ELSEVIER

Food Chemistry 51 (1994) 263–269

0308-8146/94/$7.00

The macronutrient content of fractions from Jerusalem artichoke tubers (*Helianthus tuberosus*)

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(Received 24 October 1993; accepted 10 February 1994)

Three cultivars of Jerusalem artichoke were harvested in late fall, washed thoroughly, trimmed of any damaged tissue then blanched with steam. The tubers were frozen, freeze dried then manually separated into skins and skinless tubers which were extracted with hot water. Jerusalem artichoke tubers, on a dry basis, yielded approximately 76% soluble sugars (combined fractions from the drain liquor and hot water extract of skinless tubers and skins) and the remaining 24% as an insoluble residue. Analysis showed that, on a dry weight basis, the residues contained 20–25% protein which was double the concentration in the soluble extract; the residues also contained up to 43% total dietary fiber. Soluble sugars ranged over 75–85% of the dry matter in the hot water extracts, which was double the amount retained in the residue. The lowest ash content (3·2–4·9%) was found in the skinless tubers residue and the highest (5·9–7·5) was in the skin residue.

INTRODUCTION

Jerusalem artichoke is one of a number of crops that is constantly being reviewed as an alternative to the more traditional cereal and oilseed crops. In common with many other plants it contains large concentrations of carbohydrate, stored as inulin (Fleming & Groot-Wassink, 1979). Various aspects of Jerusalem artichoke culture have been the subject of reviews which detail agronomic and compositional data (e.g. Bacon & Edelman, 1951; Fleming & GrootWassink, 1979; Kosaric *et al.*, 1984). More specific studies give details of changes in inulin content during mature tuber storage (Modler *et al.*, 1993) and tuber development (Bacon & Loxley, 1952; Praznick & Beck, 1987). The changes during storage enhance the proportion of oligosaccharides at the expense of the polysaccharides. Such changes can be eliminated by blanching and spray drying to arrest the enzyme activity and to produce a stable product suitable for long-term storage.

The occurrence of high concentrations of inulin in Jerusalem artichoke has made it an attractive prospect for the production of sweeteners, low calorie food additives, animal feeds and for the production of ethanol. More recently there has been interest in the 'neosugars' which appear to encourage the growth of *Bifidobacterium* spp. (McKellar & Modler, 1989). In addition, tubers of Jerusalem artichoke contain a significant percentage of protein, dietary fiber and ash. The sugars, dry matter and protein seem to be evenly distributed in Jerusalem artichoke (Mazza, 1985). In the fractionation process described here the concentrations in the water soluble and insoluble fractions were quite different. With the rising interest in renewable energy sources, a stable and well defined feedstock is desirable for fermentation or for incorporation into food products and animal feed.

In this study three cultivars of Jerusalem artichoke were steam blanched, freeze dried, then separated into a skin and a skinless tuber fraction. Both fractions were treated with hot water to give a 'soluble' extract and an 'insoluble' residue. Each product was assayed for ash, protein and carbohydrates; in addition, the insoluble residues were assayed for dietary fiber. These data were then used to calculate the yield of the various components from the three cultivars selected for this study.

MATERIALS AND METHODS

Sample production and fractionation

Cultivars of Jerusalem artichokes were planted in adjacent plots in a sandy loam soil location in the spring of 1991. Tubers from Challenger, Sunroot and Fusil cultivars were collected in the fall using a potato harvester and placed in plastic bags for transport to the laboratory for processing. After holding for two weeks at

