

FLAVOR COMPONENTS
OF
JERUSALEM ARTICHOKE TUBERS
(HELIANTHUS TUBEROSUS L.)

BY
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ABSTRACT

Jerusalem artichoke (Helianthus tuberosus L.) is a North American root crop with high carbohydrate yield. Potential uses of its tubers include production of fuel grade ethanol and food uses such as production of high fructose syrup, low caloric flour and a vegetable. The Jerusalem artichoke tubers (crop year 1981, 1982) used in this study were supplied by Canada Department of Agriculture Research Station, Morden, Manitoba. The moisture, carbohydrate, nitrogen, crude fat and ash contents of the fresh Jerusalem artichoke were 77.66%, 17.23%, 0.57%, 0.01% and 1.05%, respectively. Corresponding values for the dried Jerusalem artichoke were 6.50%, 72.01%, 2.30%, 0.40% and 4.20%, respectively. The flavor of Jerusalem artichoke has not been characterized, but may have prevented its food uses on a large commercial scale. Therefore, this study was designed to assess Jerusalem artichoke flavor by chemical and sensory techniques. Aroma of fresh Jerusalem artichokes was described by eight panelists as earthy, seven as grassy, four as sweet and two as woody, in a 15 member panel session. The taste was described as sweet by 12 out of 15 panelists. Volatile aroma compounds were isolated from the tubers by steam distillation and analyzed by GLC-MS. The principal compound identified was β -bisabolene present at a concentration of 71 ppm on a dry basis. This compound has a pleasant, balsam, woody odor. Other major compounds identified were: 1H-cycloprop(E)azulene, decahydro-1,1,7-trimethyl-4-methylene;

2,6,9,11-dodecatetraenal, 2,6,10-trimethyl-(E,E,E); tetradecanal; and 11,14-eicosadienoic acid, methyl ester. Non-volatile taste compounds, sugars and amino acids, were extracted from fresh Jerusalem artichoke with 80% ethanol. The three sugars identified were sucrose, fructose, and glucose which constituted 0.59%, 0.52% and 0.32% of fresh weight, respectively. Sixteen free amino acids were identified and they constituted 0.58% of the fresh tuber. Dried Jerusalem artichoke aroma was described by eight out of fifteen panelists as grassy, by seven as woody and earthy and by three as nutty. Taste was described as sweet by 12 out of 15 panelists and bitterness was also detected and lingered on as an after-taste. The principal aroma compound identified was β -bisabolene present at a concentration of 16 ppm on a dry basis. Major volatile compounds present in the fresh sample were also found in the dry sample and in addition 2-furanacetaldehyde, α -propyl- was identified. The contribution of the identified aroma and taste compounds to Jerusalem artichoke flavor is discussed using sensory data reported in the literature.

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CHAPTER 1

INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.) is a North American root crop long known to native Indians. The earliest record of the plant was a written account by Samuel de Champlain, who in 1603 saw in the hands of the welcoming Indians "some roots which they cultivate, that taste of artichoke." For the early Canadian settlers, Jerusalem artichoke tubers served as a staple winter food. The tubers were introduced to Europe soon after and received auspicious acceptance in the European diet. Throughout the 17th century, Jerusalem artichoke was an important food plant in North America and Europe. However, its popularity gradually faded away with the introduction of the potato from the southern regions of North America.

Only recently, has Jerusalem artichoke begun to stage a comeback, spurred chiefly by the discovery of its high carbohydrate yield and excellent performance in the production of fuel grade ethanol. However, there is also increasing interest in utilizing it as a food crop for: i) vegetable in salads and cooking; ii) production of high fructose syrup; and iii) production of flour. The production of both Jerusalem artichoke syrup and flour are still in the experimental stage. Due to the increasing demand for fructose as a sweetener, Jerusalem artichoke syrup is predicted to be a viable product in the sugar market. The flour produced by dehydration and milling of Jerusalem artichoke tubers has a low caloric value because inulin and related poly-

fructans, the primary carbohydrates in the tubers, cannot be digested by human beings. This flour can be used in bakery or pasta products for low caloric purposes. However, it is anticipated that the demand for Jerusalem artichoke flour will be relatively small compared to the syrup. The presence of a green, earthy flavor in the flour discouraged its use as a food ingredient on a large commercial scale. The fresh tuber has been marketed as a specialty vegetable, but again the demand is low. Considering the many different ways in which the tuber can be used in cooking, it is surprising that it does not appear more often on our table. There seems to be a reluctance to accept the flavor of the fresh tubers. Therefore, the goal of this study was to identify the possible flavor components in both the fresh and dried tubers. This project had the following objectives: i) sensory evaluation by flavor description; ii) isolation and identification of some aroma compounds; and iii) isolation and identification of some taste compounds.

CHAPTER 2

REVIEW OF LITERATURE

2.1 AGRONOMIC ASPECTS OF JERUSALEM ARTICHOKE

Jerusalem artichoke (Helianthus tuberosus L.) is native to North America and grows well on the agriculturally productive land of the Prairie provinces in Canada. It is a close relative of the sunflower (Helianthus annus L.), but unlike the sunflower it is cultivated not for extraction of oil from the seeds, but for its edible tubers.

Jerusalem artichoke grows five to twelve feet tall and is upright. The height and the degree of branching vary with the variety. Yellow flowers are borne at the terminal points of the main stems and branches. Tuber shape varies from round, knobby clusters to long, smooth single tubers. Tuber color can be either white, red or purplish. Generally, the white varieties produce higher yields per hectare.

Tubers are formed early in the growing season and the plant will reach maturity in about 130 days. Tuber weight increases rapidly during the late stages of maturity. Bacon and Loxley (1952) observed that total tuber weight per plant increased from an average of 200 g in August to 600 g or more in October and November. This increase was due partly to the increase in the number of tubers, but more to the increase in tuber size. Although Jerusalem artichoke has higher frost tolerance than crops like wheat and corn, premature heavy frost may retard or prevent growth of tubers resulting in very poor carbohydrate yields. The tubers can be harvested from the ground in late

October or they can remain underground and be harvested prior to sprouting in the spring. Seeds are produced from the flowers of Jerusalem artichoke, but the common means of propagation is through the planting of tubers.

This crop does not require a high level of management. Cultivars seem to have more effect on yield than do management practices. Dorrell and Chubey (1977) reported both fertilization and irrigation had little effect on yields under non-stress conditions. Stauffer et al. (1975) reported that disease problems affecting plant growth were not encountered during several years of investigation. Jerusalem artichoke requires little or no weeding and appears to be immune to pests. However, diseases such as white mold and soft rot are often encountered during storage after harvest because the thin epidermal layer on the tubers makes them more vulnerable to disease organisms than other root crops. Treatment of cold stored tubers with mold inhibitor reduces spoilage; other means of storage such as dehydration and freezing inhibit spoilage (Hoehn, 1982).

2.2 POTENTIAL USES OF JERUSALEM ARTICHOKE TUBERS

The potential of this crop in terms of carbohydrate yield is shown in Table 1. Comparing the carbohydrate yields of Jerusalem artichoke, corn and sugar beets, it is evident that Jerusalem artichoke with a yield of 5,211 kg/ha out-performs corn and sugar beets having yields of 4,853 kg/ha and 3,171 kg/ha,

TABLE 1 CARBOHYDRATE YIELD DATA FOR JERUSALEM
ARTICHOKE, CORN AND SUGAR BEET

Country	Carbohydrate yield (Kg/ha)
JERUSALEM ARTICHOKE TUBERS	
Canada	1,793 - 15,243
U.S.	3,844 - 7,173
Netherlanda	3,584 - 6,052; 7,262
France	2,443 - 7,621
Germany	1,210 - 3,216
U.S.S.R.	1,597 - 2,398; 9527 ^a
Mean value - 5,211	
CORN KERNELS	
Canada	3,631 - 4,147
U.S.	3,373
Mean value - 3,717	
SUGAR BEETS	
Canada	4,920 - 6,612
U.S.S.R.	3,026
Mean value - 4,853	

^a Sunflower-Artichoke hybrid

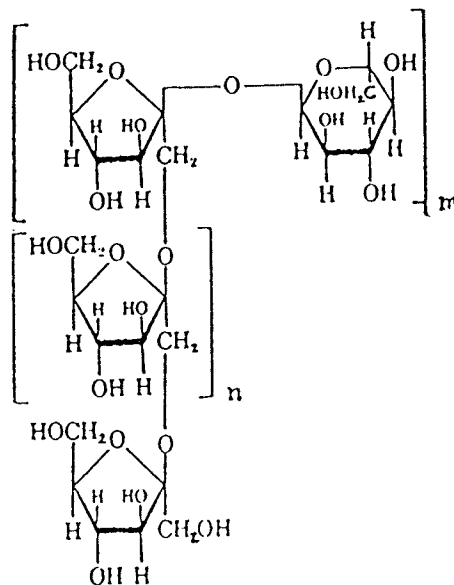
Source : Fleming and GrootWassink, 1979

respectively. The tubers are rich in carbohydrates, mainly inulin and related polyfructans (Bacon and Edelman, 1951). These are polymers of fructose with $\beta(2 \rightarrow 1)$ linkages, terminating in a glucose molecule (Fig. 1), and the degree of polymerization (DP) ranges from 2 (sucrose) to about 35 (inulin).

Due to the high yield of fermentable carbohydrate per unit area, Jerusalem artichoke is an attractive energy crop for production of fuel grade ethanol. Williams and Ziobro (1982) indicated potential ethanol yields from the tubers could approach 56 hL/ha. Apart from ethanol production, there is increasing interest in food uses for Jerusalem artichoke. Most simple of all, the tubers can be eaten as a raw vegetable. the crispy texture resembles that of water chestnuts. They can also be sautéed with parsley, boiled or fried. With some creative cooking ideas, they make an excellent accompaniment to meats. However, it is anticipated that the market for this purpose will be limited. Alternative potential uses are: i) production of high fructose syrup; and ii) manufacture of a low calorie flour.

Since fructose is the major component of Jerusalem artichoke carbohydrates, the tubers would appear to be a good starting material for production of high fructose syrup. Preparation of fructose or high fructose syrup has been reported by several researchers (Fleming and GrootWassink, 1979; Yamazaki, 1954). Processing involves extraction of inulin and polyfructans, purification of extract, followed by acid or enzyme hydrolysis

FIG. 1 INULIN MOLECULE



m represents the terminal sucrosyl group.

n represents the fructofuranose moiety,

$$[n = 1 \rightarrow (\text{approx.}) 35 .]$$

to obtain their constituent sugars, fructose and glucose. In one procedure by Hoehn (1982), syrups with 70-80% solids of which 72-85% was fructose, were produced. At present, the beverage industry has the greatest demand for high fructose syrup, however, other sectors of the food industry such as confectionary, bakery and dairy products are showing increasing interest in this product. Fructose is the sweetest of all naturally occurring sugars. It is 1.5 to 1.7 times sweeter than sucrose (Stauffer et al., 1975). Thus, to obtain the same sweetness intensity in a food product, the quantity of fructose required is less than if sucrose is the sweetener of choice. Obviously, Jerusalem artichoke is a cheap and easily available source for this sugar.

Another special characteristic of inulin and polyfructans is that they cannot be digested by human beings (Stauffer et al., 1975). For this reason, it is possible to manufacture a low calorie flour from Jerusalem artichoke tubers. Major steps in the flour making process are: i) washing; ii) slicing; iii) dehydration; and iv) milling or grinding. Jerusalem artichoke flour has a caloric value of 8.4 kJ/g (Hoehn, 1982) compared with 15.2 kJ/g and 15 kJ/g for wheat and rye flours, respectively. The flour may be employed as a low calorie filler in products such as low calorie pasta products where part of the wheat flour is replaced by Jerusalem artichoke flour. The foreseeable market for Jerusalem artichoke flour is relatively small compared to that for Jerusalem artichoke syrup.

However, the flour is technically less demanding to produce than Jerusalem artichoke syrup and the low calorie property of the flour may be of interest to "weight-watchers". Potentially useful as it may seem, there is a flavor problem associated with Jerusalem artichoke flour. Flavor of the flour has been described as earthy by Romig (1979). For Jerusalem artichoke flour to be a successful product, its flavor must be bland, similar to that of wheat flour. Consequently, there is a need to eliminate or reduce the earthy flavor.

2.3 DEFINITION OF FLAVOR

Flavor is a complex of the total sensations perceived whenever a food or drink is consumed. In 1969, the U.S. Society of Flavor Chemists proposed the following definitions (Heath, 1978):

Flavor is the sensation caused by those properties of any substances taken into the mouth which stimulates one or both of the senses of taste and smell and/or the general pain, tactile and temperature receptors in the mouth.

A flavor is a substance which may be a single chemical entity or a blend of chemicals of natural or synthetic origin whose primary purpose is to provide all or part of the particular flavor or effect to any food or other product taken into the mouth.

Food flavor is composed of a great many interrelated compounds to give an overall flavor sensation. The flavor scheme in Fig.2 was proposed by Solms (1971). Compounds of the odor class are very often products of special chemical

FIG. 2 COMPOSITION OF FOOD FLAVORS,
TENTATIVE SCHEME

FLAVOR SENSATION	LOW BOILING COMPOUNDS AND HIGH BOILING COMPOUNDS WITH ODOR EFFECT	ODOR
	POTENTIATOR AND SYNERGISTS	
	NONVOLATILE COMPOUNDS WITH TASTE AND TACTILE EFFECT	TASTE

Source : Solms, 1971

reactions which are linked with the ripening process or processing of the raw material. The number of compounds with odor effect are numerous but they are present in relatively small amounts in a food product. On the other hand, compounds of the taste fraction are generally related to the main metabolism of the raw material; they may occur in small number but large quantities (Solms, 1971).

2.4 FLAVOR OF JERUSALEM ARTICHOKE TUBERS

The first written reports concerning Jerusalem artichoke and the use of its tubers as a vegetable by Indians in Canada and the eastern United States appeared around 1600. Marc Lescarbot, a French lawyer who visited America in 1607, described the tubers as "a certain kind of root as big as one's fist, very good to eat." On the contrary, Hariot in 1585 wrote "a white kind of root ... their taste was not as good to our seeming as of the other, and therefore their place and manner of growing not so much cared for by us." Seemingly, differences in opinion existed about the flavor of the tubers. Its flavor has also been described as similar to a Brazil nut with a coconut celery after-taste (Routley, 1977).

