International Journal of Food Sciences and Nutrition

ISSN: 0963-7486 (Print) 1465-3478 (Online) Journal homepage: http://www.tandfonline.com/loi/iijf20

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To cite this article: Gaétan Kalala, Bienvenu Kambashi, Nadia Everaert, Yves Beckers, Aurore Richel, Barbara Pachikian, Audrey M. Neyrinck, Nathalie M. Delzenne & Jérôme Bindelle (2017): Characterization of fructans and dietary fibre profiles in raw and steamed vegetables, International Journal of Food Sciences and Nutrition, DOI: 10.1080/09637486.2017.1412404

To link to this article: https://doi.org/10.1080/09637486.2017.1412404

Published online: 18 Dec 2017.

INTERNATIONAL JOURNAL OF FOOD SCIENCES AND NUTRITION, 2017
https://doi.org/10.1080/09637486.2017.1412404

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RESEARCH ARTICLE

Characterization of fructans and dietary fibre profiles in raw and steamed vegetables

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ABSTRACT

Dietary fibre (DF) has many positive effects on human health associated with its functionality in the gastrointestinal tract. These benefits vary according to the type of DF. Vegetables can be a natural source of DF in the diet. However, to provide adequate nutritional advice, the content and profile of their various DF types must be characterised. This study aimed to determine the DF profile of 29 vegetables cultivated in Wallonia (Belgium) and the impact of steaming on these profiles. Using a combination of enzymatic, gravimetric and chromatographic methods, fructans, total dietary fibre (TDF), low- and high-molecular-weight soluble dietary fibre (SDF), and insoluble dietary fibre (IDF) were analysed. Results show that the DF content varies considerably among the 29 investigated vegetable varieties and species, but the influence of steaming is limited to a shift from IDF to high-molecular-weight SDF for 18 of the 29 tested vegetables, while fructans are preserved with not actual reduction in the DP.

ARTICLE HISTORY
Received 14 April 2017
Revised 28 November 2017
Accepted 29 November 2017

KEYWORDS
Steaming; fructan; insoluble dietary fibre; soluble dietary fibre; vegetable

Introduction

Dietary patterns and food constituents influence the composition of the gut microbial population. Dysbiosis can have dramatic consequences on human health and many diseases of public health significance, such as obesity, cardiovascular diseases and type 2 diabetes (Portune et al. 2017). Among food nutrients, dietary fibre (DF) is composed of various types of carbohydrates, which are in some cases embedded in a lignin matrix according to their function in the plant, as an energy reserve or as structural support. Among the diverse range of DF molecules are oligosaccharides (short chains of galactose, glucose and fructose, such as raffinose or soybean oligosaccharides), fructans (polymers of fructose), cellulose (unbranched linear chains of glucose units with β-1,4 glucosidic linkages), non-cellulosic polysaccharides or hemicelluloses (backbones of glucose units with β-1,4-glucosidic linkages and branched with a side-chain containing mostly xylose and some galactose, mannose, arabinose), pectic substances (backbones of D-galacturonic acid and various side chains with different levels of methylation), β-glucans (linear backbone of 1–3-β-glycosidic linkages), and starch (D-glucose backbone with α-1,4 and some α-1,6 branch linkages) that, for several reasons, are not digested in the upper digestive tract (Fry 2011; Popper et al. 2011). Depending on their constitutive sugars, structure and linkages with lignin, these molecules display different physical attributes such as bulkiness, water-holding capacity and solubility that impact their functionality in the intestines. DF content of food ingredients analysed as total DF (TDF) can be separated into soluble DF (SDF) and insoluble DF (IDF). Moreover, SDF can be separated into high-molecular-weight SDF (HMWSDF) by precipitation with ethanol, and the non-precipitable low-molecular-weight SDF fraction (LMWSDF).

DF has several well-documented beneficial physiological effects. For instance, it decreases the intestinal transit time, blood cholesterol levels and postprandial blood glucose or insulin, and it increases stool bulk (Brownlee 2011). However, the benefits depend on the amount and specific type of fibre in the diet. Among the DF constituents, fructans are of utmost importance since they provide diverse benefits like the ability to suppress the growth of potential pathogens in the

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colon, prevent constipation, maintain the gut mucosal barrier integrity and reduce the risk of developing colorectal cancer (Delzenne and Kok 2001; Slavin 2008; Barrett et al. 2010; Brownlee 2011).

Most practical observations of these benefits of fructans on intestinal microbiota and health have been obtained using purified molecules or plant extracts, while the many natural food ingredients of plant origin are often overlooked (Roberfroid 2007). This is a paradox because the main sources of DF in the daily diet are cereals, fruits and vegetables. With a great diversity, many factors affect the DF content of vegetables such as type, variety, cultivation technique, storage conditions and preparation techniques (Kocsis et al. 2007; Mangaraj and Goswami 2011). Yet, despite their potential crucial role in the making of healthy diets, information available in the literature on the content and profile of the various DF types (IDF, HMWSDF and LMWSDF) in vegetables is incomplete: (1) some studies only mention common vegetable names while one single name in one language may correspond to several species and, vice versa, a common name may be assigned to several varieties of the same species (Muir et al. 2007); (2) some vegetables are analysed in a form in which they are rarely consumed, for example raw instead of cooked and (3) not all DF fractions are analysed in all studies, and often different analytical procedures are used. This is particularly true for fructans, which in the few papers mentioning these compounds, are measured as fructooligosaccharides (L'homme et al. 2001), fructo-oligosaccharides of varying molecular weights and inulin (Van loo et al. 1995) or total fructans (Muir et al. 2007).

