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Observations on long-term storage and processing of Jerusalem artichoke tubers (*Helianthus tuberosus*)*

H. W. Modler,[a] J. D. Jones[a] and G. Mazza[b]

[a]Agriculture Canada, Centre for Food and Animal Research, Ottawa, Ontario, Canada
[b]Agriculture Canada, Research Station, Morden, Manitoba, Canada

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A study was undertaken to determine the effect of the period, temperature of storage and over-wintering in the soil, upon the fructooligosaccharide (FOS) profile of Jerusalem artichoke tubers (JAT). Additional experiments were conducted to determine if changes in FOS profile were related to difficulties in spray-drying macerated tubers for the purpose of producing JAT flour.

Tubers from four Jerusalem artichoke cultivars (Columbia, Challenger, Sunroot and Fusil) were harvested, trimmed, washed, placed in (150 μm) polyethylene bags and evaluated for storage stability and changes in fructo-oligosaccharide (FOS) profile. Of the five storage treatments tested (5°C, 2°C, −10°C, program cooled to −10°C, and ambient) the 2°C treatment yielded the best quality tuber at the end of 12 months of storage. Tubers kept at 5°C showed signs of sprouting after six months and some spoilage after 12 months. The other treatments were unsatisfactory.

During short-term storage (18 weeks) the inulin content of the JAT shifted to the shorter chain FOS. Tubers stored for 16 months at 5°C had virtually no FOS with a dp ≥ 10, but had accumulated substantial amounts of dp 1–4.

Difficulties in spray-drying a heat-treated macerate of the tubers were not related to the FOS content, but appeared to depend on the degree of hydration of the insoluble fibre components. The colour of JAT flour produced by spray-drying was substantially improved by heating the whole tubers prior to maceration. This serves to inactivate polyphenol oxidase, responsible for the undesirable brown colour development.

INTRODUCTION

The origin of the Jerusalem artichoke tuber (JAT) remains uncertain, but it appears that this member of the sunflower family was originally native to the Andes of South America (Klaushofer, 1986) and North America. Jerusalem artichoke tubers were first cultivated in Canada at Annapolis Royal, Nova Scotia and exported to France in 1607 by Louis Hébert, the first permanent settler in Québec City (Philpot, 1929). Cultivation of JAT reached a maximum of 110,000 hectares, mostly in central France, in 1920 (Philpot, 1929). Between 1920 and the present, there appears to have been a significant decline in world production of JAT; however, production statistics are difficult to locate.

Over the past five to ten years, considerable interest has been generated in JAT, mainly because this crop is an excellent source of both soluble and insoluble fibre. Fructooligosaccharides (FOS), the soluble fibre component, have been identified as an important substrate for desirable intestinal flora, especially bifidobacteria (Modler, 1992). These bacteria metabolize fructose and FOS to produce acetic and lactic acids in the ratio of 3:2 (McKellar & Modler, 1989). The acid environment generated by bifidobacteria in the lower gut inhibits the growth of putrefactive and pathogenic bacteria. This in turn leads to reduction of production of toxic substances such as skatole, phenols, ammonia, steroid metabolites, bacterial toxins, as well as vasoconstricting amines, e.g. histamine, tyramine, cadaverine, and agmatine (Hidaka & Eida, 1988; Mitsuoka, 1982).

In order for bifidobacteria to be of benefit to the host, it is imperative that these microorganisms be alive and metabolically active in the lower gastrointestinal tract. Thus, sources of nutrients such as FOS are required to encourage proliferation of bifidobacteria in the large bowel/cecal area. Crops such as Jerusalem artichoke and chicory are excellent sources of FOS (Modler, 1992).

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Fructooligosaccharide components from chicory are produced in Belgium and are available from two commercial sources (Raffinerie Tirlemontoise, Aandorenstraat 1, B-3300 Tienen; Cosucra, Haut-Vinâve 61, B–4350 Momalle). The extraction and purification of FOS from JAT has not progressed because of several limitations, namely:

(i) Difficulty in removing the undesirable flavour components.
(ii) Undesirable colour development during processing, due to the action of polyphenol oxidase.
(iii) Limited harvest time in the fall (2–3 weeks) and spring (1–2 weeks) and high capital costs for equipment with a narrow processing window.