Despite the versatility of the tuber in cookery, it did not maintain its popularity for long. With the introduction of potatoes, consumption of Jerusalem artichoke tubers declined. Occasionally, it is marketed as a fresh vegetable in specialty markets. Noodles containing Jerusalem artichoke flour as an ingredient can be found in health food stores. Cultivation of

this crop is limited to home gardener scale. Apparently, potatoes have definite advantages over Jerusalem artichoke tubers. The carbohydrates in Jerusalem artichoke tubers, mainly inulin and polyfructans, do not swell like starch. Consequently, cooked Jerusalem artichoke tubers remain extremely watery. In frying, a crispy coating does not develop as on potatoes. Without cold storage, tubers rot quickly. The most critical drawback is the characteristic flavor of Jerusalem artichoke which does not seem to appeal to the western palate. This is reflected in the comments from a few herbalists describing the flavor as "melancholy", "filthy", "loathsome" and "a meat more fit for swine than man" (Heiser, 1976).

Since flavor plays an important role in the acceptance of a food, it is necessary to improve the flavor appeal of the Jerusalem artichoke. As for consumption of the raw tuber, its unique flavor must simply be accepted. Consumer education about the advantages of Jerusalem artichoke tubers could be beneficial for successful marketing of the raw product. With Jerusalem artichoke flour, some form of processing technique can be implemented to overcome this flavor obstacle. One possible approach in solving this problem is to analyze the flavor components in the tubers. Then, based on results obtained from the analysis, processing techniques can be designed to reduce or eliminate undesirable flavor components of the tubers. This knowledge could be useful, particularly in the production of a bland-flavored flour from Jerusalem artichoke.

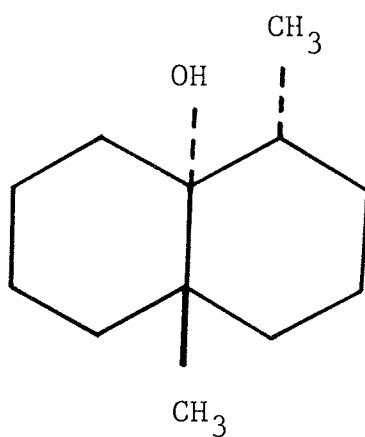
2.5 AROMA COMPOUNDS INDIGENOUS TO JERUSALEM ARTICHOKE TUBERS

The flavor of a food is derived from its odor and taste. Yet of the two, odor has a greater influence on flavor than does taste. Very often we can recognize a particular food simply by its distinct aroma or odor. Without aroma, food will be experienced primarily in terms of four taste sensations: sweet, sour, bitter and salty (Gorman, 1975).

Literally, there are thousands of volatile aroma compounds in nature. The broad aroma spectrum in foods is a result of different combinations of such compounds. Therefore, analysis of the aroma fraction is usually the first and most important step taken toward the understanding of food flavor.

There is little information compiled in the literature on volatile flavor compounds in the tubers. Kameoka et al. (1977) steam distilled fresh flowers, leaves and stems of Jerusalem artichoke to give an essential oil of 0.08%, 0.05% and 0.03% yield, respectively, the main component being β -bisabolene. However, aroma compounds in the tubers were not analyzed. Romig (1979) reported that flour made from Jerusalem artichoke tubers had an earthy flavor and the earthy component could be geosmin but no data was offered to substantiate this claim. Geosmin (trans-1,10-dimethyl-trans-9-decalol), a volatile metabolite of various Actinomycetes (Gerber and Lechevalier, 1965) and blue-green algae (Safferman et al., 1967), can be found in soil and water. The structure of this compound is illustrated in Fig. 3. The odor of this compound has been described as earthy, musty and muddy. It has caused

FIG. 3 STRUCTURE OF GEOSMIN,
TRANS-1,10-DIMETHYL-TRANS-9-DECALOL



odor problems in water supplies (Medsker et al., 1968); and fish tainted with geosmin were not marketable (Yurkowski and Tabachek, 1974). Tyler et al. (1978, 1979) isolated geosmin from beet roots. While geosmin is an undesirable odor contaminant in fish and water, its presence in beet roots is essential for the characteristic aroma of beets.

Due to lack of published information on aroma compounds in Jerusalem artichoke tubers, it may be worthwhile to look at root crops similar to Jerusalem artichoke. One such crop is chicory, a root with inulin as the major storage carbohydrate. Sannai et al. (1982) steam distilled the air dried chicory root to obtain an essential oil with a faintly sweet odor. Over 90% of the essential oil consisted of long chain fatty acids such as palmitic acid, linoleic acid, linolenic acid, oleic acid and n-pentadecanoic acid. Other compounds identified were phenylacetic acid (0.2%) with a honey-like aroma and benzothiazole (0.7%) with a peanut-like odor. No compounds with an earthy odor were found.

2.5.1 POSSIBLE PROCESSING EFFECTS ON JERUSALEM ARTICHOKE TUBER FLAVOR

The aroma of fresh food is imparted by terpenes, lactones, alcohols, aldehydes, ketones, acids, esters, amines and sulfur compounds occurring naturally in food. On the other hand, processed food develops its characteristic aroma from naturally occurring flavor compounds and also from aroma compounds that are generated from chemical reactions that occur during processing. One of the most important flavor producing reactions

in non-enzymic browning during heat processing is the well known Strecker degradation of α -amino acids. This reaction involves the deamination of α -amino acids by specific carbonyl compounds such as sugars to yield aldehydes and ketones containing one carbon atom less than the original acid. These volatile products are present in trace amounts, but their impact on food aroma is hardly insignificant. The aroma of many roasted meat products, coffee, roasted peanuts, baked goods and chocolate is derived from non-enzymic browning. During heat processing, sugars can also decompose spontaneously to form volatile aroma compounds such as aldehydes, furans, oxygenated furans, and acids (Walter and Fagerson, 1968).

The above flavor producing reactions could possibly occur during dehydration of Jerusalem artichoke tubers for flour-making. The extent of these reactions would depend on the drying temperature, moisture content and nature of the tuber. Apart from new flavor compounds being generated, naturally occurring aroma compounds could be lost through vaporization or chemical alteration due to heating involved in the process of dehydration. Therefore, the aroma of fresh Jerusalem artichoke tubers would to a certain degree differ from that of the dried tuber. Also, pretreatments and different drying temperatures would produce dried tubers with different flavor notes.

2.6 NON-VOLATILE COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS AND THEIR CONTRIBUTION TO TASTE

Composition of Jerusalem artichoke tubers as reported by Flemming and GrootWassink (1979) is shown in Table 2. The tubers have a high moisture content (80%) which is a common characteristic of vegetables. Inulin and related polyfructans account for 68.4-83.1% of the dry matter. Nitrogen content is about 1.45-1.50% of dry weight, of which only 50% is associated with proteins. The remainder of the dry matter is made up of 0.5% lipid, 4.7% ash, and 13.1% cellulosic material. Phenolic compounds have been identified, but the amount is not reported (Paupardin, 1965).

2.6.1 CARBOHYDRATES IN JERUSALEM ARTICHOKE TUBERS: INULIN, POLYFRUCTANS AND SUGARS

The carbohydrate fraction of the tubers is known to contain a homologous series of polyfructans ranging in size from sucrose (DP 2) to inulin (DP 35), along with monosaccharides such as glucose and fructose (Edelman and Jefford, 1963). Sweetness of the tubers could be imparted by glucose, fructose and sucrose. Low DP fructans e.g. DP 3 may possibly contribute to sweetness. For example, raffinose, a carbohydrate with three sugar units, has a sweetness of 22 relative to 100 for a 10% sucrose solution (Nieman, 1958). Kearsley et al. (1978) found that sweetness of the glucose syrup fraction increased with a decrease in average molecular weight of the dextrans. A similar relationship may exist for polyfructans in Jerusalem artichoke tubers - sweetness will gradually disappear as the DP of the polyfructans increases.

TABLE 2 COMPOSITION OF JERUSALEM ARTICHOKE TUBERS

Component	Composition	
	Fresh wt. (%)	Dry wt. (%)
Water	80	-
Carbohydrate	15.2-28.8	68.4-83.1
Nitrogen	0.29-0.31	1.45-1.55
Lipid	0.1	0.5
Ash	1.1	4.7
Cellulose and hemicellulose	2.62	13.1

Source : Flemming and GrootWassink, 1979

Therefore, inulin and high DP fructans in the tubers would be tasteless.

The amount of glucose, fructose, sucrose and low DP fructans varies during growth and storage. Free reducing sugars (glucose and fructose) remain fairly constant, constituting 1% or less of the total carbohydrate, but sucrose increases during storage (Bacon and Loxley, 1952). Bacon and Edelman (1951) suggested that this shift in carbohydrate composition was caused by a redistribution of fructose residues resulting in an increase in the amount of smaller molecular size polyfructans (DP 2, 3, 4, 5) at the expense of the high DP polyfructans. Consequently, stored tubers will likely have a sweeter taste than those harvested immediately after the growing season (Routley, 1970). Similarly, Kakhana et al. (1970) also noted a partial hydrolysis of inulin to polyfructans of six or less units when the tubers overwintered in the soil. These low DP polyfructans accounted for 7.6% of total carbohydrate in September and 34.6% the following April.

2.6.2 NITROGEN-CONTAINING COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS

Jerusalem artichoke tubers contain 0.29-0.31% nitrogen on a fresh weight basis. The nature of the nitrogenous fraction in Jerusalem artichoke tubers has not been elucidated. Nitrogen in living matter is usually derived from proteins, peptides, free amino acids and nucleotides. These compounds can contribute to flavor in a complex manner through taste interactions such as synergism and potentiation. A general review of the

taste effects of these substances will reveal the possible roles they may have in the taste of Jerusalem artichoke.

2.6.2.1 PROTEINS AND PEPTIDES

The taste of proteins is generally bland because size and structure prevent a taste sensation from being obtained. Naturally occurring short-chain peptides can elicit taste sensations such as bitter, sour, salty and sweet (Solms, 1971). Short chain peptides in food can also arise from acid, enzyme or heat hydrolysis of proteins during processing. In sake, soya sauce and miso, peptides contribute to a favorable balance of taste (Kirimura et al., 1969). Recently, much attention has been focused on bitter tasting peptides for their presence in food is often considered undesirable.

The concept of Q-value for predicting bitterness of peptides has been accepted by many scientists working in this field. Bitterness of a peptide is related to the average hydrophobicity (Q) of its amino acid side chains (Ney, 1971). Average hydrophobicity (Q) can be calculated using the following equation:

$$Q = \frac{\sum \Delta F}{n}$$

where: Q = average hydrophobicity

$\sum \Delta F$ = summation of transfer free energy for the amino acid side chain in the peptide

n = the number of amino acids in the peptide

Ney (1971) proposed the following hypothesis:

- i) all peptides having an average hydrophobicity

of 1,300 cal/residue or lower are not bitter in taste;

- ii) all peptides with average hydrophobicity higher than 1,400 cal/residue are bitter in taste;
- iii) no prediction can be made for peptides with values between 1,300-1,400 cal/residue; and
- iv) the sequence of amino acids in a peptide has no influence on bitterness.

This rule only applies to peptides with molecular weights up to 6,000 Daltons. Peptides having molecular weights greater than 6,000 Daltons generally do not have taste (Ney, 1979).

2.6.2.2 FREE AMINO ACIDS AND 5'-RIBONUCLEOTIDES

Taste bearing compounds such as free amino acids and 5'-ribonucleotides play a predominant role in the flavor of vegetable, meat, seafood and dairy products. However, no apparent interest has been demonstrated in the flavor potential of such compounds in Jerusalem artichoke tubers.

The taste of free L- α -amino acids, with the exception of glutamic and aspartic acid, can be described by one of the four basic tastes i.e. sweet, sour, bitter, salty. On the other hand, glutamic acid, aspartic acid and their corresponding salts, monosodium glutamate (MSG) and monosodium L-aspartate, have a unique, meaty taste. This taste is called "umami" in Japanese and is also typical of the taste of 5'-ribonucleotides such as 5'-inosinate (IMP) and disodium 5'-guanylate (GMP). 5'-ribonucleotides have very weak umami taste compared to the umami amino acids. However, it is interesting to note that the

two groups of umami substances have synergistic effects on each other (Yamaguchi, 1979).

Many vegetables are rich in glutamic acid. In potatoes, the amount of free amino acids and 5'-nucleotides are 0.07% and 0.01% respectively. The significance of glutamic acid, aspartic acid, 5'-AMP and 5'-IMP in the formation of potato taste has been discussed by Solms and Wyler (1979). Delicate carrot taste is attributed to the presence of glutamic acid, various amino acids and the buffer action of these amino acids (Otsuka and Take, 1969). The importance of umami taste substances to food flavor is emphasized by the frequent use of MSG in cooking to enhance flavor properties. Filer et al. (1979) investigated the effects of MSG on food using a panel of 180 people. The experimental results were summarized as follows:

- i) MSG has no effect on the aroma of foods;
- ii) MSG increases total taste intensity of food but its effect on the individual intensities of saltiness, sweetness, sourness and bitterness is very small;
- iii) MSG enhances continuity, mouth fullness, impact, mildness and thickness; and
- iv) MSG increases preference or palatability of foods.

Since the Jerusalem artichoke tuber is also a vegetable, amino acids, particularly glutamic acid, may be essential taste compounds for the characteristic taste of the tuber.

2.6.3 PHENOLIC COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS

Phenolic compounds in Jerusalem artichoke tubers have been examined to a limited extent. p -hydroxybenzoic, chlorogenic,

vanillic, genteric, p -coumaric, caffeic and ferulic acids were identified in the tubers by Paupardin (1965). These compounds are only associated with non-meat sources. Taste properties of phenolic acids have been classified as astringent and bitter. The taste threshold and occurrence of phenolic acids in root crops such as potato and chicory are shown in Table 3. Mondy et al. (1971) reported a significant correlation between phenolic content and perceived bitterness in potatoes. Arai et al. (1966) concluded that the sour, bitter and astringent phenolic fraction isolated from defatted soy flour had a significant influence on soy flour flavor. However, not all phenolic compounds have undesirable flavor properties. Many of them such as allyl cinnamate, ethyl vanillin and phenethyl cinnamate have widespread application in the flavor industry.

In addition to flavor, these compounds can cause darkening due to oxidation by polyphenol oxidase. Color formation in the production of Jerusalem artichoke syrup have been associated with the phenolic browning reaction. Flemming and GrootWassink (1979) have successfully produced a clear, colorless syrup using sulfur dioxide to suppress color formation and charcoal to remove color impurities. However, little investigation has been done on Jerusalem artichoke flour regarding this aspect.

