Fuel alcohol from Jerusalem artichoke

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Tubers of this fast-growing plant could yield 25 to 30 gallons of alcohol per ton of fresh weight.

Right: 'Sunchoke' is believed to be a cross of Jerusalem artichoke with an improved sunflower variety.

Below: Jerusalem artichoke tubers were first diced, then made into a thick pulpy mash, which after fermentation and distillation produced 7 to 8 percent alcohol, plus the amount of residue shown at right.

Jerusalem artichoke, *Helianthus tuberosus* L., is native to eastern North America. It has long been grown in Europe for animal feeding, and since the 17th century some tubers have been grown for human consumption.

As early as 1883, C. H. Dwinelle reported on growth trials in California. During and after World War I, extensive tests by the British Department of Scientific and Industrial Research indicated that Jerusalem artichoke would produce approximately as much fermentable carbohydrate per acre for alcohol production as sugarbeet and more than Irish potato. Recent reports from Manitoba, Canada, suggest that some Jerusalem artichoke cultivars will out-yield most crops in fermentables, including corn and sugarbeets grown with similar agronomic inputs at that locale.

The major storage product in Jerusalem artichoke is inulin, a low-molecular-weight polymer, primarily of fructose. Inulin is readily soluble in hot water and is reputedly hydrolyzed to fructose (required for yeast fermentation) after about 30 to 60 minutes in mildly acidic solutions (pH 2) at 100° C (212° F). Our agronomic and fermentation studies with the 'Sunchoke' cultivar at Davis in 1979 and 1980 reveal that ethanol yields of about 600 gallons per acre may be possible on good agricultural land. The crop appears to be essentially pest-free.

Tracy Borland

Tubers of *Helianthus tuberosus* L. 'Sunchoke', purchased at a local market, were used for all of our reserach. We believe that 'Sunchoke' originated in a Swedish sugar-crop breeding program of the 1950s, in which a native North American Jerusalem artichoke was crossed with an improved sunflower. According to the literature, the hybrid is more vigorous than either parent; it produces tubers, but the flowers are almost completely sterile and seed are rarely available (which we found to be true, too).

The Swedish breeding program was intended to extract sugar, as sucrose or fructose, from the stems (before flowering) in sufficient quantities to rival yields from sugarbeets. The tubers would remain in the ground and provide the next year's stem (and sugar) crop. Thus, the 'Sunchoke' would be a perennial sugar crop suitable for temperate zones. Little in the literature suggests that the hoped-for sugar yields were ever realized from 'Sunchoke' stem tissues, yet to this day the notion persists that Jerusalem artichoke tops are a high-yielding source of fermentable sugars, a notion we have not been able to confirm.

TABLE 1. Yield of Jerusalem Artichoke Tubers, Davis, California, 1980

Tuber yield*					
Fresh	Dry	Dry	Fermentables (dry tubers)†		Ethanol‡
tons/acre	*tons/acre*	%	%	*tons/acre*	*gal/acre*
14.7 ± 1.7	5.0 ± 0.4	34 ± 2.6	82.4 ± 5.9	4.1 ± 0.45	589 ± 65
(12.7-16.5)	(4.4-5.5)	(31-38)	(72.4-88.3)	(3.6-4.5)	(514-657)

*From 0 to 200 pounds nitrogen as ammonium sulfate were applied per acre in five increments; sampling procedures were inadequate to detect significant differences among treatments. Values shown are means, standard deviations, and ranges (in parentheses) for pooled data for five plots.

†Inulin was hydrolyzed by treating oven-dried ground tubers in acidic aqueous solutions, 0.01 N H_2SO_4 at 100° C for 30 minutes. Reducing sugars were determined colorimetrically. Tubers from each plot were assayed three times so that the value for percent fermentables is the mean of 15 samples.

‡Gallons of ethanol are computed, based on the assumption that 14 pounds of fermentables will yield 1 gallon ethanol.

Agronomic data

Small-scale trials of 1979 indicated that 'Sunchoke' is indeed vigorous. On 6 July 1979 we planted tuber pieces of approximately 2 ounces about 4 inches deep on 6- or 12-inch centers in rows 30 inches apart; growth was so rapid that canopy closure (at both densities) was achieved in early August. Furrow irrigation was at approximately 10-day intervals; ammonium sulfate was applied to give about 50 pounds nitrogen per acre. Available residual nitrogen before planting was at least 35 pounds per acre 3 feet.