Although Columbia is the highest-yielding cultivar grown in Canada (Chubey & Dorrell, 1982; Kiehn & Chubey, 1985), its tubers are very difficult to clean, particularly when grown in clay soil. Fusil (carrot–like shape), Challenger (pear-shaped) and Sunroot (egg-shaped) are easier to clean, but have lower yields than Columbia. Tuber shape, configuration (distance between tuber and stolon), smoothness, and ease of separation of stolon and tuber are important factors when selecting a cultivar (Szucs & Nagy, 1987). Others have recommended that JAT be grown in sandy soil (Barwald, 1987), but yield on heavy soils, e.g. clay, is often higher.

The objectives of this research were to:

(i) Monitor changes in FOS profile during over-wintering in the soil and long-term refrigerated storage after harvesting to determine if JAT could be stored for long periods of time and make efficient use of processing equipment and reduce capital costs.
(ii) Produce a light-coloured JAT flour which could be used as a source of bifidogenic factors such as FOS for animal feeding purposes.
(iii) Determine if the short-chain FOS are responsible for difficulty in obtaining a dry powder during spray-drying of JAT macerate.
(iv) Determine the most suitable cultivar for processing.

MATERIALS AND METHODS.

Planting and storage

This series of experiments was based primarily on the Columbia cultivar but limited quantities of Fusil, Challenger and Sunroot (Licensed cultivar of Sunroot Energy Ltd, Mississauga, Ontario) were grown to evaluate long-term storage characteristics and over-wintering ability.

The Sunroot and Columbia cultivars were grown in Ottawa while Fusil and Challenger were planted at Morden, Manitoba. The tubers were planted in sandy loam soil at both locations in early May 1988. At harvest time, the tops were removed with a forage harvester and a potato digger was used to remove the tubers from the soil. Tubers to be used in the storage treatments, were placed in burlap bags in the field and stored at 5°C during the on-going washing and trimming process. This was completed within ten days of harvest for both the local crop and the tubers shipped from Morden. After preparation the JAT were stored in 25-kg lots in polyethylene bags (150 μm) and subjected to one of five temperature treatments. The first three storage temperatures were 5°C, 2°C and −10°C. In the fourth treatment, tubers were cooled at a rate of 1°C per week (starting at 4°C) until the temperature reached −10°C and then maintained at −10°C. In the fifth treatment, the tubers were stored in burlap bags at ambient temperature in an unheated building for exposure to winter frost. The storage trials lasted for approximately 16 months.

The over-wintering studies, to study changes in FOS profile, were conducted in 1989 and were based on all four cultivars grown at the Ottawa location.

Analyses

The FOS profile of the JAT was determined using high performance liquid chromatography (HPLC) analysis. Preparation involved washing a number of tubers, e.g. 20 from each lot, to get a representative sample, grinding to a slurry, mixing an aliquot with distilled water in a weight ratio of 1:1 (1 min) and filtering through a 100-mesh nylon cloth. The filtrate was adjusted to approximately 2° Brix with distilled water (2·13% sugar at 22°C) and carbohydrate content was estimated using a hand-held refractometer. The above filtrate was then filtered through 0·45 μm and then 0·2 μm filters.

HPLC analyses were conducted using the following conditions: isocratic mode; 80 min equilibration; flow rate of 0·5 ml/min^{-1} with a sample size of 30 μl. The guard column and gel filtration columns were maintained at 65°C. The mobile phase was 95:5 water:methanol, containing 0·5% sodium azide used as a preservative. HPLC equipment used in these analyses consisted of:

Control–station	Perkin–Elmer	Model 3600
Liquid chromatograph	Perkin–Elmer	Series 4
Sampling system	Perkin–Elmer	Model ISS–100
Guard column	Supelco	Progel–TSK–Oligo (40 mm × 6.0 mm i.d.)
Gel filtration columns (2)	Supelco	Progel–TSK–G–Oligo–PW–two columns in series (300 mm × 7.8 mm)
Differential refractometer	Millipore–Waters	Model R401
Integrator–printer	Hewlett–Packard	Model 3390A

Total solids

Total solids were determined by the microwave procedure (Method 16.265, AOAC, 1984) using a CEM oven (Model AVC 80, Indian Trail, North Carolina, USA).