2.6.4 LIPIDS IN JERUSALEM ARTICHOKE TUBERS

Lipids account for 0.1% of the fresh weight of Jerusalem artichoke tubers. Upon dehydration, lipid content increases to 0.5%. Little is known about the composition of this

TABLE 3 PHENOLIC COMPOUNDS IN CHICORY, POTATO AND
JERUSALEM ARTICHOKE

Phenolic acid	Taste threshold ^a (ppm)	Type of vegetables		
		Chicory ^a (mg/Kg)	Potato ^a (mg/Kg)	Jerusalem artichoke ^b (mg/Kg)
Caffeic	90	767	280	+
Ferulic	90	0.5	28	+
Sinapic	-	0.5	3	
<i>p</i> -Hydroxybenzoic	40	11		+
Vanillic	30	0.5		+
<i>p</i> -Coumaric	40		4	+
Chlorogenic	-		+	+
Genteric	-			+

^a Maga, 1978

^b Paupardin, 1965

+ Plus sign indicates the presence of the phenolic acid
but the amount was not reported.

fraction. Generally, lipids such as triglycerides and waxes are tasteless, mainly because they are insoluble in water. Free fatty acids such as formic, acetic, propionic and butyric acid taste sour. However, as chain length increases, taste will disappear due to decreasing solubility. Sessa et al. (1976) isolated three phosphatidylcholines from defatted soy flakes and concluded that bitter taste was an inherent characteristic of these compounds.

Lipids are present in trace amounts in vegetables. It is generally assumed that this fraction has little or no influence on their taste. As in other vegetables, Jerusalem artichoke tubers have a very low lipid content. Based on the above assumption, the contribution of lipids to taste of the tubers is likely insignificant.

2.7 FLAVOR ANALYSIS

Flavor is a very important factor governing the selection of food we consume. Consequently, utilization of ingredients with high flavor quality is one of the major concerns in the manufacture and sale of a food product. A better understanding of flavor chemistry very often proves helpful in achieving this aim. In order to gain insight into the flavor profile of a food, it is necessary to isolate and identify the flavor compounds. As far as nature is concerned, flavor or aroma substances constitute a very minor part of the total product. Thus, isolation of these substances is often difficult. A number of methods have been developed for this purpose. Each

of them has its own advantages and disadvantages, which will be discussed later. Once the flavor fraction has been isolated, attention is given to separation and identification of the individual components responsible for its make-up.

At present, the most preferred means of separation and identification is gas liquid chromatography-mass spectrometry (GLC-MS). Separation by other chromatographic techniques such as liquid-liquid, liquid-solid, thin layer, paper-partition and ion-exchange have been used to some extent. In addition, fractional distillation, crystallization and sublimation procedures have been employed by some researchers. All, of course, can be very useful, and one is often the procedure of choice in a given situation. However, for universality, GLC is difficult to surpass due to its versatility, speed and resolution power.

2.7.1 ISOLATION OF AFOMA COMPOUNDS FROM FOOD PRODUCTS

Preparation of the volatile fraction for flavor analysis is a very critical aspect of flavor research. There are many procedures for obtaining the flavor fraction from food. Vegetable flavor compounds are very difficult to examine chemically for most of the vegetable is usually water, and flavor substances are present in a few parts per million. Usually the vegetable is chopped or blended into a pulpy or powdery form and then subjected to isolation. The following are commonly used methods for obtaining flavor fractions from plant materials.

Traditionally, steam distillation has been widely used for isolation of flavor volatiles from plant materials. The

sample is subjected to long periods of heating by steam. Flavor volatiles (essential oil) are carried off with the steam, and passed through water-cooled condensers. The oil, being water-insoluble will separate out on condensation and can be easily collected. However, labile organic compounds in the food can decompose on heating, thus creating artifacts. Despite this disadvantage, it is still the preferred method of many researchers. Other more sophisticated distillation techniques have been developed such as vacuum distillation and molecular distillation. High vacuum employed in these techniques helps to minimize damage to thermolabile compounds.

Another method to isolate flavor substances is by liquid-liquid extraction or liquid-solid extraction. The food is placed in direct contact with an organic solvent that will extract flavor compounds from the food. Ethanol, hexane, benzene, petroleum ether and methylene chloride have been used as extracting solvents. The extract is concentrated by evaporation of the solvent leaving behind the oleoresin. There has been an enormous amount of flavor work completed using this method. However, its short-comings include: i) extraction of non-flavoring material along with flavor compounds; ii) incomplete extraction of flavor compounds; and iii) loss of volatile flavor compounds during concentration.

A newer isolation technique is headspace sampling for analysis of volatile flavor compounds in the vapor phase above the food material. Injection of a gas sample directly from the headspace into the GLC has a appealing simplicity.

Unfortunately, this often proves unsatisfactory because the concentration of flavor volatiles in the headspace is very low and only the highly volatile compounds are detected. Therefore, concentration of aroma compounds from a large headspace volume is required to obtain detectable quantities on the GLC. With headspace analysis, sampling and concentration can be achieved in one step by means of some trapping procedures. There are three main trapping methods: i) cryogenic; ii) adsorption on charcoal; and iii) adsorption on porous polymers. Increasing amounts of flavor work have been carried out using porous polymers because of the convenience of this technique over steam distillation and solvent extraction (Barnes et al., 1981). The sample is placed in a closed system. An inert gas (N_2) is swept across it for a specified time period, carrying the volatiles to a trap packed with porous polymer. The flavor volatiles will adsorb to the polymer. After trapping is completed, the volatiles can be desorbed either by heat or by elution with an appropriate solvent (Murray, 1976; Barnes et al., 1981). The conditions for sampling of flavor volatiles are mild, usually at room temperature, and contact is brief. This greatly reduces the possibility that artifacts will be formed. There are a variety of porous polymers available for sampling headspace vapors. Those commonly used are Porapak P, Porapak Q, Chromosorb 101, Chromosorb 102, Chromosorb 103, Chromosorb 105, and Tenax GC.

Increasing sophistication of analytical techniques has enabled more advanced research in food flavor composition which has led to the identification of many important aroma compounds

in food. What has not been done to an appreciable extent is establishing correlations between chemical findings and sensory qualities. Many of the compounds isolated may have no sensory effect at all. Questions such as the following are often left unanswered: Does the identified compound have any sensory properties? If so, what are the nature of these properties? What combination of flavor components results in the typical aroma of the food product? Sensory techniques such as flavor profiles, odor recognition and difference tests can be useful for these studies. However, it is important to note that a meaningful flavor correlation is not always easy to establish partly due to the ambiguity of sensory terminology. Terms such as floral, ethereal, rancid, musty, etc. may have very different meanings to different observers based on their own sensory experiences. As a result, the ability of flavor chemists to identify flavor compounds has far surpassed the effort to establish meaningful flavor correlations. However, it is only after careful examination of the sensory properties of isolated compounds that we can understand their contribution to the flavor of food from which they are derived.

CHAPTER 3

MATERIALS AND METHODS

MATERIALS

3.1 JERUSALEM ARTICHOKE TUBERS

Jerusalem artichoke tubers (Helianthus tuberosus L.) were supplied by Dr. B. B. Chubey, Canada Department of Agriculture Research Station, Morden, Manitoba. The tubers (crop year 1981, 1982) were harvested in late October and stored in plastic bags under refrigeration at 2-4°C. The study of geosmin was carried out on tubers of the crop year 1981. The other experiments were conducted on tubers of the crop year 1982.

3.2 CHEMICALS

A pure geosmin sample was obtained through the courtesy of Dr. Hochstetler (Givaudan Corporation, New Jersey). Bisabolene (a mixture of α , β , and γ isomers) was obtained from Givaudan Corporation, Montreal. Carbowax 20 M and 5% SP-2100/0.1% SP-401 were purchased from Supelco, Inc., Pennsylvania. Dowex 50W-X8 (hydrogen-form), 20-50 mesh, was purchased from J. T. Baker Chemical Co., New Jersey. Sep-pak C₁₈ cartridges were obtained from Waters Associates, Inc., Ontario. All other chemicals and reagents used in this study were of analytical grade.

METHODS

3.3 DEHYDRATION OF JERUSALEM ARTICHOKE TUBERS

Twenty kilograms of sound, fresh Jerusalem artichoke tubers were spray-washed and sliced 0.5 cm thick. The slices were spread

evenly to a depth of 5.0 cm in the drying compartment of a fluid bed dryer (Fitz mill Model 150). Drying was carried out at 60°C for 3 h until the moisture level of the slices was reduced to approximately 6%. The moisture loss was determined using the Ohaus moisture balance. The dried Jerusalem artichoke tuber slices were stored in odor-free plastic freezer bags at room temperature.

3.4 FLAVOR DESCRIPTION OF FRESH AND DRIED JERUSALEM ARTICHOKE TUBERS

Aroma and flavor-by-mouth evaluations of fresh and dried tubers were carried out with a free choice description. Evaluation forms are shown in Appendix A. The experiment was conducted using a panel of 15 people with experience in sensory work. Two panel sessions were held. Aroma evaluation was carried out on the first day and flavor-by-mouth evaluation on the following day.

For evaluation of the aroma of fresh Jerusalem artichoke, the tubers were diced into 0.5 cm cubes and put into 15 fl. oz. glass jars (2/3 full). Similarly, the dried slices were filled 2/3 of the capacity of the jars. The glass jars were covered and left at room temperature for 2 h before evaluation. Single samples of fresh and dried samples tubers were randomly present to each panelist. They were asked to sniff the samples, report overall aroma intensity as weak, moderate or strong, and identify aroma note(s) that could be perceived.

Flavor-by-mouth evaluation was also carried out on fresh and dried samples. The fresh tubers were sliced 0.5 cm thick,

and three pieces were placed onto each odorless plastic dish. The dried tuber slices were ground into a fine powder and water was added (1 g of flour : 3.6 mL of water) to form a slurry. The amount of water added brought the solids content of the dried sample to the same level as that of the fresh sample in order to eliminate taste differences due to higher solids content in the dried sample. Fifteen millilitres of the slurry was placed into each odorless plastic container. A straw, for drawing up the slurry, was pierced through the lid of each container. Single samples of fresh and dried tubers were randomly presented of each panelist for evaluation at room temperature. The panelists were asked to report taste note(s) that could be perceived and the intensity of each taste note.

All evaluations were done in an odor and noise-free panel room with individual booths for each panelists. Red light was used to mask color differences that might affect judgment.

3.5 ISOLATION AND IDENTIFICATION OF GEOSMIN

3.5.1 GROWTH OF OSCILLATORIA CORTIANA AND EXTRACTION OF GEOSMIN

Geosmin was isolated from blue-green algae, Oscillatoria cortiana, according to the method of Tabachek and Yurkowski (1976). O. cortiana was inoculated into 6 Erlenmyer flasks, each containing 1 L of medium No. 11 (Hughes et al., 1958). Cotton plugs were used to stopper the culture flasks. The algal culture was incubated at 25°C for 6 weeks. The contents of the flasks were combined and filtered to remove the algae. The filtered medium (6 L) was transferred to a boiling flask for

steam distillation and 600 mL of the distillate was collected in a receiver packed in ice (0°C). The distillate was extracted twice with 30 mL of methylene chloride. The methylene chloride extract was reduced to ~2 mL under nitrogen, transferred to a 10 mL glass vial and stored under refrigeration until further analysis.

3.5.2 GAS CHROMATOGRAPHY OF THE ODOROUS EXTRACT FROM OSCILLATORIA CORTIANA

Separation of the compounds in the extract from O. cortiana was carried out on a Varian Model 3700 Gas chromatograph, equipped with a dual flame ionization detector and a Hewlett Packard Model 3390A Integrator. One microlitre of the sample was injected into the GLC. The column and operational conditions are given in Table 4. Retention time of the geosmin peak on the chromatogram of O. cortiana was compared to that of an authentic sample of geosmin.

TABLE 4 GAS CHROMATOGRAPHY OF GEOSMIN: COLUMN AND OPERATIONAL CONDITIONS

Column length	- 3.66 m x 2 mm ID, stainless steel
Support material	- 100/120 Supelcoport
Liquid phase	- 5% SP-2100/.1% SP-401
Injector temperature	- 190°C
Detector temperature	- 210°C
Oven temp. program	- 75°C to 200°C @ 6°C/min
Nitrogen flow rate	- 25 mL/min
Hydrogen flow rate	- 20 mL/min
Air flow rate	- 300 mL/min
AFS	- 1×10^{-11}

3.5.3 ANALYSIS OF EARTHY ODOR IN JERUSALEM ARTICHOKE TUBERS: GEOSMIN

One kilogram of fresh Jerusalem artichoke tubers was washed and 400 mL of juice was obtained from the tubers using a Braun juice maker. The juice was steam distilled in the same manner as for O. cortiana filtrate to give 40 mL of distillate. The distillate was extracted twice with 4 mL of methylene chloride and concentrated to ~20 uL under nitrogen. The concentrate was analyzed on the GLC. Column and operational conditions were listed in Table 4. The column, however, was shortened to 1.82 m and 1 uL of the concentrate was injected into the gas chromatograph. Peak retention times on the chromatogram of the concentrate from Jerusalem artichoke tubers were compared to that of a pure geosmin sample.

