatograms, it was concluded that banana inulin has a short average DP (100% with DP <5; Table 11).

*10. Wheat (*Triticum aestivum*)*

a. Human Consumption

Wheat flour is the basis of bread, and has been used by mankind for ages.

b. Inulin Content of Wheat

i. Literature Data

Nilsson and Dahlquist[38] and Rumessen[74] demonstrated the presence of 1 to 4% (on DS) fructan in wheat flour. Nilsson and Dahlquist[38] determined the fructan they examined to be of the "inulin type" because of its chain elongation through β(2 → 1) bonds. Cerning-Beroard and Guilbot[34] followed the evolution of the fructan content in developing wheat kernels. They discovered that in an early stage up to 25% of the carbohydrates are fructans. This amount decreases to 1 to 2% as the grain matures. In a representative fructan fraction, Bancal and Triboi[75] observed a maximum of 40% β(2 → 1) bonds at anthesis, which decreased to 10% at maximum grain fresh weight.

Spollen and Nelson[36] demonstrated the presence of 1-kestose in a DP3 fraction of wheat. Saunders and Walker[37] and Saunders et al.[29] found 0.16% nystose and trace amounts of neokestose in wheat bran. The DP of the fructans was relatively low: 50% had a DP >5. Nilsson et al.[39] detailed this fraction: they found 30% DP3, 13% DP4, and 6% DP5; 50% of the wheat fructans had a DP >5. Bancal and Triboi,[75] however, observed fructans with a DP up to 15. Jeong and Housley[76] isolated and characterized the wheat β(2 → 1) fructan:fructan fructosyl transferase enzyme. The best donor substrate was 1-kestose, and chain elongation occurs via β(2 → 1) fructosyl bonds. The oligosaccharides that were produced *in vitro* had a DP of up to 5. Ströh-Neben[77] discussed the fate of fructan-fructose during the grain-filling period, and Albrecht et al.[78] described the fate and function of oligofructose in wheat seedlings.

From the fact that generally the rate of hydrolysis is proportional to the substrate concentration if the concentration is much lower than K_m, together with the fact that the rate of enzymatic hydrolysis decreases with increasing molecular weight of the substrate, one may conclude that the 1 to 4% fructans in wheat flour will not be degraded by yeast invertases during the baking of bread. This fact was indirectly proved by Sutalf and Levitt,[30] who described a patient with flatulence who obtained relief only when a low-wheat diet was maintained. The patient's flatulence was correlated with the consumption of inulin. In his patent, Hill[79] mentions wheat as a natural source of inulin.

ii. Experimental Control

A sample of white and brown commercial bakery flour was refluxed with a 60% EtOH solution (eliminating most high-DP starchy sub-

TABLE 11
Inulin Content of Banana

Carbohydrate	Fresh weight (%)
Fructose	2.08
Glucose	2.20
Sucrose	11.41
DFA	0.04
F2	0.01
GF2+	0.84

Note: The DS content of banana is 25.15%; oligosaccharide analysis HPLC.

stances). After centrifugation, the inulin content of the supernatant was determined, as described in Section II.B.3. The inulin content (on DS) for the white flour was 1.17 g/100 g on DS, and for the integral flour, an inulin content of 0.95 g/100 g on DS was detected. These results match the lower bound value that is mentioned in the literature.

The inulin typically had a low DP. The highest observed DP was 7 to 8. The inulin in wheat thus actually is oligofructose.

*11. Durum Wheat (*Triticum durum*)*

a. History of Its Human Consumption

This type of grain has long been used by Mediterranean populations. It is transformed into pastas in Italy and is exported under all its forms from there into the whole (Western) world.

b. Inulin in Durum Wheat

The presence of inulin in durum wheat was demonstrated by Medcalf and Cheung.[80]

*12. Rye (*Secale cereale*)*

a. History of Its Human Consumption

Rye is a common agricultural crop that is cultivated for the baking of bread.

b. Inulin in Rye

Asami et al.[4] detected 0.6% fructans in rye and a DS content of 88.5%. Saunders et al.[29] demonstrated the presence of 0.4% nystose and 1.39 neokestose in rye bran.

*13. Barley (*Hordeum vulgare*)*

a. History of Its Human Consumption

Barley is a common agricultural crop, which is partially grown for the baking of bread, but more specifically for the production of beer and many other alcoholic beverages, such as whiskey and gin.

b. Inulin in Barley

Very young barley kernels contain 22.1% fructans. As they mature, the grains finally obtain a fructan content of 1.1%. Several authors[34,81] observed 1-kestose as the predominant fructan precursor in leaves.