Hence, faced with a deficient food composition database concerning DF contents, and to allow the use of feeding strategies that enhance the regulatory potential of some vegetables rich in functional DF, the present study aimed to measure the DF content, according to the DF type and fructans contents, in some common temperate vegetables and to assess whether steaming, chosen as one model for cooking vegetables, would impact the content and DF profiles, knowing that depending on the vegetable, there are consumed either raw, cooked or both.

Materials and methods

Food samples

Twenty-nine vegetables were sampled in triplicate ($N = 3$) from various farmers located in Wallonia (Belgium). The vegetables included *Cynara scolymus* (artichoke), *Asparagus officinalis* (asparagus), *Raphanus sativus* var. *sativus* (black radish), *Brassica oleracea* var. *italica* (broccoli), *Brassica oleracea* var. *gemmifera* (Brussels sprouts), *Cucurbita moshata* (butternut), *Cynara cardunculus* (cardoon), *Daucus carota* subsp. *sativus* (carrot), *Brassica oleracea* var. *botrytis* (cauliflower), *Apium graveolens* var. *rapaceum* (celeriac), *Apium graveolens* (celery) *Cichorium intybus* (endive), *Foeniculum vulgare* (fennel), *Helianthus tuberosus* (Jerusalem artichoke), *Allium ampeloprasum* (leeks), *Allium cepa* (onions), *Pastinaca sativa* (parsnip), *Capsicum annuum* (pepper), *Cucurbita pepo (pumpkin), Cucurbita maxima Duchesne ssp* (pumpkin), *Raphanus sativus* (radish), *Scorzonera hispanica* (salsify), *Cucurbita pep. ssp. pepo* (spaghetti squash), *Cucurbita maxima* Duchesne (squash), *Beta vulgaris* subsp. *vulgaris* (Swiss chard), *Brassica napobrassica* (swede), *Petroselinum crispum* (tuberous parsley), *Brassica rapa* subsp. *rapa* (turnips) and *Cucurbita pepo* var. *cylindrica* (zucchini). Each vegetable was sampled directly from the cultivation field or on the very same day of picking. After weighing, vegetables were washed and prepared by peeling and removing some parts considered as not edible, according to the uses in Belgian cuisine. The vegetables were then cut in small cubes of approximately 8 cm^3 and the vegetable sample was then divided into two parts: one was kept raw, while the other was steamed for 20–30 min until the samples were fully cooked using a steam cooker (Kielf Electro). During the steaming, condensing water could freely drip from the colander containing the vegetable cubes. Both raw and steamed samples were freeze-dried. Dried vegetables were ground to pass through a 1-mm mesh screen in a Cyclotec 1093 sample mill (FOSS Electric A/S, Hillerod, Denmark) before further analysis.

Chemical composition

Ground, raw and steamed vegetable samples were analysed for their dry matter (DM) contents by drying at 105 °C for 24 h, according to AOAC methods (Helrich 1990), (AOAC Method 967.03); organic matter (OM) by ashing at 550 °C for 8 h (AOAC Method 923.03), and nitrogen (N) according to the Kjeldahl method and crude protein (CP) content calculation ($N \times 6.25$; AOAC Method 981.10). The TDF, IDF, HMWSDF and LMWSDF contents were determined using an enzymatic method (AOAC Methods 2009.01 and 2011.25), in combination with chromatography columns and the Megazyme K-TDFC kit (Megazyme, Wicklow, Ireland), according to the manufacturer's instructions. HMWSDF was obtained after precipitation in ethanol

76% and LMWSDF was determined on the non-precipitable samples with HPLC columns waters 2690 (Waters Corporation, Milford, MA).

The HPLC was performed using a Sugar-Pak 1 column of Waters (300 × 6.5 mm) and a Waters 410 Differential Refractive Index Detector. Column temperature was set at 60 °C and detector temperature at 40 °C, with an injection volume of 50 ml and Calcium EDTA eluent flow of 50 mg/l. Fructans were determined by an enzymatic method (AOAC Method 999.03) using the Megazyme Fructans HK Assay kit (Megazyme, Wicklow, Ireland), according to the manufacturer's instructions.

To assess how steaming could potentially impact the solubilisation of fructans, the average degree of polymerisation (DP) in raw and steamed vegetables was compared. For this mechanistic purpose, only samples that displayed high fructans contents, namely artichokes, salsifies and Jerusalem artichokes, were analysed as described in Muir et al. (2007).

In this approach, the fructans are initially hydrolysed with fructanase, followed by the addition of hexokinase/glucose 6-phosphate dehydrogenase (HK/G6P-DH) enzymes, for measurement of glucose and fructose, respectively. The average DP was then calculated as follows: Average DP = (FB-FA)/(GB-GA), where FB was sample treated with fructanase and FA was without fructanase, GA measurement of glucose with Megazyme fructan assay and GB measurement of glucose with modified Megazyme fructan assay.