Processing

The processing scheme for the production of flour from JAT was similar to that described by Yamazaki *et al.*, (1989) and involved the following steps:

Process	*Equipment*
Washing	..... Magikist (Model 32C–4–TO)
▼	
Dicing (1-cm cubes)	..... Urschell (Model G)
▼	
Macerating (0·03–0·05 mm)	..... Vibroreactor (Model JM M/0/25)
▼	
Heating (90°C)	..... APV–Crepaco UHT pasteurizer (200 litre h^{-1})
▼	
Holding tube (10 min)	..... Ladish Tri–Clover (25mm Diameter)
▼	
Spray-drying	..... Rodgers (Model 9606-54) —Nozzle orifice #66 or #69 —Insert 4–16 —Inlet air temp. 200°C —Outlet air temp. 95–102°C

RESULTS AND DISCUSSION

All the cultivars were relatively easily harvested using a potato digger and the problem of scattering, observed by Haluschan (1987), was only evident in secondary growth. The preservation of tubers left in the ground did however vary: the Columbia and Challenger cultivars appeared more susceptible to stem rot by Sclerotinia than either Fusil of Sunroot.

All harvested tubers, regardless of the cultivar, kept well for four months at 5°C with no spoilage (Table 1) but sprouting did occur after 12 months storage at 5°C. All tubers stored at 2°C kept extremely well with no loss of turgor, or microbial spoilage after 16 months of storage. Sprouting was not a problem. This may be due to a variety of factors: reduced O_2 and rate of respiration; an accumulation of CO_2 in the polyethylene bags and high humidity. The absence of Sclerotinia also added to the longevity of all cultivars (Huang & Stauffer, 1979). The ability to store JAT in polyethylene bags for periods of up to one year is a significant improvement over conventional storage where spoilage commences between 5 and 11 weeks (Sarkozi, 1987).

Tubers stored at ambient temperature (approximately −10°C between December and March) and at −10°C (program cooled) deteriorated rapidly on thawing (Table 1). Different results may have been obtained had tubers in the latter treatment been program-cooled from 4°C to −1°C. This is the average soil temperature in Ottawa during the winter months.

Table 1. Condition of Jerusalem artichoke tuber as affected by temperature and duration of storage

Treatment	Time (months)		
	4	12	16
5°C[a]	No change	Slight sprouting with occasional spoilage	Excessive sprouting and some spoilage
2°C[a]	No change	No change	No change
−10°C(P)[a,b]	No change	Soft on thawing[d]	Spoiled[d]
−10°C[a]	No change[d]	Soft on thawing[d]	Spoiled[d]
Ambient[c]	Soft, partially spoiled	—	—

[a] All four cultivars (Fusil, Columbia, Sunroot and Challenger) stored in sealed polyethylene bags (150 μm).
[b] Program cooled from 4°C to −10°C at a rate of −1°C wk^{-1} for 14 weeks.
[c] Kept in unheated storage building in burlap bags (approximately −10°C) between December and March.
[d] Frozen.

Changes in FOS profile

FOS levels in tubers were determined following 18 weeks of storage (Table 2). Long-chain FOS in the Columbia cultivar tended to decrease in storage while the amount of short-chain FOS, varied slightly with treatment: the degree of polymerization (dp) increased from 1 to 11·0% for dp 1 in the 2°C treatment; dp 2–3 increased substantially in the −0°C treatment (program cooled), when compared to the initial tubers. The −10°C and the ambient treatment had FOS profiles similar to the initial tubers, except for substantially lower amounts of dp >10.

The results indicate that at 5°C there is sufficient metabolic activity to utilize fructose formed from the breakdown of long-chain FOS (Table 2). As the temperature drops to 2°C, the rate of respiration slows. As

Table 2. Relative percent soluble fructooligosaccharide components in Jerusalem artichoke tubers (Columbia) stored under various conditions for a period of 18 weeks[a]