3.6 ISOLATION AND IDENTIFICATION OF VOLATILE AROMA COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS

3.6.1 STEAM DISTILLATION OF JERUSALEM ARTICHOKE TUBER SAMPLES

Steam distillation was performed on the following five samples of Jerusalem artichoke tubers:

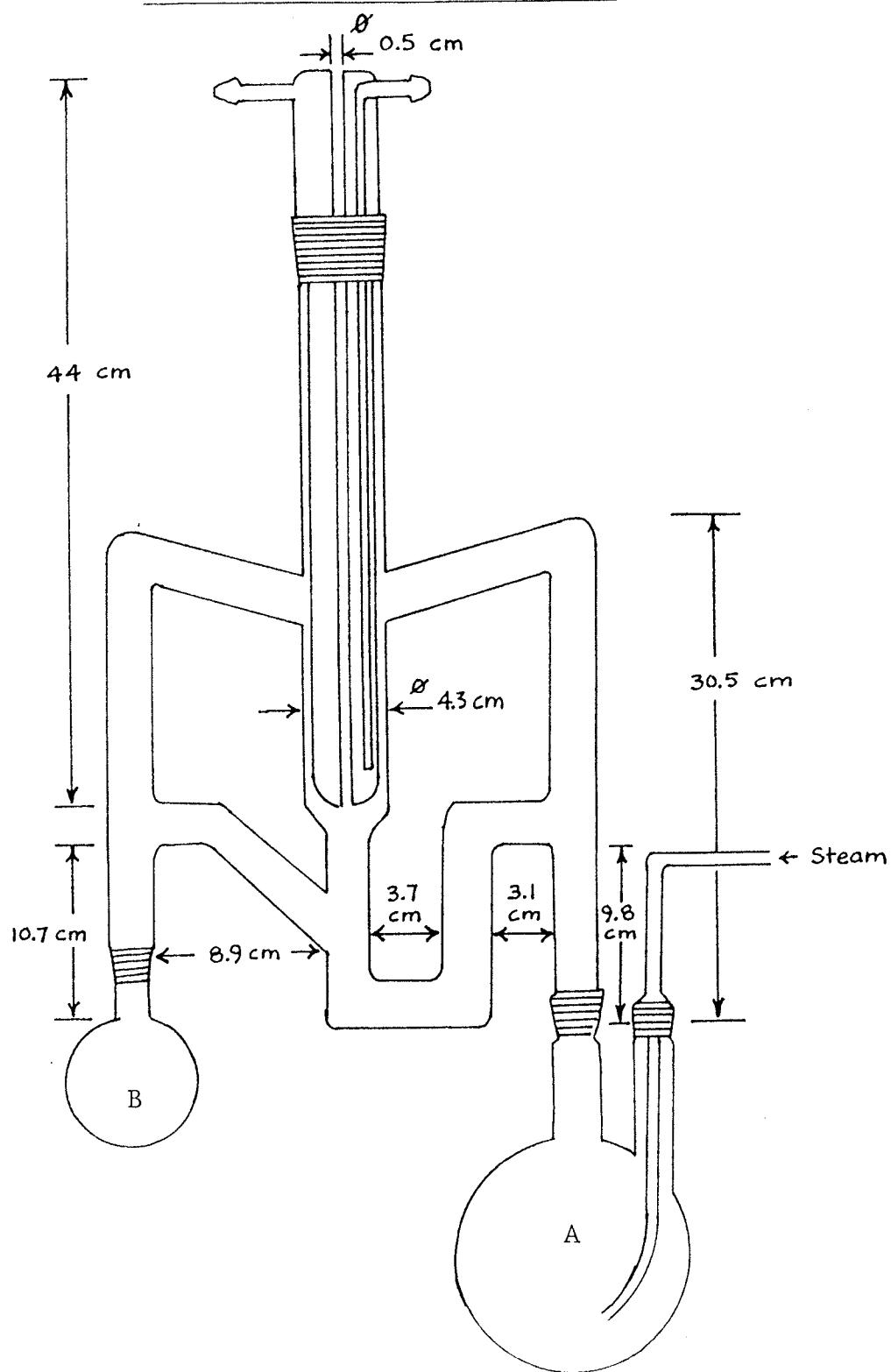
- i) 200 g of fresh tubers;
- ii) 200 g of the outer region (peel) of the fresh tubers;
- iii) 200 g of the inner region of the fresh tubers;
- iv) 50 g of dried tubers; and
- v) 20 g of ethanol extracted dried tubers.

The fresh Jerusalem artichoke tubers were washed, whole tubers. The outer region (peel) of the fresh tubers was obtained by

removing the outer skin area of the tuber which amounted to approximately 1/3 of the total tuber weight. The remaining portion of the tuber was taken as the inner region (2/3 of the total tuber weight). The purpose of analyzing flavor compounds in the inner and outer regions was to determine the distribution of flavor compounds within the tubers. The dried tubers were prepared by dehydration as described in Section 3.3. Ethanol extracted dried tuber samples were prepared by the method described in Section 3.9.1 - the residue remaining after extraction of sugars and nitrogenous compounds with 80% ethanol was dried at 60°C.

The apparatus employed for steam distillation of Jerusalem artichoke tuber samples was similar to that used by Romer and Renner (1974) and is illustrated in Fig. 4. The sample was placed in a 1 L round bottom flask (A) and 1 g of calcium carbonate was added to neutralize the organic acids. The flask containing the sample was attached to the steam distillation extraction head. Pentane (160 mL) was placed in a 250 mL round bottom flask (B) and attached to the solvent arm of the head. Distillation of the sample was carried out for 2 h under atmospheric pressure. The extract was concentrated to ~20 uL by removal of pentane in a rotary evaporator. The concentrated extracted (steam volatile oil) was stored under refrigeration in a 2 mL glass vial until further analysis.

FIG. 4 STEAM DISTILLATION APPARATUS



3.6.2 GAS CHROMATOGRAPHY OF STEAM VOLATILE OILS FROM JERUSALEM ARTICHOKE TUBER SAMPLES

GLC of steam volatile oils was carried out on a Varian Model 3700 Gas Chromatograph equipped with a Vista Model 401 chromatography data system. The column and operational conditions are listed in Table 5. Injected volume was 0.5 uL. Quantitation of β -bisabolene in the sample was accomplished by measuring its peak area relative to the peak area of an external standard of bisabolene.

TABLE 5 GLC OF STEAM VOLATILE OIL FROM JERUSALEM ARTICHOKE TUBER: COLUMN AND OPERATIONAL CONDITIONS

Column length	- 1.82 m x 2 mm ID, stainless steel
Support material	- chromosorb W (high performance), 100/120 mesh
Liquid phase	- 5% Carbowax 20 M
Injection temperature	- 190°C
Detector temperature	- 210°C
Oven temperature program	- 80°C to 200°C at 3°C/min and hold at final temperature for 20 min
Carrier gas (N ₂) flow rate	- 25 mL/min
Hydrogen flow rate	- 20 mL/min
Air flow rate	- 300 mL/min
AFS	- 4 x 10 ⁻¹⁰

3.6.3 IDENTIFICATION OF STEAM VOLATILE COMPOUNDS IN FRESH AND DRIED JERUSALEM ARTICHOKE TUBERS BY GLC-MS

GLC-MS analysis was carried out on the steam volatile oils from fresh and dried Jerusalem artichoke tubers. The combined GLC-MS apparatus (Finnigan Model 4000) was equipped with an Incos 2300 Data Acquisition System. The column was a 30 m x 0.25 mm glass capillary coated with Carbowax 20 M. The column oven temperature was programmed from 60-220°C at 4°C/min. Nitrogen flow rate was 30 mL/min. The end of the column was interfaced with the mass spectrometer via a platinum capillary tube (0.1 mm ID). The mass spectra were recorded at 70 eV, the electron current was 500 uA, the temperature of the ion source and the interface was 250°C, and the scanning speed was 1 s from 40 to 650 m/e. Mass spectra identifications were confirmed by computer assisted matching of literature spectra.

3.7 PROXIMATE ANALYSIS OF JERUSALEM ARTICHOKE TUBERS

Proximate analyses for determination of moisture, kjeldahl nitrogen, crude fat and ash in fresh and dried Jerusalem artichoke tubers were performed in triplicate according to AOAC methods, (1975).

3.8 DETERMINATION OF TOTAL WATER-SOLUBLE CARBOHYDRATES IN JERUSALEM ARTICHOKE TUBERS

One hundred grams of Jerusalem artichoke tubers were extracted with 3 L of water at 80°C for 50 min. The extract was freeze-dried. The lyophilized sample was suitably diluted

with water (10-70 ug/mL of water) and aliquots were analyzed by the method described by Dubois et al. (1956). Fructose was used as the standard for construction of the calibration curve.

3.9 ANALYSIS OF FREE AMINO ACIDS, PEPTIDES, PROTEINS AND SUGARS IN FRESH JERUSALEM ARTICHOKE TUBERS

Extraction of nitrogenous compounds (free amino acids and ethanol-soluble peptides) and sugars was carried out according to the method of Alabran and Mabrouk (1973).

3.9.1 EXTRACTION OF NITROGENOUS COMPOUNDS AND SUGARS

Two hundred grams of sound fresh Jerusalem artichoke tubers were washed and dried by blotting with paper towels. Then the tubers were diced and placed into a heavy-duty Waring blender with 850 mL of 80% ethanol which was previously cooled to about -10°C . The contents were blended for 2 min and 1 g of calcium carbonate was added to the slurry to neutralize organic acids to prevent sugar hydrolysis. The slurry was filtered through Whatman No. 41 filter paper. The resulting filtrate was kept cool at -10°C while the residue was extracted for 16 h with 80% ethanol in a Soxhlet apparatus. All ethanol extracts were combined and concentrated in a rotary evaporator. The concentrated extract was frozen at -10°C and freeze-dried.

3.9.2 FRACTIONATION OF JERUSALEM ARTICHOKE TUBER ETHANOLIC EXTRACT INTO SUGAR AND NITROGENOUS FRACTIONS

The lyophilized sample was dissolved using a minimum amount

of water. The solution was percolated through a Dowex 50W-X8 (hydrogen-form) resin (1 g of extract/4 g of resin). The column was washed with 1 L of distilled deionized water to remove sugars. The eluate was frozen and freeze-dried. This sugar fraction was stored in a desiccator under room temperature. The free nitrogenous compounds were desorbed from the column using 1 L of 2 N ammonium hydroxide. The eluate was concentrated in a rotary evaporator at 40°C, frozen and freeze-dried. The lyophilized nitrogenous fraction was stored in a desiccator under room temperature until further analysis.

3.9.3 ANALYSIS OF THE SUGAR FRACTION

The lyophilized sugar sample was diluted suitably with water (7-10 mg/mL). The solution was purified with Sep-pak C₁₈ cartridges. The purified solution was analyzed for sugars with a Waters Associates Model 440 High Performance Liquid Chromatograph (HPLC). Conditions for operation of the HPLC are specified in Table 6. Quantitation of the sugars was obtained by integrating the areas under the curves and dividing by the response of standard sugars compounds.

TABLE 6 HPLC OPERATIONAL CONDITIONS FOR SEPARATION OF SUGARS IN JERUSALEM ARTICHOKE TUBER EXTRACT

Column	- HPX-87H Organic Acid Analysis, 300mm x 7.8 mm
Eluant	- 0.01 N H ₂ SO ₄
Flow rate	- 0.6 mL/min
Temperature	- 45°C
Detector	- Differential Refractive Index @ 8X

3.9.4 AMINO ACID ANALYSIS

The nitrogenous fraction obtained from ethanol extraction was analyzed on the amino acid analyzer. A first aliquot was analyzed on the amino acid analyzer with no acid hydrolysis (RUN 1). The second aliquot was analyzed on the amino acid analyzer after acid hydrolysis (RUN 2). Acid hydrolysis was carried out with 6 N HCL for 24 h at 110°C and under vacuum. The amounts of free amino acids and ethanol-soluble peptides were calculated as follows:

Free amino acids = RUN 1

Ethanol-soluble peptides = RUN 2 - RUN 1

The amount of total proteinaceous material (or total amino acids) in the fresh tubers was obtained by amino acid analysis after acid hydrolysis of a sample of tubers (RUN 3). The term "total proteinaceous material or total amino acids" refers to the total amount of proteins, peptides and free amino acids. The amount of protein was calculated as follows:

Protein = RUN 3 - RUN 2

Amino acid analyses were carried out using a Beckman Model



121 Automatic Amino Acid Analyzer. The Beckman modification of the single column procedure of Spackman et al. (1958) was applied. Specification for sample treatment, reagents, resins, columns, temperatures and buffer flow rates were those given in the instrument manual. Sodium citrate was used as the sample and column buffer. The respective concentrations of the amino acids were calculated by the use of elution times and integration constants of selected individual standards.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FLAVOR DESCRIPTIONS OF FRESH AND DRIED JERUSALEM ARTICHOKE TUBERS

To begin the flavor study of Jerusalem artichoke, a flavor description panel was carried out to evaluate the taste and aroma of fresh and dried tuber samples. Panelists were permitted to describe flavor characteristics with a free choice description. Aroma evaluation was conducted first, followed by taste evaluation. The flavor descriptions for fresh and dried tubers are summarized in Table 7. The individual comments of panelists are recorded in Appendix B.

The overall aroma intensity of the fresh sample was described as moderate to weak. The aroma notes reported were earthy, grassy, sweet and woody. The taste of the fresh tubers was described as weak to moderately sweet. Jerusalem artichoke flavor was also associated with potato, carrot and coconut. No after-taste was detected.

The overall aroma intensity of the dried sample was described as strong. This result suggested that there was an increase in the overall aroma of the dried sample as compared to that of the fresh sample. Terms used to describe the aroma of the dried Jerusalem artichoke were grassy, woody, earthy and nutty. The woody note was mentioned by seven out of fifteen panelists for the dried sample and only two out of fifteen panelists for the fresh sample. Thus, it appeared that the woody note was more pronounced in the dried tubers than in the

TABLE 7 FLAVOR DESCRIPTIONS OF FRESH AND DRIED
JERUSALEM ARTICHOKE TUBERS

Sensory characteristic	Flavor descriptor	Frequency ^a
FRESH JERUSALEM ARTICHOKE		
Aroma	Earthy	8
	Grassy	7
	Sweet	4
	Woody	2
Flavor-by-mouth	Sweet	12
	Carrot-like	2
	Potato-like	1
	Coconut-like	1
DRIED JERUSALEM ARTICHOKE		
Aroma	Grassy	8
	Woody	7
	Earthy	7
	Nutty	3
Flavor-by-mouth	Sweet	12
	bitter	5
	earthy and grassy	4
	After-taste: slightly bitter and astringent and earthy	8

^a The number of panelists in a 15 member panel that detected the flavor note.

fresh tubers. In addition, nutty was mentioned only in the dried sample. Taste of the dried tubers was described as moderately sweet. Bitterness was detected and lingered on as an after-taste.

Differences between the flavor of fresh and dried tubers might have been caused by the dehydration process. During dehydration, some volatile aroma compounds occurring naturally in the tubers could have been lost through vaporization or chemical alteration; new aroma compounds could have been generated through Strecker degradation. Changes occurred to the porosity, structural components and moisture of the dried tissue during dehydration could be a contributing factor to the characteristic flavor of the dried sample. Therefore, it is not surprising that the dried tubers did not possess the same flavor notes as the fresh tubers.

Although certain descriptive terms have become well established by use and understood by the majority, the mere reading of the flavor descriptions of Jerusalem artichoke gives a limited picture as to the complex flavor of the tubers. The major obstacle in conveying a sensory impression is to come up with standard terminology. For example, the term "green" which is commonly used in describing aroma can range from freshly cut grass to that of damp leaf or even garden herbs; all of which are quite different yet collectively classified as green. However, reference to some well-defined substances or chemicals which display the particular odor or flavor can be helpful (Durr, 1979; Meilgaard, 1982). Finally, these flavor description are very

subjective judgments, therefore, they should only be regarded as a basis or a guide for discussion.