Tuber filling began in September, at or shortly after flowering, and was essentially complete by mid-October when leaves were nearly dead. At harvest on 13 November, when the tops were dry, fresh tuber yields were 12 to 15 tons per acre (17 to 19 percent dry matter), and top dry weight was approximately 1.5 tons per acre. Assuming 80 percent of the dry tuber is fermentable (see 1980 data in table 1), about 2 tons per acre of fermentables were produced in approximately three months.

In 1980 we designed one plot to determine the potential of the tops as a source of fermentables and the effect of top harvest on tuber yield. Shoots harvested on 17 July yielded nearly 15 fresh tons per acre with 10 percent dry matter. Sugar content was about 2 percent on a fresh-weight basis (or approximately 0.3 ton per acre).

Shoot regrowth of the cut plants was rapid; canopy closure occurred by 27 August. On this date, flower buds were observed on all plants that had not been cut on 17 July. Shoot harvests of the plants with flower buds revealed up to 20 percent sugars (weight to volume) in the press juice—largely sucrose with small amounts of fructose and glucose. Shoot dry weight on 27 August was slightly more than 3 tons per acre with approximately 30 percent extractable sugars (1 ton fermentables per acre).

Tuber formation began in early September, except on plants in which the shoots had been harvested at flowering. Tubers on plots where tops were cut back in July probably would not warrant harvest, since tuber yield was reduced 25 percent, and there were essentially no tubers of harvestable size on plants cut back in late August.

Tubers were completely filled in most other cases by the end of October and were harvested on 12 November, when the shoot system was essentially dry. Yields were 13 to 16 tons per acre at over 30 percent dry matter to give roughly 5 dry tons and 4 tons of fermentables per acre. The high dry weight percentage in these trials reflects the loss of water by tubers before harvest in the field.

Following mild acid hydrolysis of the oven-dried, powdered tubers, sugar analyses revealed generally over 80 percent fermentables, largely as fructose. The computed alcohol yields were about 600 gallons per acre, approximately the same as for sweet sorghum, also grown at Davis under similar conditions. These tests do not document crop response to nitrogen, an important factor that remains to be established.

Harvest procedures

After the tops were cut, a potato harvester successfully dug the tubers, but at least half of them fell through the spaces between the conveyor rods. Yield data in table 1 are for hand-harvested plots, but hand harvesting is unrealistic for any large-scale operation.

Modified potato harvesters have been used for Jerusalem artichoke tubers, but we do not know if they are available commercially. Conveyor system modifications required would depend on tuber size. Since soil type affects the size (to some as-yet unknown extent)—small tubers predominate in heavy clay loams and large tubers in lighter sandy loams—modifications should be made only after on-site tuber studies have been completed.

Tuber storage

Preliminary studies have shown that tubers can be stored without great losses at 2.5° C for five months. Field-dug tubers with rot or damaged tissue were removed; the remainder were surface-sterilized in a 0.025 percent sodium hypochlorite solution. After air drying, the tubers were placed in metal cans, moved to a 2.5° C storage chamber, and cooled rapidly. The cans were sealed and partially evacuated to reduce O_2 levels to 2 to 5 percent. The atmosphere in the cans was monitored frequently and maintained at 10 to 15 percent CO_2 and 2 to 5 percent O_2.

Approximately 79 percent of the tubers survived five months without disease symptoms; the remainder were partially rotted by an unidentified fungus. Some growers have successfully stored tubers at 0° C (32° F) after packaging the surface-dried tubers in plastic bags and cooling them rapidly.

Although no quantitative data were collected, tubers stored in the field over winter appeared to be in good condition. They were considerably more turgid than those kept in cold storage.

Processing and fermentation

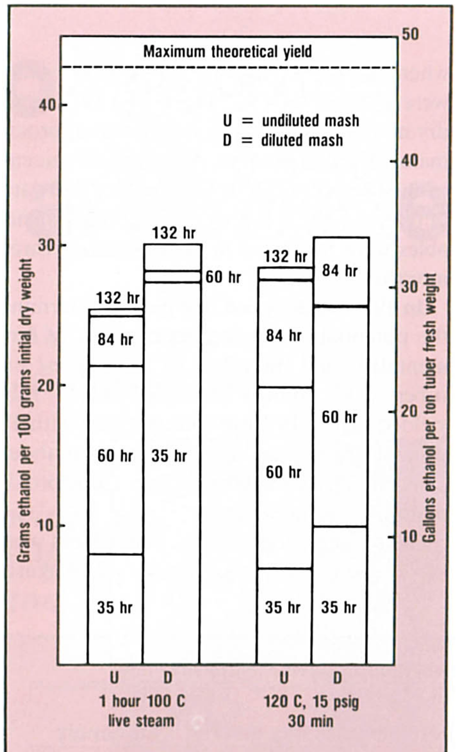
Before fermentation, freshly harvested, washed tubers were diced into 1-cm cubes, and processed with a Reitz Disintegrator (screen size approximately 0.05 inches) into a thick, pulpy mash, which turned from a creamy white color to a dark brown. This browning had no apparent effect on further processing or fermentation. The tuber pulp was either directly hydrolyzed or diluted with water, two parts pulp to one part water, by weight, before further processing.