Degree of polymerization	Storage Treatment (°C)					
	Initial[b]	5	2	−10	−10	Ambient[d]
1	0·8	1·0	11·0	5·0	1·3	3·6
2	11·0	16·4	11·0	19·0	11·5	11·3
3	8·3	14·0	7·0	15·0	10·3	11·0
4	7·5	13·0	6·0	11·4	10·0	8·7
5	8·0	12·0	7·0	10·0	10·6	9·7
6	8·5	10·5	8·0	8·5	10·3	9·2
7	7·8	8·0	8·0	6·7	9·3	7·9
8	6·8	6·0	7·3	5·0	8·0	6·6
9	6·0	4·7	7·0	4·0	7·0	5·8
10	5·5	4·0	7·0	3·4	6·4	5·4
>10	29·0	10·3	21·4	11·2	15·2	19·8

[a] Harvested 15 Nov. 1987, trimmed, washed and stored in sealed polyethylene bags (150 μm).
[b] S.D. reported in Table 3 for dp 1 to >9.
[c] Program cooled 1°C wk^{-1}, starting at 4°C.
[d] Kept in an unheated storage building in burlap bags (approximately −10°C) between December and March.

Table 3. Relative percent of soluble fructooligosaccharide components in Jerusalem artichoke tubers (Columbia) stored at 5°C for up to 16 months[a]

Degree of poly-merization	Duration of storage (5°C)			
	2 wks	(S.D.)[b]	12 months	16 months
1	0·8	(1·08)	6·0	12·3
2	11·0	(1·08)	32·7	40·9
3	8·3	(1·11)	16·1	17·6
4	7·5	(0·44)	12·4	10·9
5	8·0	(0·26)	9·4	6·8
6	8·5	(0·19)	7·2	4·7
7	7·8	(0·20)	5·1	2·9
8	6·8	(0·22)	3·6	1·6
9	6·0	(0·26)	2·4	1·1
>9	34·5	(2·07)	5·2	1·3

[a] Trimmed, washed and stored in sealed polyethylene bags (150 mm). Planted in April 1987 and harvested in November 1987.
[b] Standard Deviation based on 15 samples of two-week-old tubers.

a result, less energy is utilized which results in a large accumulation of dp 1 (1 to 11%), with some increase in dp 2–8. Polymers, with a dp of ≥8, decreased during the 18-week storage period.

Tubers held at 5°C in long-term storage had decreased amounts of long-chain FOS (dp > 9; Table 3). Initially, the Columbia tubers contained 34·5% of dp > 9 and this dropped to approximately 1·3% at the end of 16 months storage. As expected, there was a relatively large increase in the amount of FOS in the dp 1–4 range (Table 3). This has been confirmed by others (Klaushofer, 1986; Sarkozi, 1987). The amount of total FOS was not quantitated, but a loss of 5 to 10% during storage in the soil or at 2°C, has been reported by Beck and Praznik (1986).

The data in Table 4 are a comparison of the FOS of the four cultivars after over-wintering in the soil. (All cultivars grown and harvested in Ottawa in the spring of 1989.) The harvest dates were based on the earliest signs of sprouting so that tubers would be in a similar physiological stage of growth, rather than selecting the same harvest date for all tubers.

Table 4. Comparison of the relative percentage amounts of soluble fructooligosaccharide in four cultivars of Jerusalem artichoke tubers, following spring harvest[a]

Degree of poly-merization	Cultivar			
	Fusil[b]	Columbia[c]	Sunroot[c]	Challenger[d]
1	3·4	2·3	2·5	4·8
2	8·9	25·0	11·2	12·4
3	8·1	15·0	7·8	9·0
4	7·4	13·2	7·7	8·0
5	7·6	11·0	7·9	7·8
6	8·4	8·8	8·2	7·7
7	8·2	6·6	7·8	7·2
8	7·2	5·2	7·3	6·1
9	6·5	3·8	6·4	5·7
10	5·9	3·0	5·9	5·1
>10	28·3	6·2	27·4	25·1

[a] All tubers grown and harvested in Ottawa.
[b] Harvested 12 May 1989.
[c] Harvested 24 April 1989.
[d] Harvested 1 May 1989.

The Fusil, Sunroot and Challenger cultivars had similar FOS profiles while the Columbia cultivar had undergone substantial depolymerization even though it appeared to be at the same physiological state of development. Columbia is an early maturing cultivar and reaches the flowering stage at about 105 days compared to 130–135 days for the other tubers.