Data analysis

The influence of steaming on each of the 29 vegetables that were studied was evaluated by a pairwise comparison of the composition of the steamed vegetables against their raw counterparts by means of an analysis of variance using the MIXED procedure of the SAS 9.4 software (SAS Inc., Cary, NC). The vegetable sample ($N = 3$) was considered as the experimental unit and the thermal treatment was the effect that was tested.

Results

Composition of raw vegetables

The composition of the vegetables varied widely according to the species and variety (Tables 1 and 2). The DM content ranged from 6.2 to 22.5 g/100 g fresh vegetables. Raw vegetables with the highest DM were salsify, parsnip, tuberous parsley, Jerusalem artichoke, butternut and Brussels sprouts. Those with the lowest DM contents included spaghetti squash, zucchini, pumpkin and asparagus.

The CP contents of the raw vegetables ranged from 3.8 to 26.0 g/100 g DM. Cardoon, squash, artichoke, tuberous parsley, turnip, parsnip and pumpkin had low CP contents, while those with high CP contents were broccoli, Swiss chard, Brussels sprouts and leek.

The TDF content of the raw vegetables ranged from 21.3 to 82.3 g/100 g DM. Those with low TDF were squash, butternut, tuberous parsley, pumpkin, parsnip and turnip. Raw salsify, artichoke and Jerusalem artichoke had the highest TDF contents. The raw vegetables contained 0.2–69.5 g of fructans/100 g DM (Table 1). Salsify and Jerusalem artichoke displayed the highest fructans levels (69.5 and 65.8 g/100 g DM, respectively) followed by artichoke with 60.9 g/100 g DM, onion 32.6 g/100 g DM, leek with 5.4 g/100 g DM and cardoon 4.0 g/100 g DM. Species with high fructans levels also exhibited high SDF contents. Radish, broccoli and fennel had the lowest fructans contents.

The average DP, evaluated for vegetables with the highest fructans contents, i.e. over 50 g/100 g DM ranged from 11.7 to 13.5 for salsify, 15.0 to 15.3 for Jerusalem artichoke and from 15.0 to 15.5 for artichoke (Table 3). These values are an average between the fractions with different DP.

Influence of steaming on proximate composition

The data in Table 1 show that cooking vegetables can significantly modify the type of fibre of several vegetables but not all, while the TDF, OM and CP contents are not affected on a DM basis. Cooking slightly increased ($p < .05$) the fructans content of salsify (69.5 versus 71.9 g/100 g DM for raw and cooked, respectively) and Jerusalem artichoke (65.8 versus 68.3 g/100 g DM for raw and cooked, respectively). Regarding the DF contents, TDF was not affected by the cooking but for some vegetables; an important shift in magnitude, from IDF towards HMWSDF was observed (Table 2). This was apparent for 18 out of the 29 investigated vegetables. For example, broccoli (31.2 versus 26.3 IDF g/100 g DM and 3.9 versus 11.1 HMWSDF g/100 g DM for raw and steamed), celeriac (33.8 versus 27.1 IDF g/100 g DM and 2.7 versus 11.3 HMWSDF g/100 g DM for raw and steamed), celery (30.9 versus 19.4 IDF g/100 g DM and 4.5 versus 16.6 HMWSDF g/100 g DM for raw and steamed) and onions (11.5 versus 9.2 IDF g/100 g DM and 3.7 versus 8.1 HMWSDF g/100 g DM for raw and steamed). Nevertheless, no effect of the

Table 1. Dry matter (DM, g/100 g fresh vegetables), organic matter (OM), crude protein (CP), fructans and total dietary fibre (TDF) of raw and steamed vegetables (g/100 g DM) ($N = 3$).