4.2 ANALYSIS OF VOLATILE AROMA COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS

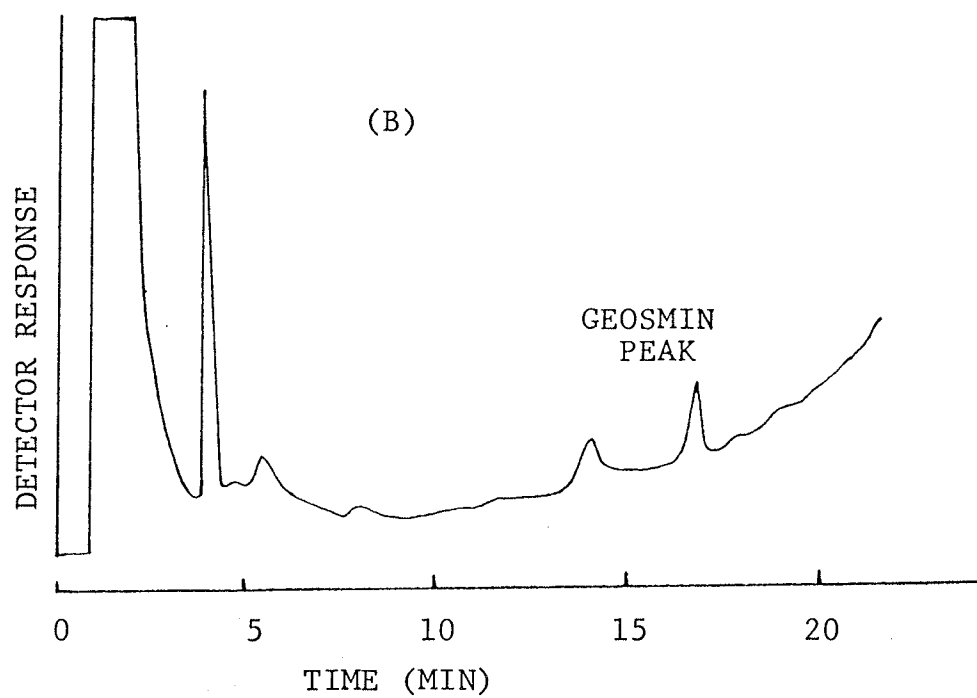
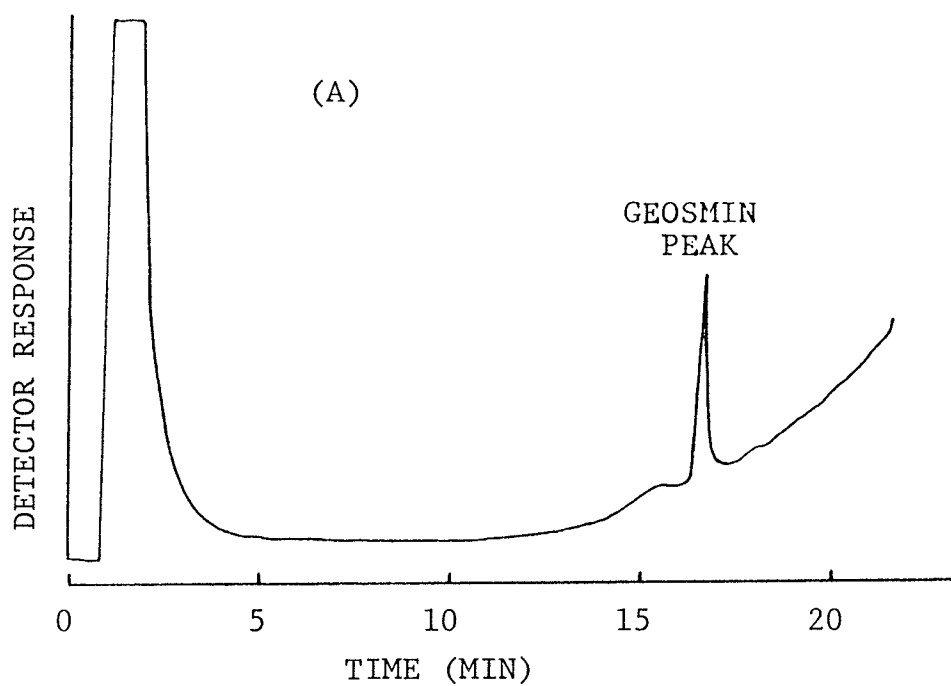
Chemical analysis of flavor compounds in Jerusalem artichoke was carried out to identify compounds that contribute to the unique flavor of the tubers. This work was accomplished by steam distillation, GLC and MS.

4.2.1 ANALYSIS OF EARTHY ODOR IN JERUSALEM ARTICHOKE TUBERS: GEOSMIN

Referring to the flavor descriptions, earthy was one of the distinctive odor notes in the fresh and dried tubers. Romig (1979) reported that the earthy odor was imparted by a compound called geosmin. However, no data was offered to substantiate this claim. To confirm the presence of geosmin, it was necessary to obtain an authentic sample of geosmin for comparison. O. cortiana, a blue-green algae capable of producing geosmin, was cultured and the earthy odor was extracted from the growth medium. The odor extract was analyzed on GLC using an SP-2100 column and geosmin was present as shown in Fig. 5B. The retention time of geosmin from O. cortiana was compared to a pure geosmin sample obtained by chemical synthesis and the two were identical (Fig. 5A).

Extract from Jerusalem artichoke juice was prepared in the

FIG. 5 GAS CHROMATOGRAMS OF (A) AN AUTHENTIC
SAMPLE OF GEOSMIN AND (B) AN EARTHY ODOR
EXTRACT FROM OSCILLATORIA CORTIANA



same manner as from O. cortiana. GLC peak retention times of Jerusalem artichoke extract were compared to that of geosmin. No peak having the same retention time as geosmin was found (Fig. 6A, 6B). Therefore, it was concluded that the earthy note in Jerusalem artichoke was not derived from geosmin.

4.2.2 VOLATILE AROMA COMPOUNDS IN FRESH JERUSALEM ARTICHOKE TUBERS

A volatile yellowish oil was obtained by atmospheric steam distillation of fresh Jerusalem artichoke tubers. GLC analysis of the steam volatile oil yielded ~40 peaks (Fig. 7) indicating that Jerusalem artichoke flavor may not be due to a single compound, but may be due to a mixture of many volatile components. Peak C, the major peak, accounted for 40.58% of the total GLC peak area on the chromatogram (Table 8). This compound was identified to be β -bisabolene by MS (Fig. 8) and GLC retention evidence. The concentration of β -bisabolene in fresh tubers was 16 ppm or 71 ppm on a dry basis.

Bisabolene is a colorless, slightly viscous oil, soluble in alcohol but insoluble in water. The molecular weight of the compound is 204. Bisabolene can exist in three isomeric forms (Fig. 9), but only the β form was found in Jerusalem artichoke tubers. The aroma of bisabolene (a mixture of the three isomers) is described as a pleasant, balsam, woody odor (Givaudan Corporation, 1983). Referring to the aroma description of fresh Jerusalem artichoke, woody was one of the descriptive terms used by the panelists. β -Bisabolene was very likely the source of

FIG. 6

GAS CHROMATOGRAMS OF (A) AN AUTHENTIC
SAMPLE OF GEOSMIN AND (B) AN ODOR EXTRACT
OF FRESH JERUSALEM ARTICHOKE TUBERS

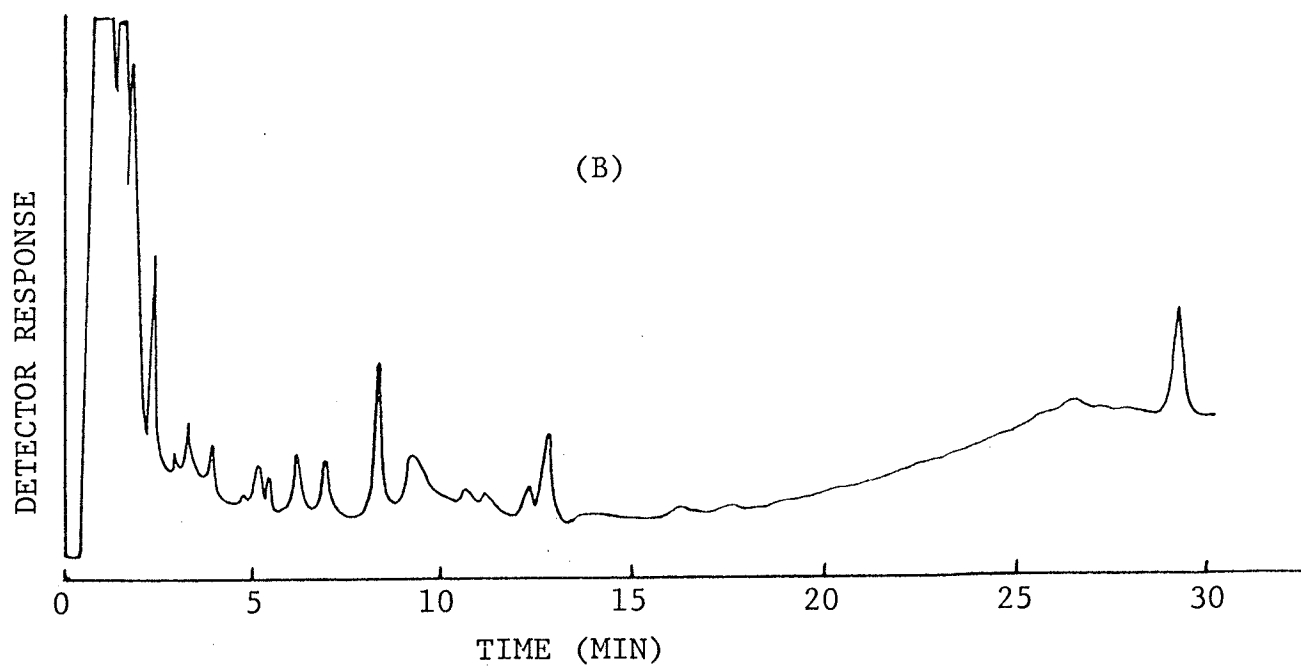
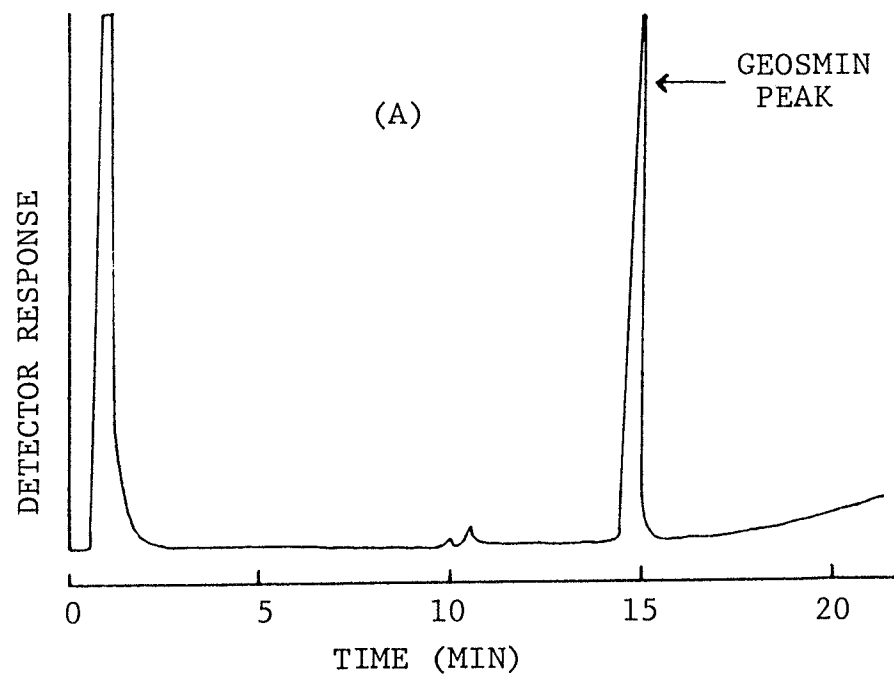


FIG. 7

GAS CHROMATOGRAM OF STEAM VOLATILE OIL FROM FRESH WHOLE
JERUSALEM ARTICHOKE TUBERS

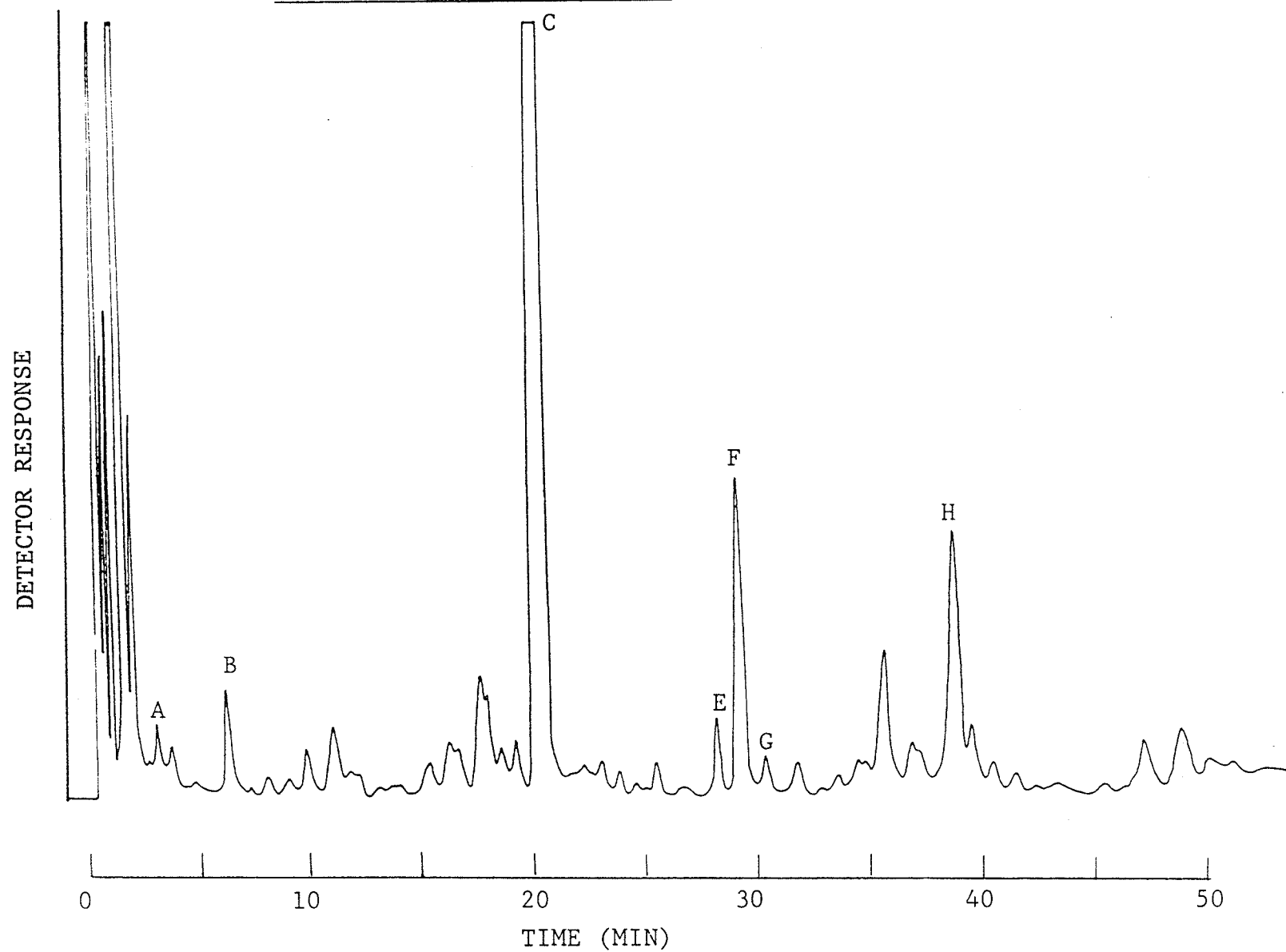


TABLE 8 COMPARISON OF MAJOR PEAK AREA PERCENTAGES FROM THE GAS CHROMATOGRAMS
OF FRESH WHOLE TUBERS, DRIED TUBERS, OUTER REGION AND INNER REGION OF
FRESH TUBERS