Spray-drying JAT

The macerate of Jerusalem artichoke tubers is a difficult product to spray-dry. There are three contributing factors: the fibrous material causes excessive wear to processing equipment; nozzle plugging is an on-going problem due to the insoluble fibre; the spray-dried product tends to stick to the walls of the dryer chamber during processing.

Initially, it was thought that the sticking problem was related to the content of short-chain FOS in the macerate. This aspect was investigated by hydrolyzing the FOS with an inulase preparation (supplied by Meiji Seika Kaisha Limited, Saitama, Japan) which reduced all the long-chained FOS to dp 5 or less (confirmed by HPLC analyses). This treatment did not exacerbate the sticking problem in spray-drying of JAT macerates. After further investigation, it was observed that hydration of the insoluble fibre component (cellulose, hemicellulose and lignin), was the main cause of the difficulty in drying, i.e. powder sticking to the dryer walls. This can be circumvented by reducing the holding time between heat-treatment and spray-drying. Cooling the macerate prior to drying had little influence on slowing hydration of the insoluble fibre components.

The spraying of JAT macerate was facilitated by operating the equipment at outlet air temperatures of 95 to 102°C. This reduced sticking, but also meant that measures had to be taken to remove the flour from the spray dryer box as it was produced, in order to reduce caramelization. The flour tended to be hygroscopic and had to be packaged and sealed immediately upon removal from the spray-dryer.

It was also observed that pressure atomization is the method of choice rather than rotary disc atomization in the spray-drying of JAT macerate. When using pressure atomization, nozzle type is important: less plugging was encountered when using SBC design than either ST or SX design (Spraying Systems Co., North Avenue, Wheaton, IL 60188, US).

Improvements can be made to both the colour and flavour of spray-dried products if the tubers are blanched prior to macerating. Heating the whole tubers, prior to slicing, inactivates polyphenol oxidase and reduces formation of undesirable brown pigments.

In addition, longer-chain FOS are rapidly hydrolyzed in cut tubers (Vukov *et al.*, 1987) due to the action of inulase (Edelman & Jefford, 1968); however, these enzymes can also be inactivated by heating prior to cutting. Four blanching methods were evaluated:

(1) Autoclaving at 138 kPa for 20 min (2 × 25-kg lots per autoclaving).
(2) Use of the continuous ABCO blancher. Sunroot was easier to blanch than Columbia and only required 20 min at 69 kPa steam pressure compared with 30 min for Columbia but this may be related more to tuber size, than the difference in the rate of heat transfer.
(3) Microwave heating (small scale).
(4) Continuous heating with APV-Crepaco UHT pasteurizer.

The ABCO (Cummings *et al.*, 1984) blancher proved to be the most suitable equipment for continuous blanching of the JAT. This blancher is designed for regeneration of heat and can process 8 kg of product/kg of steam which is substantially better than hydrostatic blanchers at 3:1 or hot water blanchers at 2:1. Drain liqueur from the ABCO blancher is of excellent quality in terms of clarity and colour. Upon cooling, the longer chain FOS precipitated from this fraction. Autoclaving is a satisfactory technique for small-scale production of JAT flour product; however, it does yield a darker product due to caramelization.

CONCLUSIONS

Columbia is the highest-yielding cultivar; however, the tubers are difficult to clean mechanically and like Challenger tend to rot from the stem-end when overwintered in the soil. Challenger, Fusil and Sunroot are easy to clean with the latter two varieties having a higher content of long-chain FOS at the time of spring harvest.

Jerusalem artichoke tubers, which have been washed and are free of Sclerotinia, can readily be stored for six months at 5°C and possibly as long as one year or more at 2°C in polyethylene bags (150 μm). During cold storage at 5°C, there is a decrease in the relative amounts of oligosaccharide (dp > 9) with a corresponding increase in the short-term FOS. The ability to store tubers for an extended period has implications in terms of reducing capital expenditure on equipment.

Jerusalem artichoke tubers are difficult to spray-dry owing to the high content of insoluble abrasive fibre which tends to hydrate after maceration and heating to cause problems during spray-drying. The presence of short-chain FOS has little influence on the ability to spray-dry JAT macerate; however, the powder must be sealed immediately after drying and properly stored owing to its hygroscopic nature.

Heating of the whole tubers prior to processing inactivates polyphenol oxidase and results in the production of a light- coloured flour.

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