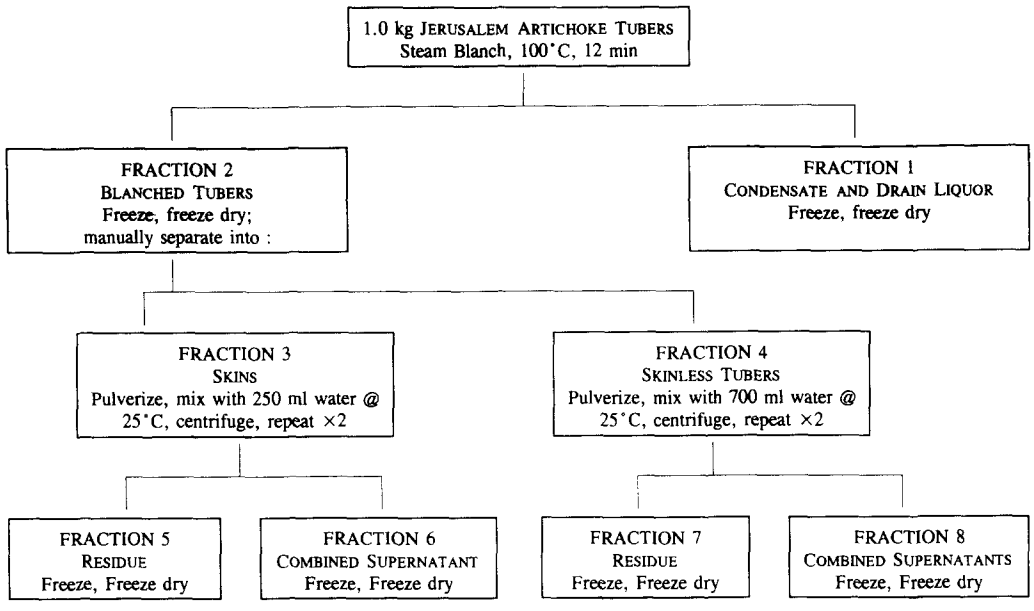

Fig. 1. Flow diagram for the fractionation of Jerusalem artichoke.

room temperature, tubers were manually cleaned by washing and trimming in cold water. The tubers were allowed to dry in air at ambient temperature, divided into lots weighing 1 kg and stored in plastic bags at 4°C.

Each lot was fractionated according to the scheme shown in Fig. 1. The first step in processing was to deactivate endogenous browning enzymes, such as polyphenol oxidase, by steam blanching and inactivated inulases to prevent further degradation of the inulin during storage. Each batch was placed in a steam kettle and subjected to steam blanch at 100°C for 12 min. After cooling, the drain liquor condensate (Fraction 1), and blanched tubers (Fraction 2) were frozen separately (−30°C), freeze-dried, and the weights recorded. The outer skins of the tubers were manually removed from the inner tissue and collected separately; the skins and skinless tubers then became Fractions 3 and 4, respectively.

The freeze dried skins (Fraction 3), were ground to a fine powder in a small coffee mill, mixed with approximately 250 ml of water at 25°C then centrifuged for 30 min at 8 000*g* at 20°C. The supernatant was decanted off and the residue re-extracted once more with water. The residue (Fraction 5) and the combined supernatants (Fraction 6) were frozen and freeze-dried. The same system of extraction was repeated for the skinless tubers, using approximately 700 ml of water, to produce Fractions 7 (residue) and 8 (supernatant). After weighing, the dried samples were stored in sealed plastic bags at 4°C to avoid rehydration.

Dry matter

Although the fractions were freeze dried there was still some residual moisture (~4%) remaining which was quantified by drying duplicate 1 g samples in a vacuum oven at 100°C for 5 h; after cooling in a dessicator for 30 min the samples were reweighed.

Ash

Duplicate samples of Fractions 1, 6 and 8 (3 g), and Fractions 5 and 7 (1·5 g) were weighed into tared ceramic ashing crucibles. After the addition of three drops of olive oil, the crucibles were placed in a forced air oven at 100°C overnight. The samples were charred in a fume hood then heated in a muffle furnace to 550°C for 4 h, cooled to room temperature and the residue wetted with water. After drying, the samples on a steam bath, they were reashed in the muffle furnace for 4 h at 550°C, placed directly into a dessicator to cool for 1 h, then reweighed

Fiber

The soluble and insoluble dietary fibers were determined by gravimetric methods (Mongeau & Brassard, 1980) developed at Health and Welfare Canada. The water soluble fiber analysis utilized the Fibertec System E (Tecator, Sweden), the filtering aid was Celite; for insoluble fiber analysis Fibertec equipment was used for the digestion and filtration procedures. The sample size in both soluble and insoluble fiber measurement was 500 mg. Total dietary fiber was expressed as the sum of soluble and insoluble dietary fiber.