Since the major tuber carbohydrate, inulin, is not directly fermentable by standard yeast strains (*Saccharomyces cerevisiae*), we used a mild acid hydrolysis procedure to break down the inulin into fermentable sugars. We adjusted the pH of the pulp samples to about 2.0 by carefully adding about 8 ml of concentrated sulfuric acid per kilogram (2.2 pounds) of original tuber pulp. The acidified pulp samples were then cooked, either for one hour at 100° C (flowing steam) or for 30 minutes at 15 psig steam pressure (autoclave). After the mash cooled, we adjusted the pH to about 4.5 with about 15 ml of a 25 percent, by weight, sodium hydroxide solution per kilogram of original tuber.

Mash samples were then inoculated with 0.5 gram of *Saccharomyces cerevisiae* (Distillers Active Dry Yeast) per kilogram of original tuber pulp and fermentation proceeded at room temperature. Samples were periodically analyzed for ethanol content by standard chemical methods.

A slightly higher percentage of the initial carbohydrates was converted to ethanol in the diluted mashes (see graph). All of the procedures resulted in yields between 60 and 75 percent of the theoretical maximum yield, which is satisfactory for a first attempt. Commercial industrial alcohol fermentations achieve 90 to 95 percent of theoretical yield.

The maximum theoretical yield calculated for the tubers used in this study was greater



Ethanol production by yeast fermentation of tubers as related to hydrolysis treatment, pulp dilution, and fermentation time. Numbers on bars are times when mash was sampled for ethanol content.

than 47 gallons per ton "fresh weight." This high value is probably due to the high dry matter content and partially dehydrated condition of the tubers used. A maximum theoretical yield of about 25 to 30 gallons per ton of normal fresh weight tubers is expected.

In addition to the need for good yields of ethanol per ton of tubers, fermented mashes must contain a high enough ethanol concentration to permit economic recovery by distillation. The concentrations of between 7 and 8 percent by weight for the diluted mashes (table 2) are all acceptable for alcohol recovery using the proper distillation equipment.

TABLE 2. Ethanol Production from Fermentation of Fresh Jerusalem Artichoke Tubers as a Function of Dilution and Hydrolytic Procedure

Treatment	Time for maximum ethanol production	Maximum weight/weight ethanol at maximum time
	hr	%
A. Pulped fresh tubers; (*undiluted*, 100° C cooking)	132	9.33
B. Pulped fresh tubers (diluted 2 parts pulp plus 1 part water, 100° C cooking)	84	7.31
C. Undiluted (autoclaved at 15 psig)	132	10.87
D. Diluted as in B (autoclaved at 15 psig)	84	7.88

Based on our results and observations, it seems best to dilute Jerusalem artichoke pulp with at least one-third to one-half of its own weight with water, depending on tuber condition. The resulting mash has an acceptable 7 to 8 percent alcohol content and is easier to handle than undiluted pulp. Undiluted pulp is a very thick slurry, containing 20 to 30 percent solids. The consistency hinders steady release of fermentation gases (carbon dioxide), causing sporadic, explosive disgorgement of gas and mash from the fermentation vessel.

Further research

The Jerusalem artichoke trials were reasonably successful, but additional research is needed in a number of areas:

■ Day-length. Almost all Jerusalem artichoke cultivars require short days for tuber formation (early September for 'Sunchoke' at Davis). We now have tubers of some cultivars from a French research station, which are reported to form tubers in August. A day-neutral or long-day cultivar would permit earlier fall harvests and land preparation for fall planting.

■ Effects of planting date on 'Sunchoke' yield, to learn if the cultivar can be grown as a "quick" summer crop after winter grains.

■ Continual cultivation without replanting, since small tuber pieces remain in the field, even after hand harvesting, and plants regrow the following spring.

■ A more definitive answer to the question of sugar yields from harvest of the shoot systems.

■ Storage of harvested tubers and changes occurring in those left in the ground.

■ Improvement and simplification of initial processing and fermentation, including the possible use of native inulin hydrolyzing enzymes or direct hydrolysis by yeasts or bacteria, and problems associated with fermenting thick, high-solids mashes.

■ Use of spent mash after alcohol distillation.

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