Common name	Scientific name	Cooking	DM	CP	OM	Fructan	TDF
Artichoke	*Cynara scolymus*	Raw	21.2 ± 1.1	5.1 ± 0.0^{b}	95.4 ± 0.7	62.0 ± 0.7	75.5 ± 2.0
		Steamed	22.9 ± 1.2	9.4 ± 0.0^{a}	95.3 ± 0.8	63.8.±0.6	75.0 ± 1.9
Asparagus	*Asparagus officinalis*	Raw	6.9 ± 1.5	10.5 ± 0.1^{b}	90.9 ± 1.2	0.4 ± 0.2	34.6 ± 4.8
		Steamed	6.7 ± 1.1	15.2 ± 0.1^{a}	91.5 ± 0.9	0.5 ± 0.3	34.4 ± 4.2
Black radish	*Raphanus sativus var.sativus*	Raw	7.0 ± 1.1	12.7 ± 1.6	91.8 ± 0.9	0.4 ± 0.3	32.7 ± 0.5
		Steamed	7.6 ± 1.2	13.4 ± 2.2	92.2 ± 0.7	0.5 ± 0.2	32.8 ± 0.4
Broccoli	*Brassica oleracea var. italica*	Raw	12.2 ± 1.5	26 ± 1.0	91.3 ± 0.7	0.2 ± 0.3	36.0 ± 4.6
		Steamed	12.5 ± 1.5	27.2 ± 3.5	91.5 ± 0.6	0.3 ± 0.1	38.4 ± 4.1
Brussels sprouts	*Brassica oleracea var. gemmifera*	Raw	15.2 ± 1.7	25.5 ± 0.0	92.3 ± 0.8	0.9 ± 0.2	35.0 ± 1.3
		Steamed	15.3 ± 1.8	24.1 ± 0.2	92.2 ± 0.9	0.8 ± 0.2	39.3 ± 3.6
Butternut	*Cucurbita moshata*	Raw	15.7 ± 2.3	6.8 ± 0.9	94.2 ± 1.3	0.9 ± 0.5	21.4 ± 0.5^{a}
		Steamed	14.7 ± 1.0	4.6 ± 0.9	94.1 ± 1.7	0.7 ± 0.5	14.1 ± 2.6^{b}
Cardoon	*Cynara cardunculus*	Raw	8.3 ± 0.7	3.8 ± 0.0	88.6 ± 8.1	4.0 ± 2.5	38.7 ± 1.6
		Steamed	8.3 ± 0.8	3.4 ± 0.0	89.2 ± 7.1	3.2 ± 0.0	37.9 ± 1.2
Carrot	*Daucus carota subsp. sativus*	Raw	13.3 ± 0.9	6.1 ± 0.3	83.0 ± 1.8	2.0 ± 0.0	25.4 ± 2.1^{b}
		Steamed	11.9 ± 1.3	6.4 ± 0.1	81.7 ± 3.3	1.5 ± 0.5	28.7 ± 1.3^{a}
Cauliflower	*Brassica oleracea var. botrytis*	Raw	11.4 ± 1.4	19.2 ± 5.5	75.3 ± 1.1	0.9 ± 0.5	29.7 ± 1.6
		Steamed	11.0 ± 0.9	21.1 ± 8.8	74.4 ± 2.1	1.0 ± 0.7	28.6 ± 0.7
Celeriac	*Apium graveolens var. rapaceum*	Raw	6.6 ± 1.4	9.1 ± 1.1	84.2 ± 4.2	0.5 ± 0.1	36.9 ± 1.8^{b}
		Steamed	9.5 ± 1.2	10.0 ± 1.0	84.8 ± 3.7	0.4 ± 0.1	39.0 ± 1.5^{a}
Celery	*Apium graveolens*	Raw	9.9 ± 1.6	11.3 ± 1.6	88.4 ± 1.5	0.3 ± 0.2	35.9 ± 2.1
		Steamed	6.5 ± 1.4	11.3 ± 0.5	89.7 ± 1.7	0.3 ± 0.2	36.4 ± 1.6
Endive	*Cichorium intybus*	Raw	8.3 ± 1.1	25.4 ± 2.3	71.1 ± 5.0	1.6 ± 0.3	24.6 ± 0.3
		Steamed	10.4 ± 1.0	25.8 ± 2.0	69.5 ± 2.0	1.4 ± 0.4	24.3 ± 0.2
Fennel	*Foeniculum vulgare*	Raw	7.4 ± 0.6	9.7 ± 1.5	88.7 ± 2.2	0.2 ± 0.1	38.1 ± 0.7
		Steamed	6.6 ± 0.3	9.5 ± 0.9	88.9 ± 1.5	0.3 ± 0.1	38.3 ± 0.7
Jerusalem artichoke	*Helianthus tuberosus*	Raw	18.5 ± 1.2	11.0 ± 0.8	92.9 ± 0.9	62.8 ± 4.9^{a}	73.2 ± 2.0^{b}
		Steamed	17.1 ± 0.5	11.1 ± 0.1	93.6 ± 1.8	68.3 ± 0.7^{b}	78.4 ± 6.0^{a}
Leek	*Allium ampelprasum*	Raw	8.8 ± 1.1	20.4 ± 3.0	91.2 ± 3.6	3.0 ± 2.8	35.2 ± 1.6^{b}
		Steamed	10.1 ± 1.3	18 ± 1.5	92.3 ± 3.4	3.3 ± 2.3	37.1 ± 1.8^{a}
Onions	*Allium cepa*	Raw	13.7 ± 1.2	11.1 ± 0.1	79.6 ± 0.5	32.6 ± 0.6	47.2 ± 0.1
		Steamed	13.0 ± 1.3	10.9 ± 0.1	79.4 ± 1.2	32.7 ± 0.5	49.8 ± 0.2
Parsnips	*Pastinaca sativa*	Raw	21.3 ± 1.8	5.9 ± 0.0	94.9 ± 0.2	1.3 ± 0.2	26.8 ± 1.0^{b}
		Steamed	21.0 ± 2.5	5.9 ± 1.0	94.8 ± 0.2	0.3 ± 0.5	29.5 ± 0.8^{a}
Pepper	*Capsicum annuum*	Raw	9.3 ± 1.9	11.6 ± 2.1	71.9 ± 2.1	2.2 ± 0.3	22.5 ± 1.7
		Steamed	7.9 ± 1.2	12.0 ± 1.4	72.0 ± 1.1	1.0 ± 0.2	23.4 ± 2.0
Pumpkin	*Cucurbita pepo*	Raw	6.5 ± 1.5	8.5 ± 0.0	92.7 ± 1.1	0.6 ± 0.2	27.7 ± 1.9^{a}
		Steamed	6.8 ± 1.4	7.8 ± 2.4	93.5 ± 1.3	0.7 ± 0.2	25.2 ± 2.0^{b}
Pumpkin	*Cucurbita maxima duchesne ssp*	Raw	8.0 ± 1.4	6.4 ± 0.0	92.5 ± 2.9	0.9 ± 0.1	23.8 ± 3.3^{b}
		Steamed	7.4 ± 1.0	7.4 ± 0.4	92.8 ± 1.5	1.1 ± 0.4	25.0 ± 1.9^{a}
Radish	*Raphanus sativus*	Raw	12.8 ± 1.3	11.9 ± 0.1	88.6 ± 0.6	0.2 ± 0.1	33.5 ± 0.2^{b}
		Steamed	12.8 ± 1.1	12.8 ± 0.0	87.8 ± 4.8	0.2 ± 0.1	36.4 ± 0.8^{a}
Salsify	*Scorzonera hispanica*	Raw	22.5 ± 2.3	10.1 ± 0.0	97.0 ± 0.7	69.5 ± 0.0	82.3 ± 6.7
		Steamed	23.2 ± 2.1	11.1 ± 0.0	96.8 ± 0.8	71.9 ± 5.7	81.0 ± 8.7
Spaghetti squash	*Cucurbita pepo ssp. pepo*	Raw	6.2 ± 0.5	10.9 ± 0.3	90.3 ± 3.7	1.1 ± 0.3	28.8 ± 4.1^{a}
		Steamed	6.2 ± 0.2	11.6 ± 0.8	92.0 ± 0.8	1.3 ± 0.2	24.8 ± 1.7^{b}
Squash	*Cucurbita maxima duchesne*	Raw	17.9 ± 1.5	3.8 ± 0.4	92.7 ± 4.7	0.4 ± 0.1	21.3 ± 2.0^{a}
		Steamed	18.4 ± 0.8	4.4 ± 0.6	93.7 ± 4.5	0.7 ± 0.2	17.0 ± 3.2^{b}
Swiss chard	*Beta vulgaris subsp. vulgaris*	Raw	7.8 ± 0.1	25.5 ± 0.1^{a}	77.9 ± 3.3	0.2 ± 0.1	34.5 ± 2.7
		Steamed	4.9 ± 0.1	16.6 ± 0.1^{b}	80.3 ± 2.4	0.2 ± 0.2	35.0 ± 2.3
Swede	*Brassica napobrassica*	Raw	12.2 ± 0.1	7.7 ± 0.0	93.0 ± 3.7	0.9 ± 0.0	36.3 ± 0.8^{b}
		Steamed	10.6 ± 0.1	8.3 ± 2.0	93.6 ± 2.5	0.6 ± 0.3	41.1 ± 1.2^{a}
Tuberous parsley	*Petroselinum crispum*	Raw	20.9 ± 3.2	5.6 ± 0.0	95.0 ± 1.2	0.5 ± 0.2	21.7 ± 3.4
		Steamed	19.0 ± 2.1	5.6 ± 0.7	95.1 ± 0.9	0.3 ± 0.2	24.2 ± 3.3
Turnips	*Brassica rapa subsp. rapa*	Raw	9.9 ± 0.9	5.8 ± 0.0	92.0 ± 1.9	0.8 ± 0.2	28.8 ± 5.2^{b}
		Steamed	9.5 ± 1.8	6.5 ± 0.7	92.5 ± 1.5	0.5 ± 0.1	32.0 ± 4.3^{a}
Zucchini	*Cucurbita pepo var. cylindrica*	Raw	6.2 ± 1.3	17.8 ± 0.0	88.1 ± 1.1	0.8 ± 0.2	23.3 ± 3.5
		Steamed	5.7 ± 1.6	19 ± 0.3	89.8 ± 1.3	1.0 ± 0.2	24.5 ± 3.7