Soluble sugars

The total soluble sugars were determined by the phenol-sulfuric acid colorimetric method (Rao and Pattabiraman, 1989). This procedure produced some variation in color development probably due to difficulties in consistent mixing. The method was modified as follows: sample weights were adjusted to obtain a reading of 0·2–0·4 AU, this required a solution of 200 mg of the freeze-dried extracts of Jerusalem artichoke in 100 ml water. Sugar-containing solution (20 μl) was combined with 3·9 ml of water and then 10·0 ml reagent

grade sulfuric acid was added and immediately mixed on a vortex mixer. The solution was cooled in ice water for 2 min and removed to ambient air at 23°C. After the addition of 100 μl of 50% phenol, the solution was mixed and held in a water bath at 23°C for 30 min. Absorbance values were measured at 480 nm after a time interval of 30–60 min after the addition of phenol. A standard curve was prepared using purified inulin from Jerusalem artichoke (Sigma Chemical Co.).

Protein

Samples of 1 g were analyzed in duplicate using a Gerhardt Kjeldatherm Digestion System (Macro), Model 60200D KT20S (Bonn, Germany). The catalyst was $CuSO_4/K_2SO_4$, and a conversion factor used for N to protein was 6·25.

RESULTS AND DISCUSSION

One of the goals of the fractionation process was to concentrate the water-soluble carbohydrates for further processing, but in so doing fiber-rich fractions were also created which also contained significant amounts of protein. The batch to batch control of the blanching process proved to be difficult, affecting the weight of dry matter in the fractions, particularly the drain liquor (Fraction 1), which was also the smallest of the fractions recovered with insufficient material to complete protein analysis on all batches (Table 1).

Analyses of the drain liquor (Fraction 1) revealed that all cultivars had approximately the same per cent soluble sugar on a dry basis. The Fusil and Sunroot cultivars contained 12·2 and 12·5% protein in the drain liquor, compared to 9·4% for Challenger; ash content ranged over 6·8–9·8%.

In the analysis of the residues (Table 2, Fractions 5 and 7) the protein was slightly higher in Fusil and Sunroot than in Challenger in both the skins and in the skinless tubers. The ash content of the skins residue was nearly double the content of ash in the skinless tuber residue. There was a large variation in the soluble sugars content between cultivars and between lots within the cultivars; Fusil had a higher content in the skinless tubers (38·5%) than in the skins (30·2%) whereas in Sunroot the reverse was true. The variation between lots was probably due to the enzyme activity during cold storage (Modler *et al.*, 1993). The cumulative per cent of ash, protein and soluble sugars accounted for 56·9–66·4% of the total solids in the skinless tubers; the remainder of the residue was accounted for as dietary fiber (Table 3). The insoluble fiber in the residue (Fractions 5 and 7) within each cultivar showed very little variation but differences were noted between the skins and skinless tubers: generally the skinless tubers had 2–3% more insoluble fiber than the skins (Table 3). The soluble fiber showed large variations which correlate with the variation in the soluble sugars; i.e. within cultivars, for a given sample, a high soluble sugar content results in a correspondingly lower soluble fiber content and vice versa. This holds true for both the skin samples as well as the skinless tuber samples.