*14. Dandelion (*Taraxacum officinale *Weber)*

a. History of Its Human Consumption

Dandelion is eaten in the Western world as dandelion leaf salad. Yanovski and Kingsbury[13] reported in 1938 on the consumption of dandelion by the Indian populations of Columbia.

b. Inulin of Dandelion

Yanovski and Kingsbury[13] determined a DS content of 51.2%, and an inulin content of 12.8% in fresh plant material. In 1951, Bacon and Edelman[15] confirmed that this plant contained inulin.

In 1986, Klaushofer[32] published that the edible roots contained 40% inulin on DS. The FFT-enzyme (fructan:fructan fructosyltransferase) isolated was only active with $\beta(2 \rightarrow 1)$ oligofructans.[82]

Because the plant is eaten raw, none of the inulin present is degraded before consumption.

*15. Burdock (*Arctium lappa*)*

a. History of Its Human Consumption

The roots of burdock have been used by the Japanese as a cooked vegetable under the name "gobo".[31] Fried in fat, it has historically been an important item of the Japanese diet.[83,84] Another member of the same genus is common burdock (*A. minus*), which is also valued as a food plant in

Europe and the U.S. The stems of this plant can be gathered and cooked like asparagus, whereas the roots and shoots may be cooked or dried and saved, a practice of the Iroquois Indians in the U.S.[83–85] and the Scottish in Europe.[31]

b. Inulin in Burdock

Burdock roots contain a DS content of 21.5% and an inulin content of 3.6% in fresh plant material.[4] This is a confirmation of the results of Jumelle,[14] who mentioned a DS content of 26% and 3.4% "starch". Krantz and Carr,[83,84] however, observed an inulin content of 50 to 70% in dried roots, which would mean that the inulin content varied between 12 and 17% in fresh root.

16. Other Food Plants

Inulin is a universal food component. This is illustrated in Table 12. Many roots and tubers, and even receptacles of thistles that are eaten by indigenous populations, contain inulin or oligofructose.

The oldest evidence dates from prehistoric findings, where in ancient pottery containing carbonized food, the remnants of thistle receptacles were identified.

VI. ESTIMATIONS ON THE ACTUAL DAILY INTAKE OF INULIN OR OLIGOFRUCTOSE

Due to their presence in many food plants, it can be stated that inulin and oligofructose have been a component of the daily food of mankind for eons. Based on the figures in Table 2, the actual daily per capita intake of inulin and oligofructose in Western countries (the U.S. and Europe) has been estimated.

A. Estimation of the Daily Inulin/ Oligofructose Intake in the U.S.

The data in Table 2 were combined with detailed American data on the consumption of the different inulin- or oligofructose-containing foodstuffs.[87] This allowed an estimation of the daily intake by the North American population. The extensive amount of specific food consumption data present in the USDA files, combined with detailed demographic data to which the authors had access, showed how the inulin or oligofructose intake varies with season, age group, sex, race, and region. A summary of the results is presented in Table 13.

Egan and Heimbach[87] observed that the plant foodstuffs that most abundantly contribute to the human intake of inulin generally also have a relatively low DP (DP <20). The situation for inulin thus also applies to oligofructose.

The figures in Table 13 indicate that an average North American consumes between 0.014 and 0.054 g inulin or oligofructose per day per kilogram of body weight (BW). This corresponds to an intake of 1 to 4 g by a 165-lb person (75 kg). The simulated intake values for the 90th percentile indicate that 10% of the population eats double this amount, that is, 2 to 8 g inulin or oligofructose per day (75-kg person). There is a subgroup (0.5% of the population) that consumes 10 times the average amount on a daily basis.

It is reasonable to accept that occasionally people have peak intakes of inulin or oligofructose (bowl of French onion soup, salsify dish, etc.), which can easily exceed 10 g (Table 14). This illustrates that via their normal diet some and, at certain times potentially all, of the population consumes high quantities (>10 g/d) of this fructan.

It also follows that wheat, onion, and banana, and to a lesser extent garlic, are the most important sources of inulin and oligofructose in the North American diet.

Table 13 further demonstrates that the inulin intake depends on the season, sex, race, and age group: children of 1 to 6 years of age take in significantly higher amounts of inulin or oligofructose per kilogram of body weight than the rest of the population. Hispanic North Americans are the most important inulin- or oligofructose-consuming group. The seasonal fluctuations can be correlated with periods of harvest or of shortage of vegetables or fruits.