[a,b]For one vegetable, values followed by different letters in the columns means the nutrient content of raw and steamed vegetables differ at a significance level of 0.05.

steaming was found regarding the DP of fructans ($p = .73$) (Table 3).

Discussion

This study provides relevant information related to the DF profile of 29 raw vegetables that can be incorporated into the development of health-promoting feeding strategies and for nutritional guidance as well as the impact of steaming on the DF profiles.

The results obtained here show that only few vegetables display high fructans contents. While most vegetables displayed fructans contents in line with previously reported data (Muir et al. 2007), minor

Table 2. Insoluble (IDF), total soluble (SDF), high (HMWSDF) and low molecular weight soluble dietary fibre (LMWSDF) contents of raw and steamed vegetables (g/100 g DM) ($N=3$).

Common name	Scientific name	Cooking	IDF	SDF	HMWSDF	LMWSDF
Artichoke	*Cynara scolymus*	Raw	12.8 ± 2.2	62.6 ± 1.2	56.6 ± 3.0	6.0 ± 1.2
		Steamed	10.4 ± 1.8	64.6 ± 1.2	56.1 ± 3.0	8.5 ± 1.0
Asparagus	*Asparagus officinalis*	Raw	24.6 ± 4.5	10.1 ± 0.5	9.5 ± 0.3	0.6 ± 0.2
		Steamed	25.1 ± 3.2	9.3 ± 1.0	8.8 ± 0.9	0.4 ± 0.2
Black radish	*Raphanus sativus var.sativus*	Raw	30.0 ± 0.4^{a}	2.6 ± 0.2^{b}	2.1 ± 0.1^{b}	0.5 ± 0.1
		Steamed	23.2 ± 0.5^{b}	9.6 ± 0.7^{a}	9,3 ± 0.8^{a}	0.3 ± 0.1
Broccoli	*Brassica oleracea var.italica*	Raw	31.2 ± 4.0^{a}	4.8 ± 1.8^{b}	3.9 ± 1.6^{b}	0.9 ± 0.4
		Steamed	26.3 ± 3.2^{b}	12.0 ± 1.6^{a}	11.1 ± 1.5^{a}	0.9 ± 0.3
Brussels sprouts	*Brassica oleracea var.gemmifera*	Raw	30.3 ± 2.0^{a}	4.7 ± 0.9^{b}	3.6 ± 0.6^{b}	1.1 ± 0.4
		Steamed	25.2 ± 1.8^{b}	14.1 ± 4.0^{a}	11.7 ± 3.7^{a}	2.4 ± 0.4
Butternut	*Cucurbita moshata*	Raw	12.5 ± 2.2^{a}	9.0 ± 2.7^{a}	7.9 ± 3.3	1.0 ± 0.6
		Steamed	8.2 ± 3.6^{b}	6.0 ± 1.0^{b}	5.3 ± 0.5	0.7 ± 0.5
Cardoon	*Cynara cardunculus*	Raw	23.9 ± 1.4	14.7 ± 1.2	8.5 ± 0.9	6.3 ± 1.3
		Steamed	23.3 ± 1.4	14.6 ± 1.4	8.7 ± 1.0	5.9 ± 1.3
Carrot	*Daucus carota subsp.sativus*	Raw	20.0 ± 2.6	5.3 ± 0.4^{b}	5.0 ± 0.8^{b}	0.4 ± 0.4
		Steamed	20.1 ± 3.8	8.6 ± 0.3^{a}	7.7 ± 3.4^{a}	0.9 ± 0.2
Cauliflower	*Brassica oleracea var.botrytis*	Raw	27.0 ± 1.1^{a}	2.7 ± 0.5^{b}	2.2 ± 0.6^{b}	0.5 ± 0.1
		Steamed	23.3 ± 0.1^{b}	5.4 ± 0.6^{a}	5.1 ± 0.6^{a}	0.2 ± 0.0
Celeriac	*Apium graveolens var.rapaceum*	Raw	33.8 ± 2.4^{a}	3.2 ± 0.7^{b}	2.7 ± 0.8^{b}	0.5 ± 0.1
		Steamed	27.1 ± 1.6^{b}	11.9 ± 0.8^{a}	11.3 ± 0.8^{a}	0.7 ± 0.2
Celery	*Apium graveolens*	Raw	30.9 ± 1.9^{a}	4.9 ± 1.4^{b}	4.5 ± 1.6^{b}	0.5 ± 0.2
		Steamed	19.4 ± 1.7^{b}	17.0 ± 1.5^{a}	16.6 ± 1.8^{a}	0.4 ± 0.3