Table 1. Analysis of drain liquor (Fraction 1)

Cultivar	Lot number	g/kg Starting material (dry weight)	% Composition of Fraction 1			
			Protein (A)	Soluble sugars (B)	Ash (C)	A + B + C
cv Fusil	1	4·9	[a]	77·4	7·8	NA[b]
	2	39·0	12·1	79·4	6·6	98·9
	3	21·6	12·3	78·9	7·2	98·2
	4	24·8	12·3	81·6	6·8	100·6
	5	33·5	12·2	79·2	7·4	98·8
		Mean[c]	(8) 12·2 ± 0·06	(10) 79·3 ± 1·35	(10) 7·2 ± 0·43	
cv Sunroot	6	9·0	[a]	78·6	9·8	NA
	7	6·5	[a]	81·7	7·8	NA
	8	11·0	[a]	83·2	7·7	NA
	9	13·7	12·8	83·0	7·8	103·5
	10	12·5	12·9	79·8	7·8	100·4
	11	22·2	11·9	79·3	8·2	99·4
		Mean	(6) 12·5 ± 0·45	(12) 80·9 ± 1·81	(12) 8·2 ± 0·74	
cv Challenger	12	4·3	[a]	83·1	7·7	NA
	13	10·7	[a]	80·4	7·9	NA
	14	14·8	9·4	80·1	7·3	99·8
	15	16·6	9·3	82·7	7·5	9·6
		Mean	(4) 9·4 ± 0·07	(8) 81·6 ± 1·34	(8) 7·6 ± 0·22	

[a]Insufficient sample available for analysis.
[b]NA, not applicable.
[c](Number of observations), Mean ± Standard Deviation.

Table 2. Analysis of residue, dry weight basis

Cultivar	Lot no.	Skins (Fraction 5)					Skinless tubers (Fraction 7)				
		Dry wt recovered g/kg starting material	% Composition				Wt recovered g/kg starting material	% Composition			
			Protein (A)	Soluble sugars (B)	Ash (C)	A + B + C		Protein (A)	Soluble Sugars (B)	Ash (C)	A + B + C
cv Fusil	1	15·3	23·1	25·6	7·5	56·1	21·0	23·0	41·7	3·8	68·5
	2	15·6	23·0	28·4	7·4	58·8	17·0	25·7	34·1	3·2	63·0
	3	16·6	24·5	24·7	6·4	55·6	19·4	24·8	40·1	3·6	68·5
	4	21·1	21·5	34·7	7·1	63·2	20·9	23·2	40·6	3·9	67·7
	5	20·8	21·5	37·5	7·0	66·0	17·3	25·8	35·1	3·4	64·3
		Mean[a]	(10) 22·7 ± 1·13	(10) 30·2 ± 5·06	(10) 7·0 ± 0·39	(5) 59·9 ± 4·1		(10) 24·5 ± 1·19	(10) 38·5 ± 3·33	(10) 3·6 ± 0·26	(5) 66·4 ± 2·30
cv Sunroot	6	22·7	23·0	39·8	6·1	68·9	17·8	27·0	34·0	3·7	64·7
	7	23·3	23·1	37·3	6·2	66·6	24·7	25·9	32·2	3·8	61·9
	8	23·1	22·5	41·2	5·9	69·6	31·8	23·8	38·3	4·3	66·5
	9	16·5	24·1	31·8	6·2	62·2	30·1	25·1	34·3	3·9	63·3
	10	20·0	23·2	31·6	6·0	60·7	29·7	25·2	29·8	4·0	59·0
	11	20·1	23·5	33·0	6·4	62·9	25·7	26·6	31·8	3·8	62·3
		Mean[a]	(12) 23·2 ± 0·50	(12) 35·8 ± 3·87	(12) 6·2 ± 0·17	(6) 65·2 ± 3·40		(12) 25·6 ± 1·09	(12) 33·4 ± 2·65	(12) 3·9 ± 0·20	(6) 63·0 ± 2·34
cv Challenger	12	18·8	19·4	25·4	7·0	51·7	32·6	18·5	42·3	4·9	65·7
	13	16·2	20·7	27·7	6·9	55·3	23·2	23·2	26·2	4·1	53·6
	14	14·7	21·9	25·5	6·9	54·3	24·5	22·6	26·5	3·9	53·1
	15	15·9	22·2	19·4	6·9	48·5	23·3	23·2	27·8	4·2	55·2
		Mean[a]	(8) 21·1 ± 1·11	(8) 24·4 ± 2·94	(8) 6·9 ± 0·43	(4) 52·5 ± 2·63		(8) 21·9 ± 1·97	(8) 30·7 ± 6·72	(8) 4·3 ± 0·38	(4) 56·9 ± 5·14

[a](Number of observations), Mean ± Standard Deviation.