B. Estimation of the Daily Inulin or Oligofructose Intake in Western Europe

No literature on this topic can be traced. The inulin or oligofructose intake in western Europe

TABLE 12
Inulin or Oligofructose Content of Some Food Crops That Are or Were Commonly Used in Other Human Diets

Plant (edible parts)	%DS	%Inulin	Eaten by	Ref.
Dahlia (tuber)	NA	90 (on DS)	Aztec Mexicans	[a]
Allium nuttalii S. Wats (bulb)	31.2	18.1	Indian	13
Balsamorhiza deltoidea (root)	92.8	7.1	Indian	13
B. sagittata (root)	93.0	9.4	Indian	13
Wyethia amplexicaulis (root)	82.3	16.1	Indian	13
Wyethia spp. (root)	42.0	2.7	Indian	13
Scallion (bulb)	8.5	0.2	Universal	4
Arthropodium spp. — vanilla lily	NA	Present	Aboriginals[b]	86
Bulbine bulbosa — Bulbine Lily	NA	Present	Aboriginals[b]	86
Caesia spp. — grass lily	NA	Present	Aboriginals[b]	86
Chamaescilla corymbosa — blue stars	NA	Present	Aboriginals[b]	86
Dichopogon spp. — chocolate lily	NA	Present	Aboriginals[b]	86
Thysanotus spp. — fringe lily	NA	Present	Aboriginals[b]	86
Polyporus mulittae — native bread	NA	Present	Aboriginals[b]	86
Some acacia gums	NA	Present	Aboriginals[b]	86
Inula helenium (root)	NA	44	Europe	31, 32
Thistles			In Europe in	
Carlina acaulis (receptacle)	NA	Present	Mountain pastures	31
Onopordium acanthium (receptacle, root)	NA	Present	Italy	31
Scolymus hispanicus (leaves and shoots)	NA	Present	Mediterranean	31
Tragopogon porrifolius (roots and shoots)	NA	Present	Mediterranean	31
Silybum marianum (receptacle, shoots, leaves)	NA	Present	Mediterranean	31
Tragopogon pratensis (roots, shoots)	NA	Present	Europe	31
Sircium eriophorum (receptacle)	NA	Present	Central Europe	31
Other				
Camassia quamash (roots)	49.5	22.0	Indians north U.S.	13
Microseris scapigera (roots) or Murnong	26.9	8–13	Aboriginals	86
Yacon	13–31	3–19	Japan	4

Note: NA = data not available.

[a] California Natural Products Newsletter, March 1987.
[b] Australia.

was estimated based on the values of Table 2 and on Eurostat data.[88] It was calculated that the average daily per capita inulin or oligofructose intake varies between 3.2 and 11.3 g (75-kg person BW). The averaged results for Belgium (ranging from 2.8 to 10.4 g per capita per day) as well as for Spain (ranging from 5.7 to 17.1 g inulin or oligofructose per capita per day), which is the highest inulin-consuming European country, are presented in Table 14.

As an illustration, the estimated peak intakes of inulin or oligofructose, for example, after consumption of a bowl of French onion soup (6 to 18 g inulin or oligofructose per bowl) or a salsify dish (6 to 9 g inulin or oligofructose per dish), are shown.

Again, it is observed that the most important source of inulin originates from wheat, followed by onion, garlic, and leeks, which all typically have a relatively low DP. The observations for inulin thus also apply for oligofructose.

V. NUTRITIONAL IMPLICATIONS

From the many publications on the nutritional properties of inulin and oligofructose,[39,55,89–93] it can be concluded that these compounds behave as dietary fiber; they are not hydrolyzed in the gastrointestinal tract, except in the colon where they have a specific effect on the microflora, more

TABLE 13
Distribution of the Inulin or Oligofructose Intake by the North American Population

	% Contribution to daily inulin and oligofructose intake (based on lower bound inulin contents)	% Contribution to daily inulin and oligofructose intake (based on upper bound inulin contents)
Wheat	78.0	76.0
Onion	10.0	18.0
Banana	5.0	3.0
Barley	3.0	1.6
Asparagus	1.3	0.6
Garlic	1.3	0.5
Artichoke	0.3	0.3
Estimated per capita inulin intake		
Average	1 g · d–1 · capita–1	4 g · d–1 · capita–1
50th percentile	0.8 g · d–1 · capita–1	3 g · d–1 · capita–1
90th percentile	2 g · d–1 · capita–1	8 g · d–1 · capita–1

Inulin intake also depends on following parameters: n

Seasonal variation	**g inulin per 75-kg person and per day**
Spring	4.0
Summer	3.8
Autumn	4.1
Winter	4.0
Racial variation	
Hispanics	4.3
Non-hispanic whites	4.0
Non-hispanic blacks	3.4
Non-hispanics other than black or white	4.4
Regional variation	
Northeast	3.8
North central	4.0
Southern	3.9
Western	4.1