Endive	*Cichorium intybus*	Raw	21.6 ± 0.3^{a}	3.0 ± 0.0^{b}	2.1 ± 0.2^{b}	0.9 ± 0.2
		Steamed	16.0 ± 8.7^{b}	8.3 ± 0.1^{b}	6.8 ± 2.7^{a}	1.5 ± 0.3
Fennel	*Foeniculum vulgare*	Raw	34.8 ± 1.0^{a}	3.3 ± 0.2^{b}	2.8 ± 0.4^{b}	0.5 ± 0.1
		Steamed	26.9 ± 0.0^{b}	11.4 ± 0.6^{a}	11.2 ± 0.7^{a}	0.2 ± 0.0
Jerusalem artichoke	*Helianthus tuberosus*	Raw	8.6 ± 2.0	64.7 ± 0.5^{b}	23.7 ± 2.9^{a}	40.9 ± 2.5^{b}
		Steamed	6.4 ± 0.6	72.0 ± 5.5^{a}	17.7 ± 4.0^{b}	54.3 ± 3.0^{a}
Leek	*Allium ampelprasum*	Raw	27.1 ± 1.7^{a}	8.1 ± 0.6^{b}	3.8 ± 0.4^{b}	4.3 ± 0.7
		Steamed	21.5 ± 1.6^{b}	15.7 ± 0.8^{a}	11.2 ± 0.5^{a}	4.5 ± 0.8
Onions	*Allium cepa*	Raw	11.5 ± 0.0	35.7 ± 0.1^{b}	3.7 ± 0.4^{b}	32.0 ± 0.5
		Steamed	9.2 ± 0.5	40.6 ± 0.3^{a}	8.1 ± 0.0^{a}	32.4 ± 0.3
Parsnips	*Pastinaca sativa*	Raw	20.4 ± 1.2^{a}	6.4 ± 0.9^{b}	4.8 ± 0.9^{b}	1.6 ± 0.2
		Steamed	13.9 ± 0.4^{b}	15.7 ± 0.8^{a}	13.5 ± 0.7^{a}	2.2 ± 0.2
Pepper	*Capsicum annuum*	Raw	15.4 ± 0.8	7.1 ± 0.8	6.6 ± 0.9	0.5 ± 0.1
		Steamed	13.9 ± 4.6	9.5 ± 0.6	8.7 ± 0.1	0.8 ± 0.2
Pumpkin	*Cucurbita pepo*	Raw	19.4 ± 3.3	8.3 ± 1.4	7.5 ± 1.6	0.8 ± 0.2
		Steamed	17.2 ± 3.1	8.0 ± 0.9	7.3 ± 1.4	0.7 ± 0.1
Pumpkin	*Cucurbita maxima duchesne ssp*	Raw	13.9 ± 2.9^{a}	9.9 ± 0.4	8.6 ± 0.4	1.3 ± 0.5
		Steamed	17.1 ± 1.1^{b}	7.9 ± 1.3	6.8 ± 0.7	1.1 ± 0.9
Radish	*Raphanus sativus*	Raw	31.1 ± 0.8^{a}	2.4 ± 1.0^{b}	2.0 ± 0.9^{b}	0.4 ± 0.2
		Steamed	27.1 ± 1.5^{b}	9.3 ± 2.3^{a}	9.1 ± 2.3^{a}	0.2 ± 0.0
Salsify	*Scorzonera hispanica*	Raw	8.3 ± 1.0	73.9 ± 6.5	15.5 ± 2.2^{a}	58.4 ± 4.8^{b}
		Steamed	8.4 ± 0.2	72.6 ± 8.5	11.0 ± 2.6^{b}	61.6 ± 7.8^{a}
Spaghetti squash	*Cucurbita pepo ssp.pepo*	Raw	23.6 ± 4.7^{a}	5.2 ± 0.7^{b}	4.4 ± 0.6^{b}	0.8 ± 0.1
		Steamed	16.6 ± 1.0^{b}	8.2 ± 0.8^{a}	7.2 ± 0.6^{a}	1.0 ± 0.2
Squash	*Cucurbita maxima duchesne*	Raw	11.4 ± 2.5	9.9 ± 0.5^{a}	8.4 ± 0.4^{a}	1.4 ± 0.2
		Steamed	11.4 ± 2.4	5.6 ± 0.8^{b}	4.7 ± 0.6^{b}	0.9 ± 0.2
Swiss chard	*Beta vulgaris subsp.vulgaris*	Raw	24.7 ± 2.1	9.9 ± 0.8	9.4 ± 0.8	0.5 ± 0.1
		Steamed	26.0 ± 0.6	9.0 ± 2.1	8.4 ± 2.1	0.6 ± 0.4
Swede	*Brassica napobrassica*	Raw	31.4 ± 0.4^{a}	5.0 ± 1.0^{b}	4.2 ± 0.6^{b}	0.7 ± 0.1
		Steamed	23.5 ± 0.5^{b}	17.7 ± 1.5^{a}	16.6 ± 2.2^{a}	1.0 ± 0.0
Tuberous parsley	*Petroselinum crispum*	Raw	18.5 ± 2.8^{a}	3.3 ± 0.5^{b}	2.4 ± 0.6^{b}	0.9 ± 0.0
		Steamed	14.6 ± 1.6^{b}	9.7 ± 1.7^{a}	9.2 ± 1.6^{a}	0.4 ± 0.1
Turnips	*Brassica rapa subsp.rapa*	Raw	26.4 ± 4.8^{a}	2.5 ± 0.5^{b}	1.8 ± 0.4^{b}	0.7 ± 0.3
		Steamed	19.2 ± 3.4^{b}	12.7 ± 1.3^{a}	12.3 ± 1.3^{a}	0.4 ± 0.1
Zucchini	*Cucurbita pepo var.cylindrica*	Raw	18.8 ± 2.8	4.4 ± 1.0^{b}	3.9 ± 1.0^{b}	0.5 ± 0.0
		Steamed	17.4 ± 2.7	7.1 ± 1.6^{a}	6.8 ± 1.6^{a}	0.3 ± 0.0