Table 3. Analysis of dietary fiber in residue, dry weight basis

Cultivar	Lot No.	Skins (Fraction 5)				Skinless Tubers (Fraction 7)			
		% Composition				% Composition			
		Insoluble fiber	Soluble fiber	Total fiber	[b]Protein, soluble sugars, ash, fiber	Insoluble fiber	Soluble fiber	Total[b] fiber	Protein soluble sugars, ash, fiber
cv Fusil	2	9·5	28·8	38·3	97·1	9·4	32·9	42·3	105·3
	3	9·9	30·6	40·5	96·2	10·1	28·8	38·8	107·3
	4	9·6	24·0	33·6	96·9	13·7	25·5	39·1	106·8
	Mean[a]	(6) 9·7 ± 0·17	(6) 27·8 ± 2·79	(6) 37·5 ± 2·88	(3) 96·7 ± 0·39	(6) 11·1 ± 1·88	(3) 29·1 ± 3·03	(6) 40·1 ± 1·58	(3) 106·5 ± 0·85
cv Sunroot	8	8·8	20·2	29·0	98·6	12·0	20·1	32·1	98·6
	9	10·8	27·0	37·9	100·1	12·1	22·7	34·8	98·2
	10	10·1	24·6	34·7	95·4	13·8	22·6	36·4	95·4
	Mean	(6) 9·9 ± 0·83	(6) 23·9 ± 2·82	(6) 33·9 ± 3·68	(3) 98·0 ± 1·96	(6) 12·6 ± 0·83	(6) 21·8 ± 1·20	(6) 34·6 ± 1·93	(3) 97·4 ± 1·42
cv Challenger	12	11·6	28·8	40·4	92·1	14·4	21·7	36·1	101·8
	13	10·9	29·7	40·6	95·9	14·2	29·7	43·9	97·5
	14	11·5	32·1	43·6	98·0	14·5	29·0	43·4	96·5
	Mean	(6) 11·3 ± 0·31	(6) 30·2 ± 1·39	(6) 41·5 ± 1·46	(3) 95·3 ± 2·44	(6) 14·4 ± 3·62	(6) 26·8 ± 0·12	(6) 41·1 ± 3·56	(3) 98·6 ± 2·30

[a](Number of observations), Mean ± Standard Deviation.
[b]Based on data from Table 2.