Peak	Compound	Fresh tubers (%) ^a	Dried tubers (%) ^a	Outer region of fresh tubers (%) ^a	Inner region of fresh tubers (%) ^a
A	not identified	0.28	2.22	0.07	-
B	not identified	0.94	3.10	0.61	0.19
C	β -Bisabolene	40.58	9.39	26.47	68.01
D	2-Furanacetaldehyde, α -propyl-	-	1.74	0.30	-
E	1H-Cycloprop(E)azulene, decahydro- 1,1,7-trimethyl-4-methylene	1.86	1.52	2.92	0.85
F	2,6,9,11-Dodecatetraenal, - 2,6,10-trimethyl-(E,E,E)	2.64	3.13	1.76	2.44
G	Tetradecanal	1.13	1.83	2.83	1.01
H	11,14-Eicosadienoic acid, - methylester ^b	4.49	3.00	4.92	5.82
I	11,14-Eicosadienoic acid, - methylester ^b	-	3.63	-	-

^a as % of total GLC peak area

^b Peak I and peak H are geometric isomers.

FIG. 8

MASS SPECTRA OF (A) A COMPOUND ISOLATED FROM JERUSALEM
ARTICHOKE TUBERS AND (B) β -BISABOLENE STANDARD

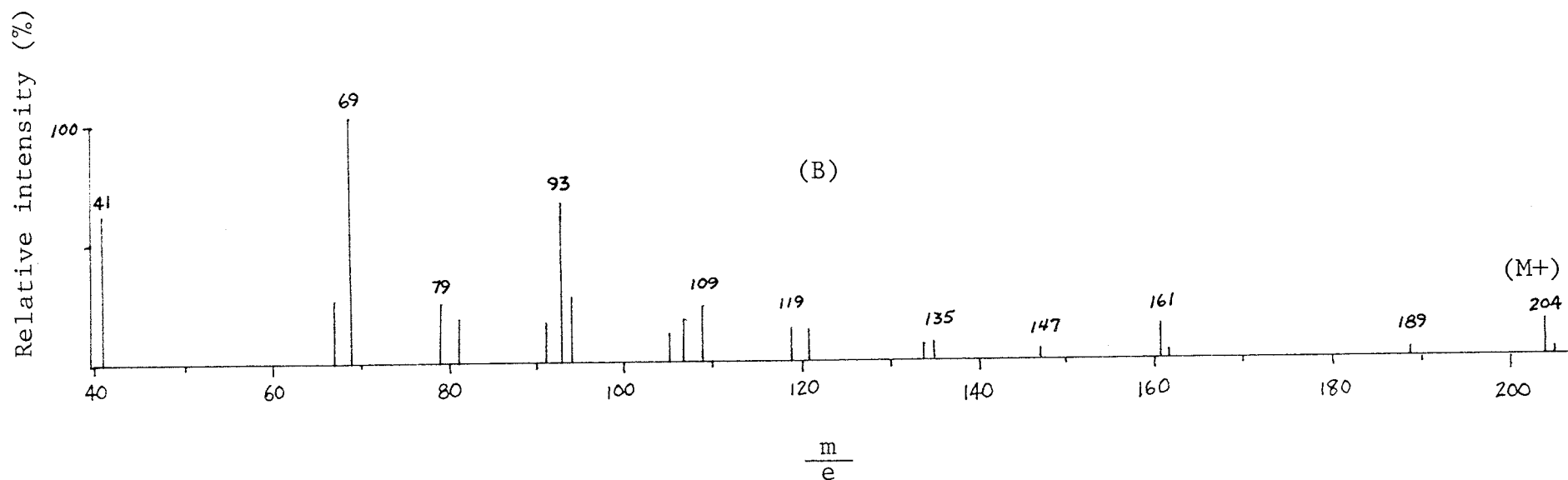
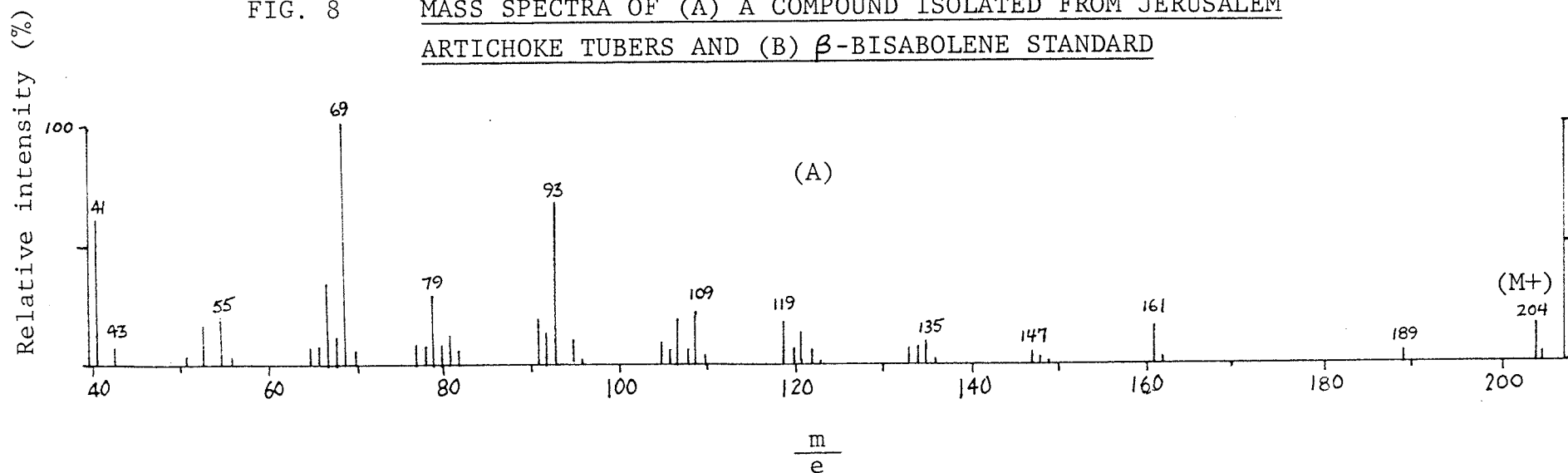
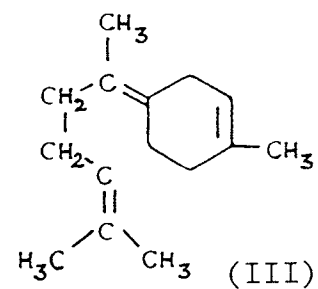
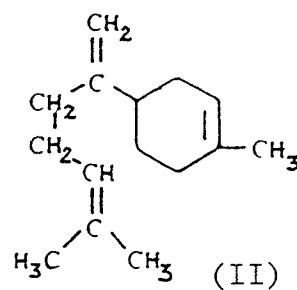
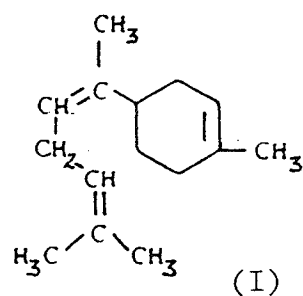


FIG. 9 STRUCTURES OF BISABOLENE ISOMERS

$C_{15}H_{24}$



- (I) α -BISABOLENE; 1-METHYL-4-(1,5-DIMETHYL-1,4-HEXADIENYL)-1-CYCLOHEXENE
 (II) β -BISABOLENE; 1-METHYL-4-(5-METHYL-1-METHYLENE-4-HEXENYL)-1-CYCLOHEXENE
 (III) γ -BISABOLENE; 1-METHYL-4-(1,5-DIMETHYL-4-HEXENYLIDENE)-1-CYCLOHEXENE

this odor note. Bisabolene is also used as flavoring compound in foods, soap, detergent and perfume. The concentrations of bisabolene in these products are shown in Table 9. Besides β -bisabolene, other major compounds that were identified in the fresh Jerusalem artichoke tubers were: 1H-cycloprop(E)azulene, -decahydro-1,1,7-trimethyl-4-methylene (peak E); 2,6,9,11-dodecatetraenal, 2,6,10-trimethyl-(E,E,E) (peak F); tetradecanal (peak G); and 11,14-eicosadienoic acid, methyl ester (peak H). Among the major compounds identified, only β -bisabolene is a terpenoid or monocyclic sesquiterpene. Generally this type of hydrocarbon compound has distinctive odor properties. As for the other major peaks, no information was found regarding their aroma. In general, azulenes are odorous compounds, and aldehydes have green, sour, buttery aroma notes (Coleman et al., 1981). Therefore, the presence of these compounds in the Jerusalem artichoke tuber may be of importance to its overall aroma. Other minor compounds that were identified are listed in Appendix C.

In order to study the distribution of the major volatile compounds within the fresh tubers, they were divided into inner and outer regions by hand-peeling. The inner and outer regions were subjected to steam distillation separately and the volatile oils were analyzed with a GLC (Fig. 10 and Fig. 11). β -Bisabolene (peak C) made up 68.01% of the total GLC peak area on the chromatogram for the inner region whereas only 26.4% of the total peak area of the outer region was due to β -bisabolene (Table 8). There were also minor variations among the other major peaks. This chemical finding indicated that the flavor constituents in the inner and outer region might differ.

TABLE 9 CONCENTRATION OF BISABOLENE IN FRAGRANCES
AND FOOD PRODUCTS

Products	Concentration (ppm)
FRAGRANCES ^a	
Soap	200
Detergent	20
Cream, lotion	50
Perfume	2,000
FOOD ^b	
Non-alcoholic beverages	3
Alcoholic beverages	3
Ice cream, ices	3
Candy	5
Baked goods	5
Gelatins and puddings	3
Preserves and spreads	3

^a Concentration of bisabolene in fragrances are taken from Opdyke, 1975.

^b Concentration of bisabolene in food products are taken from Givaudan Corporation, 1983.