[a,b]For one vegetable, values followed by different letters in the columns means the nutrient content of raw and steamed vegetables differ at a significance level of 0.05.

discrepancies can be ascribed to storage conditions (Jaime et al. 2001), the stage of maturation (Ould-Ahmed et al. 2014) and environmental factors (Nordheim-Viken and Volden 2009). These results confirm the literature findings (Hendry 1993), showing that plants that accumulate fructans as an energy storage, mainly belong to the Asteraceae, Poaceae and the former Liliaceae families. The high fructans contents of Jerusalem artichoke, salsify and artichoke were expected because these plants belong to the Asteraceae family that accumulates carbohydrates as energy storage mainly in the form of fructans (Hendry 1993), which is one of the main carbon storage forms in plants besides starch and sucrose (Gallagher et al.

Table 3. Average degree of polymerisation (DP) of fructans contained in raw and steamed artichokes, salsifies and Jerusalem artichokes ($N = 3$).

Common name	Scientific name	Cooking	DP
Artichoke	*Cynara scolymus*	Raw	15.0 ± 0.3
		Steamed	15.5 ± 0.8
Salsify	*Scorzonera hispanica*	Raw	11.7 ± 0.5
		Steamed	13.5 ± 0.2
Jesusalem artichoke	*Helianthus tuberosus*	Raw	15.0 ± 0.1
		Steamed	15.3 ± 0.2

2007). Cardoon, one of the species with fairly high fructans content, also belongs to the Asteraceae. Leek, onion and garlic are also known for being rich in fructans (Muir et al. 2007). They belong to the Amaryllidaceae family formerly part of Liliaceae family. Surprisingly, compared with the literature (Shepherd and Gibson 2006), the asparaguses analysed in this study contained very small amounts of fructans.