Age group and sex	**in mg inulin per 10-kg BW and per day**
Children (1–6)	1E + 03
Males (20+)	5E + 02
Females (20+)	4E + 02

Note: The simulation of the daily intake of inulin and/or oligofructose-containing foodstuffs was performed by means of the data in Table 2. The higher and lower bound values that are mentioned there are reflected in higher and lower bond values of inulin and/or oligofructose intake figures.

specifically by promoting very selectively the growth of bifidobacteria to the detriment of other (potentially pathogenic) microorganisms. It also has been shown that inulin reduces the serum triglyceride level, as well as the LDL-to-HDL ratio in rats. Overall, the use of inulin and oligofructose has been suggested to have a beneficial role in human nutrition.[94–99]

It can be concluded from the data presented in this article that the average individual daily intake

TABLE 14
Estimation of the Average Inulin and Oligofructose Consumption in Europe, Benelux, and Spain

Europe[a]	**Per capita consumption in g/day**	**Inulin intake in Euro12 (LBV)**	**Inulin intake in Euro12 (HBV)**
Garlic	3.6	0.3	0.6
Onion	26.8	0.5	1.6
Leek	4.9	0.1	0.5
Artichoke	7.9	0.2	0.8
Wheat	195.0	2.0	7.8
Average consumption of inulin		3.2	11.3
Benelux[a]	**Per capita consumption in g/day**	**Inulin intake in Benelux (LBV)**	**Inulin intake in Benelux (HBV)**
Garlic	0.4	0.0	0.1
Onion	18.5	0.4	1.1
Leek	16.4	0.5	1.6
Artichoke	0.5	0.0	0.1
Wheat	187.7	1.9	7.5
Average consumption of inulin		2.8	10.4
Spain[a]	Per capita **consumption in g/day**	**Inulin intake in Spain (LBV)**	**Inulin intake in Spain (HBV)**
Garlic	19.2	1.7	3.1
Onion	63.2	1.3	3.8
Leek	4.0	0.1	0.4
Artichoke	18.8	0.6	1.9
Wheat	199.7	2.0	8.0
Average consumption of inulin		5.7	17.2
Particular dishes	g inulin per serving (LBV)	g inulin per serving (HBV)	
French onion soup containing 300 g onion	6.0	18.0	
Salsify dish, based on 300 g salsify	6.0	9.0	

Note: LBV and HBV = lower bound value and higher bound value, respectively. The values were obtained by multiplying the per capita consumption with the LBV and HBV values of the respective food crops as mentioned in Table 4. Consumption of dishes composed of vegetables rich in inulin may cause high peak intakes of the fructan.

[a] Data based on Eurostat 1987 statistics.

of inulin or oligofructose amounts to several grams. Peak intakes may reach up to 20 g. It is generally thought that the daily intake of classic dietary fiber ranges between 10 and 20 g per day for Western countries and that the intake of naturally occurring sugars is about 7 g for fructose and 13 g for sucrose.[100]

VI. CONCLUSION

Inulin and oligofructose are natural food ingredients in the Western diet. The main carriers of these fructans are wheat and onion in both the U.S. and Europe. The occurrence of inulin and oligofructose in these and many more food plants was derived from the literature data. The values were checked by means of standardized methods of analysis.

From a practical point of view, and with many other authors as an example, the definition of inulin has been broadened to the concept of "fructan wherein the majority of fructosyl units are linked by means of $\beta(2 \rightarrow 1)$-bonds". The observation of F_m compounds and $\beta(2 \rightarrow 6)$ fructofuranosyl bonds in "pure" inulin samples founded this conceptual approach. Based on these results, other research teams have estimated the daily per capita intake of inulin and oligofructose in the U.S., which was found to be between 1 and 4 g. An attempt was made to estimate the average daily intake of these fructans in Europe. Values ranging between 2 and 12 g were calculated.

As to their nutritional properties, inulin and oligofructose behave as dietary fibers. The average daily per capita inulin intake of the order of magnitude of 5 g compares very well with the daily dietary fiber intake (7 to 20 g/d), or the intake of sugars such as fructose (7 g) or sucrose (13 g). These compounds were almost never listed in food tables and are not always mentioned as dietary fiber, the reason being that they are not detected by the classic methods of fiber analysis (Englyst, AOAC, Van Soest, etc.).

Due to the per capita daily quantity of inulin and oligofructose that is consumed and the nutritional properties of these food ingredients, the authors believe that these substances deserve to be considered or evaluated in dietary advice and in the composition of nutritional tables.

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