FIG. 10

GAS CHROMATOGRAM OF STEAM VOLATILE OIL FROM THE OUTER
REGION (PEEL) OF FRESH JERUSALEM ARTICHOKE TUBERS

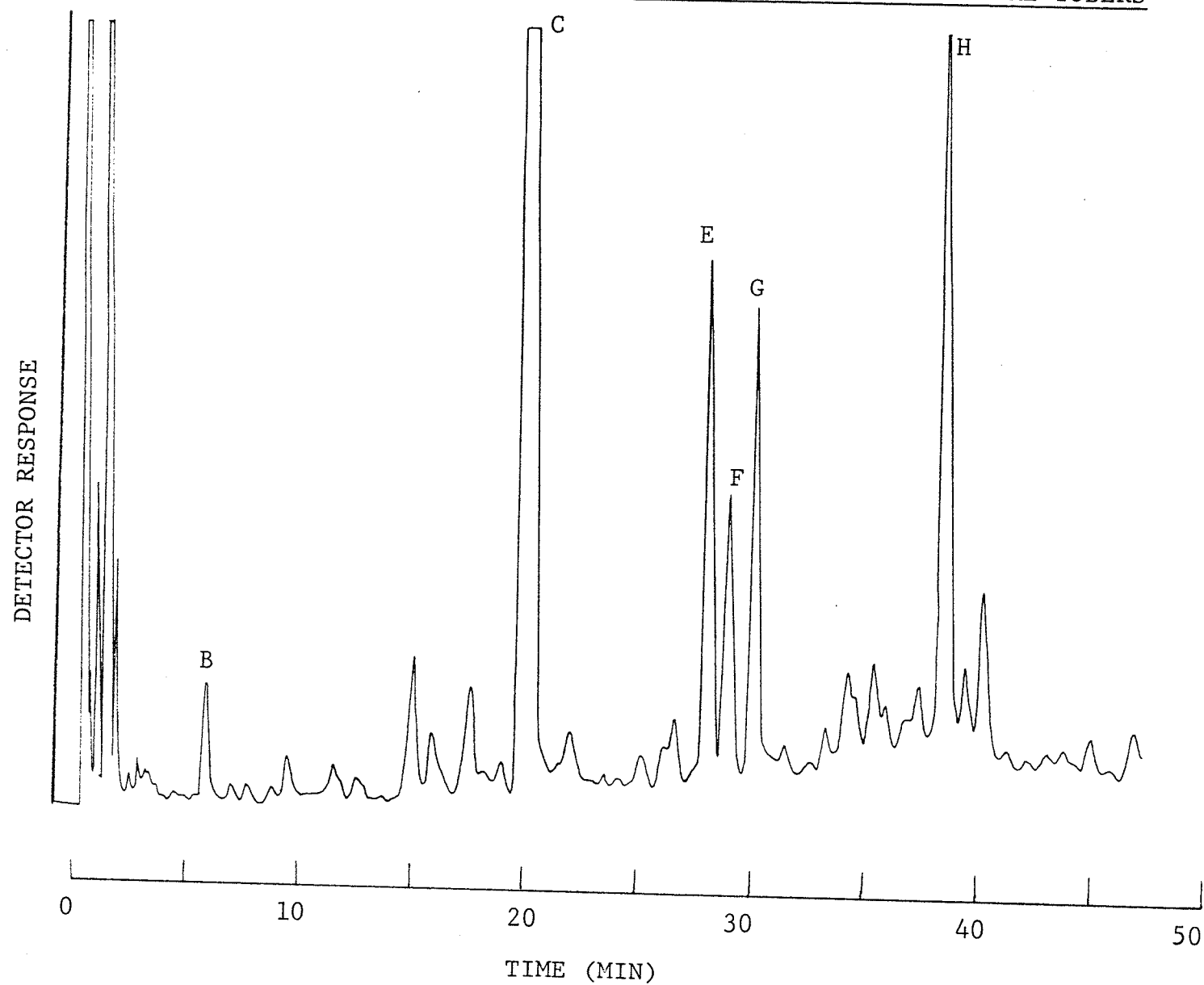
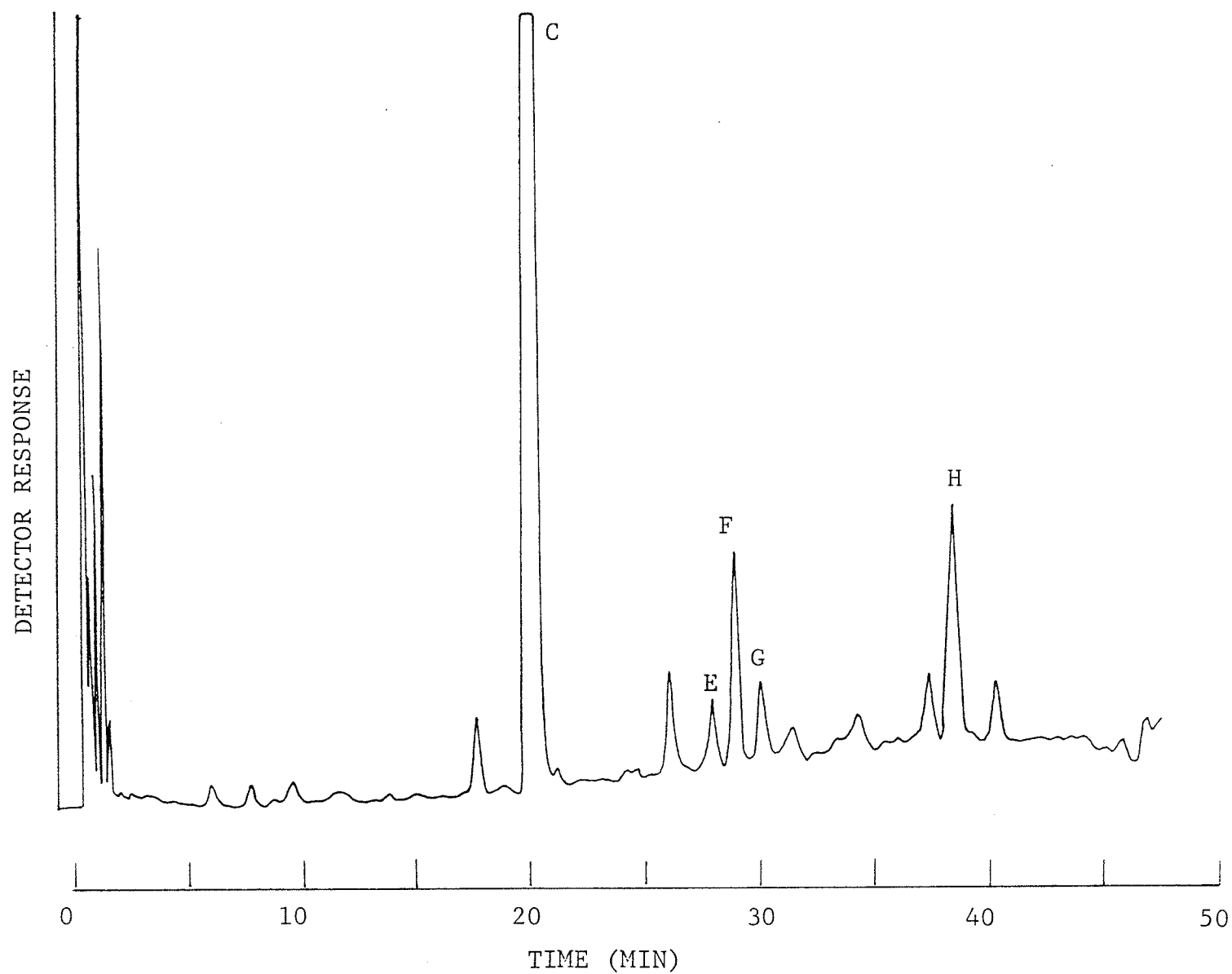


FIG. 11

GAS CHROMATOGRAM OF STEAM VOLATILE OIL FROM THE INNER REGION
OF FRESH JERUSALEM ARTICHOKE TUBERS

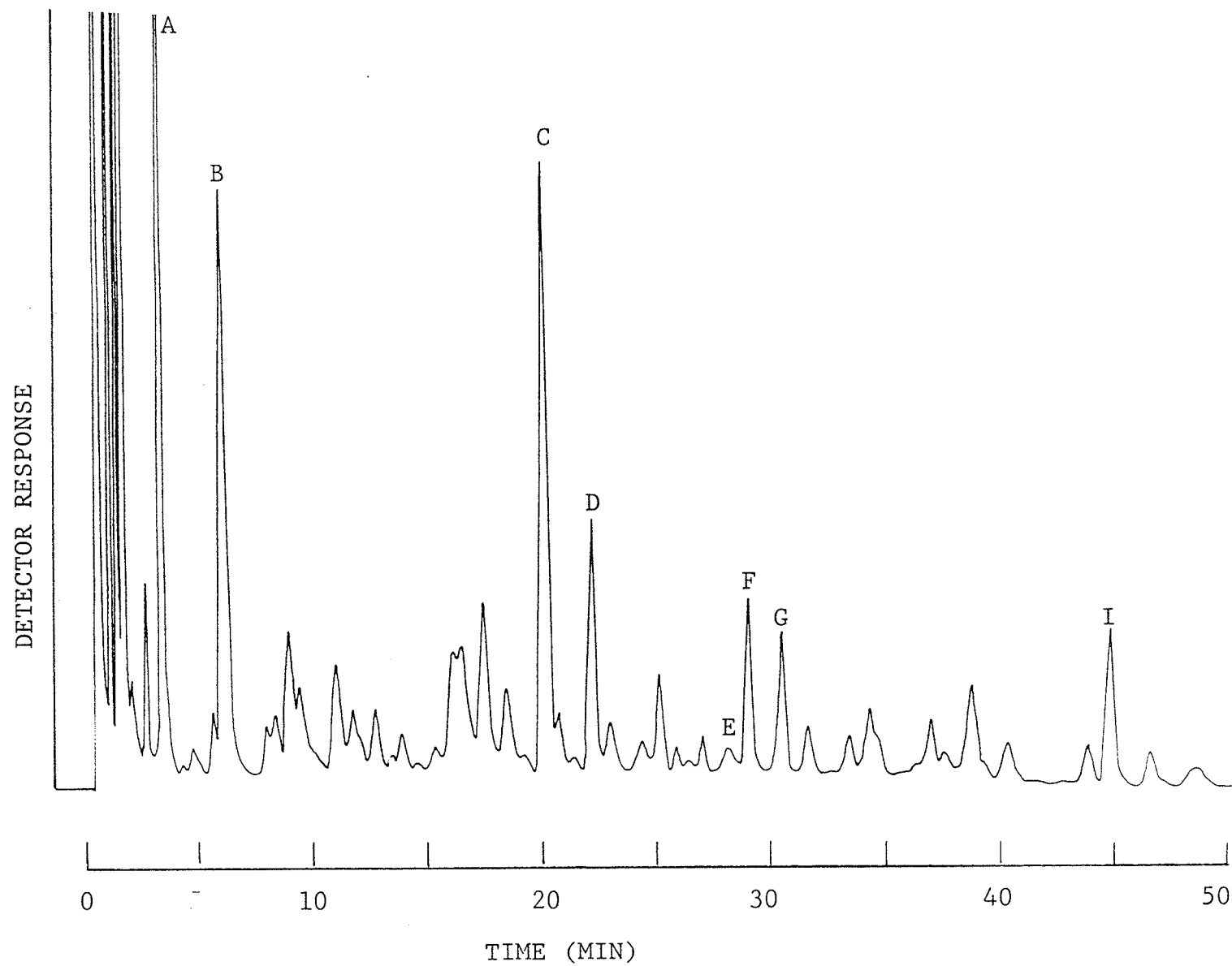


4.2.3 VOLATILE AROMA COMPOUNDS OF DRIED JERUSALEM ARTICHOKE TUBERS

Steam distillation of the dried Jerusalem artichoke tubers yielded a yellowish oil which was analyzed by GLC-MS. The GLC chromatogram of the steam volatile oil is shown in Fig. 12. The major component, β -bisabolene (peak C), accounted for 9.39% of total GLC peak area (Table 8). The concentration of β -bisabolene was 15 ppm in the dried tubers or 16 ppm on a dry basis. Comparison of β -bisabolene in the fresh and dried sample on a dry basis revealed that the amount of this compound in the fresh sample was four times that in the dried sample. During dehydration, β -bisabolene could be lost through evaporation or chemical alteration due to heating. β -Bisabolene, being a sesquiterpene, has a propensity to oxidize; being unsaturated, it also has a tendency to polymerize (Fischetti, 1980). In addition to the peaks identified in the fresh tubers, 2-furanacetaldehyde, α -propyl- (peak D) and 11,14-eicosadienoicacid,-methylester (peak I) were found in the dried tubers. Peak H and peak I were both identified as 11,14-eicosadienoicacid,-methylesters by MS. The two peaks could be the result of cis and trans conformations within the structures. Other minor compounds, identified in the dried tubers are listed in Appendix D. 2-Furanacetaldehyde, α -propyl- was very likely a product of non-enzymic browning. Peak A and peak B (both unidentified) accounted for 2.22% and 3.10% of the total GLC peak area, respectively (Table 8). These values were 9X and 3X higher than those present in the fresh tubers. The % GLC peak areas

FIG. 12

GAS CHROMATOGRAM OF STEAM VOLATILE OIL FROM DRIED
JERUSALEM ARTICHOKE TUBERS



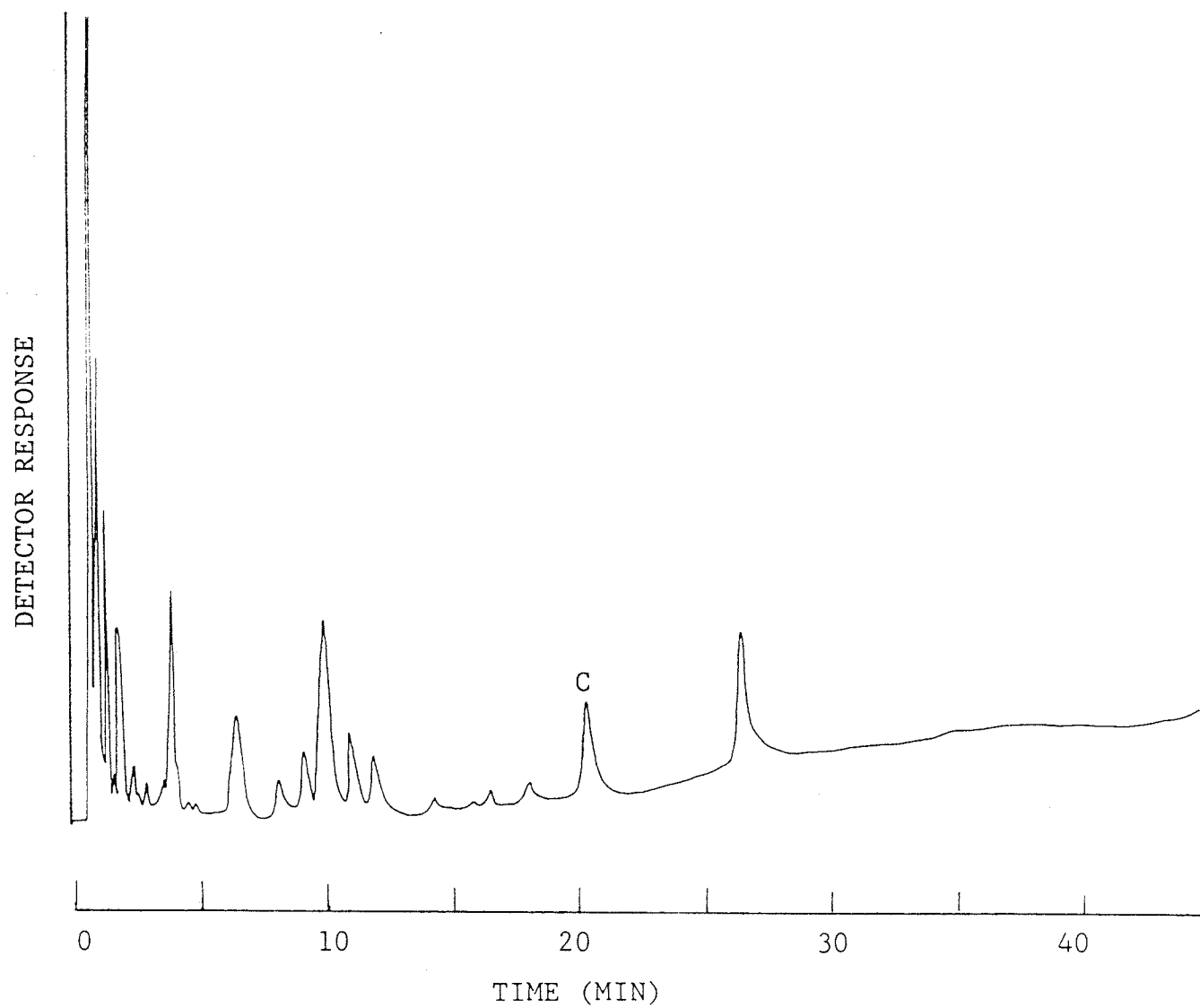
of peak E, F, G and H remained similar to that of the fresh tubers. It is also interesting to note that the chromatogram of the dried tubers yielded more aroma fractions or peaks than the chromatogram of the fresh tubers. As previously mentioned, this might have been the result of non-enzymic browning, generating new aroma compounds. Although the amount of these compounds may be very small, their contribution to the aroma cannot be considered insignificant without further investigation.