Table 4. Analysis of supernatant, dry weight basis

Cultivar	Lot no.	Combined supernatant (skins – Fraction 6)					Combined supernatant (skinlesss tuber – Fraction 8)				
		Dry wt recovered g/kg starting material	% Composition				Wt recovered g/kg starting material	% Composition			
			Protein (A)	Soluble sugars (B)	Ash (C)	A + B + C		Protein (A)	Soluble sugars (B)	Ash (C)	A + B + C
cv Fusil	1	20·9	11·7	78·9	5·5	96·2	87·0	11·8	79·3	7·5	98·6
	2	22·7	11·5	77·5	5·6	94·6	79·6	11·1	75·8	6·8	93·7
	3	24·8	11·8	78·1	5·5	95·4	80·1	11·6	75·4	6·3	93·5
	4	23·1	11·6	78·7	5·5	95·9	93·8	12·3	74·9	6·7	93·8
	5	24·5	11·3	80·8	5·6	97·8	70·3	11·9	75·3	6·8	93·9
		Mean[a]	(10) 11·6 ± 0·18	(10) 78·8 ± 1·11	(10) 5·5 ± 0·05	(5) 96·0 ± 1·06		(10) 11·7 ± 0·38	(10) 76·1 ± 1·61	(10) 6·8 ± 0·39	(5) 94·7 ± 1·95
cv Sunroot	6	24·4	13·8	82·8	5·9	102·5	62·6	15·3	76·5	7·4	99·2
	7	26·5	13·3	83·9	5·9	103·0	89·6	14·4	76·0	7·1	97·5
	8	22·1	12·8	82·6	5·2	100·6	88·4	14·6	75·8	6·8	97·2
	9	23·2	12·9	81·3	5·1	99·3	94·9	14·4	79·3	6·4	100·1
	10	22·5	12·9	80·0	5·4	98·3	101·4	14·6	79·4	6·6	100·9
	11	23·5	13·4	80·5	5·6	99·5	91·9	14·0	76·2	6·6	96·9
		Mean	(12) 13·2 ± 0·35	(12) 81·9 ± 1·37	(12) 5·5 ± 0·31	(6) 100·5 ± 1·71		(12) 14·5 ± 0·57	(12) 77·2 ± 1·54	(12) 6·8 ± 0·34	(6) 98·6 ± 1·52
cv Challenger	12	18·8	8·4	82·2	5·6	96·2	89·9	8·3	82·4	6·9	97·6
	13	18·4	9·0	85·3	5·4	99·7	91·1	8·8	83·4	6·7	98·8
	14	19·3	8·6	82·8	5·3	96·7	97·8	8·3	79·8	6·9	95·0
	15	20·9	8·8	81·3	5·9	96·0	88·6	8·3	82·2	6·5	97·5
		Mean	(8) 8·7 ± 0·21	(8) 82·9 ± 1·49	(8) 5·6 ± 0·23	(4) 97·2 ± 1·29		(8) 8·5 ± 0·24	(8) 82·0 ± 1·32	(8) 6·8 ± 0·17	(4) 97·2 ± 1·38

[a](Number of observations), Mean ± Standard Deviation.

Table 5. Yield of components from Jerusalem Artichoke tubers

	100 kg Jerusalem artichoke (dry matter)					
	Residue (kg)			Water-soluble solids (kg)		
	Fusil	Sunroot	Challenger	Fusil	Sunroot	Challenger
Skins	10·2	11·7	9·9	13·4	13·1	11·8
Pulp	11·0	14·8	15·7	47·5	48·9	—
Drain Liquor	—	—	—	16·1	6·9	7·0
Total	21·2	26·5	25·6	77·0	68·9	74·5

In the supernatant fractions (Table 4), the entire amount of dry matter is accounted for in protein, ash and soluble sugars; dietary fiber should not be present in Fractions 6 and 8. The Sunroot samples contained more protein than the other cultivars in both the skins and the skinless tubers. The ash content was greater in skinless tubers than the skins in all cultivars and Challenger contained the largest amount of soluble sugars. The overall mean recovery of protein, soluble sugar and ash for all cultivars was 96·9% of the total solids component ($N = 15$).

The data in Table 5 summarize theoretical yields of the various components that a processor could anticipate recovering from 100 kg of JAT dry matter. There is some variation in dry matter yield from cultivar to cultivar, but the residue from the skins and skinless tubers accounted for about 24% of the total recovery. The remainder, being the water soluble solids and the drain liquor, would be combined in a commercial process due to the similarity in composition. Despite some compositional differences in the residue from skins and skinless tubers (Fractions 5 and 7), there appears to be little benefit in processing these two components separately whether they are used for feed, food or pharmaceutical preparations.

ACKNOWLEDGMENTS

The authors wish to acknowledge the technical support of Nicoliene G. J. Alberts (Hogeschool Drenthe, Emmen, The Netherlands), Albert Collins, as well as the scientific advice offered by the late Dr J. D. Jones.

Contribution No. 2177 of the Centre for Food and Animal Research.

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