The fructans of the artichoke have a special feature. While the fructans content is 62%, LMWSDF content is only 6% while HMWSDF content is 56%. It appears that a larger fraction of the artichoke fructans would have a higher DP than that of two other vegetables. This has already been confirmed in the literature by Van Loo et al. (1995), who show that the distribution of FOS and fructans varies according to the species, but also, for a given species strong variations in fructans contents can be found according to various factors such as cultivar, growing stage, or storage conditions (Benkeblia 2013).

Besides the species rich in fructans, parsnip, Brussel sprouts, swede and tuberous parsley, although low in fructans, seem interesting for their significant SDF contents. SDF has a higher potential for fermentation in the large intestine than IDF (Dhingra et al. 2012), leading to a potentially higher functional role of those vegetables regarding positive shifts in the microbiota composition.

Regarding the TDF contents, turnips, celery, carrot and broccoli showed higher values than data reported by Dhingra et al. (2012). However, comparing DF content of raw vegetables with the literature must be done with caution because of possible differences in analytical methods. For example, some data are expressed as neutral detergent fibre (NDF) (Zia-ur-Rehman et al. 2003). Comparing NDF content with TDF content is impractical because the two methods cover partly different chemical substances with different physical properties.

In general, the fibre profile in vegetables depends on the group to which the vegetables belong. It has been shown that leafy vegetables contain more IDF compared with fruits, flowers, roots or tubers vegetables that have high content of SDF (Marlett 1991; Wang et al. 1991; Su-Chen et al. 1995). This situation was observed in this study, where almost all raw leafy vegetables have IDF content approximately 30% higher than fruit, flower, root or tuber vegetables.

The increase in HWSDF observed in two-thirds of the vegetables due to the steaming in this study is consistent with Dhingra et al. (2012) but the shift from IDF to SDF is still controversial as several authors mention an increase (De Almeida Costa et al. 2006; Vega-Gálvez et al. 2015) or decrease (Kutoš et al. 2003) or no effect at all. In this regard, Farhath et al. (2000) observed an increase in SDF due to cooking of 9–11% for root and tuber vegetables and 9–16% for leafy vegetables using a pressure cooker (Farhath et al. 2000). In contrast, in the present study, the majority of vegetables that had an increase in SDF had very high values compared with the trend of Farhath et al. (2000): black radish, fennel, parsnips, swede, leek, celery and tuberous parsley, for example. Before steaming, their content in SDF was between 2.6% and 8.1%. After steaming, the SDF content obtained for the same vegetables ranged from 9.6% to 17.7%, accounting for a two to three-fold increase. This shows that steaming has a potential positive effect on the vegetables fibre profile for fermentation and health-related consequences since SDF is usually more fermentable than IDF. On the causes of the increase in SDF due to steam cooking, in cooked pea and common bean, a similar phenomenon was ascribed to the solubilisation of polysaccharides (Kutoš et al. 2003; De Almeida Costa et al. 2006). How steaming can change the physicochemical characteristics of DF will vary according to the composition of vegetables. Two antagonist mechanisms are actually at play: (1) hemicellulose chains are freed by the swelling and the softening of the cellulose matrix during the steaming and (2) the formation of resistant starch and fibre-protein complexes that are resistant to heating and are quantified as IDF can take place (Zyren et al. 1948; Caprez et al.1986). However, in the analytical method used in this study, residual, CP bound to the fibre matrix was determined and removed during the calculation.

Hence, the main effects in this study were probably related to the increasing availability of the high value of hemicelluloses linked to IDF at the SDF-pool at the expense of the IDF-pool. Interestingly, the length of the chains of SDF pool seemed little affected by the steaming since for most vegetables samples for which SDF dominated, the major impact was observed with

HWSDF with very smaller shifts in LWSDF. This is also consistent with the absence of effects of steaming on the average DP of fructans (Table 3).

It seems that the heat of steaming is not able to degrade the covalent bounds linking the different monomers in the chains of the polysaccharides. Moreover, the rapid rise in temperature to reach a plateau of 100 °C with steaming probably quickly deactivates the endo- and exopolysacharidases (Van Loo 1995) that could more significantly free short-chain polysaccharides and oligosaccharides contributing to an increase in LWSDF.

Finally, cooking vegetables in boiling water may provoke a decrease in TDF due to the lixiviation of SDF in water. In the present study, this was not the case because steaming was used instead of boiling.

Conclusions

It can be concluded from this study that the choice of vegetables in a diet can lead to the intake of DF profile differing strongly. Only a few vegetables among the list of vegetables that were analysed would provide the 10–14 g daily dose of fructans to cover requirements that were proven to be health-promoting (Delzenne et al. 2013).

Steaming vegetables seems to be an interesting cooking method because it improves the DF profile of insoluble fibre in favour of soluble fibre that is usually more fermentable. However, other methods of cooking should also be investigated.

Acknowledgements

The authors express their gratitude to the farmers who contributed to provide samples for the study.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was co-funded by the Walloon Government (Namur, Belgium) and Liège University in the frame work of the FOOD4GUT excellence research project.

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