4.2.4 VOLATILE FLAVOR COMPOUNDS IN ETHANOL EXTRACTED DRIED JERUSALEM ARTICHOKE TUBERS

An attempt was made to remove flavor compounds from dried Jerusalem artichoke by ethanol extraction. The tubers were extracted with 80% ethanol and then dried. The dried residue obtained by this process had a very faint aroma. Analysis of volatile compounds from this sample indicated that most of the major peaks were removed with this treatment (Fig. 13). β -Bisabolene was reduced from 15 ppm in the dried tuber sample with no treatment to 2.5 ppm in the ethanol-extracted sample. Besides flavor compounds, amino acids and sugars were also extracted by 80% ethanol. Willaman (1921) reported that inulin and related polyfructans were soluble in ethanol solution. From the viewpoint of reducing the "unpleasant" aroma in Jerusalem artichoke flour, this treatment would be effective, but only at the expense of partial losses of polyfructans.

FIG. 13

GAS CHROMATOGRAM OF STEAM VOLATILE OIL FROM DRIED JERUSALEM
ARTICHOKE TUBERS WITH ETHANOL EXTRACTION



4.3 COMPOSITION OF JERUSALEM ARTICHOKE TUBERS

Composition of fresh and dried Jerusalem artichokes are shown in Table 10. Water was the major component making up $77.66 \pm 0.89\%$ of fresh tuber weight. The remainder was mainly carbohydrate ($17.23 \pm 0.15\%$). Kjeldahl nitrogen, crude fat, and ash were $0.57 \pm 0.02\%$, $0.01 \pm 0.03\%$, and $1.05 \pm 0.19\%$, respectively. For the dry Jerusalem artichoke, moisture accounted for $6.50 \pm 0.30\%$ of the total weight. Carbohydrate, kjeldahl nitrogen, crude fat and ash were $72.01 \pm 0.38\%$, $2.30 \pm 0.12\%$, $0.40 \pm 0.07\%$ and $4.20 \pm 0.18\%$, respectively.

4.4 TASTE COMPOUNDS IN JERUSALEM ARTICHOKE TUBERS

It is known that the carbohydrate fraction is composed of inulin, related polyfructans and a small amount of sugars. The sweet taste of Jerusalem artichoke tubers is imparted by sugars. The nitrogen content in the tubers is largely derived from proteins, short-chain peptides and free amino acids. Proteins are generally tasteless because the bulky size and structure prevent a taste sensation from being elicited. Short chain peptides and free amino acids are taste-contributing substances and their importance to taste of vegetables has been discussed in Section 2.6.2.2. Consequently, the two groups of compounds, free amino acids and sugars, were the major focus in the study of taste compounds in Jerusalem artichoke.

During heating, losses of sugars and amino acids may be related to non-enzymic browning - Strecker degradation. The extent of the reaction will vary with principal variables such

TABLE 10 COMPOSITION OF FRESH AND DRIED JERUSALEM
ARTICHOKE TUBERS

Component	Composition	
	Fresh tuber wt. (%)	Dried tuber wt. (%)
Moisture	77.66 $\pm$ 0.89 ^a	6.50 $\pm$ 0.30
Water soluble carbohydrate	17.23 $\pm$ 0.15	72.01 $\pm$ 0.38
Kjeldahl nitrogen	0.57 $\pm$ 0.02	2.30 $\pm$ 0.12
Crude fat	0.10 $\pm$ 0.03	0.40 $\pm$ 0.07
Ash	1.05 $\pm$ 0.19	4.20 $\pm$ 0.18

^a Each value is the mean $\pm$ S. D. from three trials.

as nature and concentration of reactions, moisture, temperature and heating period. Rohan and Steward (1967) reported that chocolate precursor aroma extract, heated in the dry state for one hour at 100°C, lost 30% of the amino acids due to browning reaction. When the extract was lightly moistened, amino acid degradation was reduced to 9% under the same heating conditions. When the reaction mixture was wetted with an equal weight of water, no degradation was observed. A moisture content of 5-6% in cocoa beans was sufficient to inhibit browning at lower heating temperatures. Since Jerusalem artichoke tubers were dried at 60°C to a moisture level of 6.5%, the amount of browning reaction taking place could be expected to be very small and not likely to incur any noticeable losses of sugars and amino acids. However, the volatile products derived from browning reaction could have a significant impact on the aroma of the dried tubers even if the concentrations are in the range of ppm. Blanc (1978) reported that fructose was released from inulin during roasting of chicory at temperatures above 150°C; no changes in the content of free fructose were observed at lower roasting temperatures. Considering the mild drying temperature (60°C) used in this study, release of fructose from inulin was not likely to occur based on Blanc's observation of inulin in chicory.

The results in Table 10 also demonstrated that the dehydration had simply removed moisture — the proportions of carbohydrate and nitrogen in the dry matter of fresh tubers were similar to that of the dried tubers. This result indi-

cated that the dehydration process had not caused any significant damage to sugars and free amino acids. Therefore, quantitative analysis of taste compounds were carried out only on the fresh Jerusalem artichoke. The amount of these taste compounds in the dried tubers can be obtained by appropriate adjustment of the quantities of such compounds in the fresh tubers to taken into account the reduction of moisture due to dehydration.

4.4.1 SUGARS IN JERUSALEM ARTICHOKE TUBERS

Three sugars were identified - sucrose, glucose and fructose, together constituting 1.43% of fresh tuber weight (Table 11). Of the three, sucrose was present in the largest quantity (0.59%), followed by fructose (0.52%) and then glucose (0.32%). Pangborn (1963) reported that the taste thresholds of sucrose, fructose and glucose in water were 0.017%, 0.016% and 0.132%, respectively. Although the thresholds of sugars in a complex medium such as Jerusalem artichoke will be different from those in water, it was assumed that the threshold values reported by Pangborn were adequate indicators as to whether these sugars will impart sweetness in the tubers. Results indicated that the amount of each sugar in Jerusalem artichoke far exceeded its taste threshold. Therefore, they might impart sweetness to the tubers. The amount of sugars can vary during storage - glucose and fructose remain fairly constant, but the amount of sucrose increases with storage due to metabolic breakdown of inulin. Bacon and Loxley (1952)

TABLE 11 SUGARS IN FRESH JERUSALEM ARTICHOKE TUBERS

Sugar	Concentration (g/100 g)
Sucrose	0.59 ^a
Fructose	0.52
Glucose	0.32
Total	1.43

^a Each value is the mean of three trials.

observed that after two months of storage, the concentration of sucrose increased by three times (Table 12). This information would imply that the sweetness of tubers would also increase with storage. Sweetness of sucrose can be estimated using the power function

$$S = 1.4C^{1.3} \quad (\text{Moskowitz, 1974})$$

where S is the sensory response and C is % sucrose concentration. When the exponent in the equation exceeds 1.0, the sensory ratios will be greater than the physical ratios i.e. doubling the concentration will more than double the response, and vice versa. Since the exponent for sucrose is 1.3, doubling the sucrose concentration will produce a 2.4 fold change in perceived sweetness intensity. Using the above equation, sweetness was calculated for data reported by Bacon and Loxley (1952) on the variations in sucrose content during a two month storage period (Table 12). The table shows that a three-fold increase in sucrose content during this period could be accompanied by a four-fold increase in sweetness. Glucose and fructose also contributed to sweetness. However, the mixture of the three sugars in the tubers could interact synergistically to give a sweetness intensity that exceeds the sum of the individual sweetness intensities of glucose, fructose and sucrose (Solms, 1971).

As for the dried tubers, increase in sugar content will not occur during storage. The amount of sucrose, fructose and glucose would be 2.46%, 2.16% and 1.33%, respectively, based on results obtained for the fresh tubers.

TABLE 12 EFFECT OF STORAGE TIME ON THE SWEETNESS OF
JERUSALEM ARTICHOKE TUBERS

Storage time	Concentration of sucrose ^a (%)	Predicted sweetness ^b
Harvest	0.70	0.88
0.5 month	1.72	2.83
1.5 month	1.73	2.85
2.0 month	2.25	4.01

^a Bacon and Loxley, 1952

^b Sweetness was calculated using the power function
of sucrose

$$S = 1.4C^{1.3}$$

where S is the sensory response (sweetness) and C is
the concentration of sugar.

4.4.2 PROTEINACEOUS MATERIAL IN FRESH JERUSALEM ARTICHOKE TUBERS

Results of the amino acid analyses are shown in Appendix E. Based on these data, the amino acid composition of proteins, ethanol-soluble peptides and the free amino acid fraction were calculated (Table 13). The term "proteinaceous material or total amino acids" used in the following discussion includes proteins, ethanol-soluble peptides and free amino acids. Proximate analysis showed that % nitrogen in the fresh Jerusalem artichoke tubers was 0.57%. Since the nitrogen recovery was 87.17% in Run 3 of the amino acid analysis (Appendix E), it can be assumed that the nitrogen associated with proteinaceous material was well over 90%. The amount of proteinaceous material can be approximated by multiplying 0.57% by a conversion factor of 5.70 to give 3.25%. This value would include proteinaceous material as well as non-protein nitrogen containing compounds. However, due to the high nitrogen recovery, it would be a good approximation of the quantity of proteinaceous material in Jerusalem artichoke. Of the 3.25%, the relative amounts of proteins, ethanol-soluble peptides and free amino acids were 2.29%, 0.28% and 0.72%, respectively, based on the relative proportions of amino acids recovered from the amino acid analyses.

The sixteen free amino acids identified, along with their concentrations, are recorded in Table 13. Cystine was not quantified. Serine, asparagine and glutamine were co-eluted as one peak using sodium citrate buffer. The identified free

TABLE 13

AMINO ACID COMPOSITION OF PROTEINS, ETHANOL-
SOLUBLE PEPTIDES AND THE FREE AMINO ACID
FRACTION IN 100 g OF FRESH JERUSALEM ARTICHOKE
TUBERS

Amino acids	Proteins (mg/100 g)	Ethanol-soluble peptides (mg/100 g)	Free amino acids (mg/100 g)
Arg	296.4	15.5	332.1
Asp	246.8	68.2	46.3
Glu	344.0	127.5	24.3
Phe	51.4	-	14.6
His	39.6	1.2	13.2
Leu	79.4	1.5	8.4
Lys	97.6	3.5	8.1
Thr	61.6	1.3	7.9
Trp	-	-	6.9
Ile	54.2	1.0	5.9
Pro	295.3	0.3	4.0
Val	68.5	1.3	3.6
Tyr	34.4	0.2	2.4
Ala	88.0	0.7	1.6
Gly	67.0	2.4	0.1
Met	17.2	trace	trace
Ser	-	-	} 104.6
Gln	-	-	
Asn	-	-	
Total	1,841.4	224.6	584.0

amino acids amounted to 0.584% of the fresh tuber weight. In Table 14, the free amino acids are grouped according to their taste. Included also in the table are the taste thresholds for the amino acids. Using these figures, 66.3% of the free amino acids in the tubers could be classified as bitter-tasting, 12.1% as MSG-like taste and 3.7% as sweet. Arginine was the most abundant of all the amino acids. According to Kirimura et al. (1969), this is a bitter-tasting substance, but Ney (1979) reported it as a non-bitter amino acid. In the sensory evaluation of fresh Jerusalem artichoke, bitterness was not detected. In the dried tubers, bitterness was mentioned. However, for most plant materials, the source of bitterness is usually derived from phenolic compounds and alkaloids (Maga, 1978). The free amino acid compositions in carrot and potato were compared to that of fresh Jerusalem artichoke (Table 15). In all three root crops, MSG-like amino acids (glutamic and aspartic acids) are present in quantities exceeding the taste thresholds as determined in water. Vegetables are usually rich in MSG-like amino acids (Solms, 1971). They can intensify the taste of foodstuff and increase mouth fullness. Other amino acids may not exert typical taste stimulating activities but rather a general background effect called ternary synergism (Tanaka et al., 1969 a, b). In addition, the buffer action of free amino acids may also have an important role in the sapidity of foods by fine regulation of pH (Otsuka and Take, 1969; Kirimura et al., 1969).

During extraction of free amino acids with 80% ethanol, some peptides were extracted along with the free amino acids.

TABLE 14 SENSORY CHARACTERISTICS OF AMINO ACIDS

Sensory characteristics ^a						
Amino acids	Taste thresholds					Free amino acids in Jerusalem artichoke
	(mg/100 mL)	Sweet	Salty	Sour	Bitter	MSG (mg/100 g)
SWEET AMINO ACIDS						
Lys	50	++			++	8.1
Ala	60	+++				1.6
Gly	130	+++				0.1
Ser	150	+++		+		+
Thr	260	+++		+		7.9
Pro	300	+++			+++	4.0
SOUR AND MSG-LIKE AMINO ACIDS						
Asp	3			+++		+
Glu	5			+++		++
BITTER AMINO ACIDS						
His	20				++	13.2
Met	30				+++	trace
Val	40				+++	3.6
Arg	50				+++	332.1
Ile	90				+++	5.9
Phe	90				+++	14.6
Trp	90				+++	6.9
Leu	190				+++	8.4
Tyr	-				bitter	2.4

^a Kirimura et al., 1969

TABLE 15 COMPARISON OF FREE AMINO ACID CONTENTS IN CARROT, POTATO AND JERUSALEM ARTICHOKE WITH TASTE THRESHOLD VALUES

Amino acid	Taste threshold ^a (mg/100 mL)	Carrot ^b (mg/100 g)	Potato ^c (mg/100 g)	Jerusalem artichoke tuber (mg/100 g)
Ile	90	24	10.6	5.9
Leu	190	11	6.1	8.4
Lys	50	-	6.8	8.1
Met	30	-	9.2	trace
Cys	-	9	1.2	-
Phe	90	24	11.8	14.6
Tyr	-	20	11.0	2.4
Thr	260	63	8.0	7.9
Trp	90	-	3.0	6.9
Val	40	68 ^d	25.8	3.6 ^d
Arg	50	69 ^d	19.8	332.1 ^d
His	20	16 ^d	4.2	13.2
Ala	60	265 ^d	10.1 ^d	1.6 ^d
Asp	3	392 ^d	46.8 ^d	46.3 ^d
Glu	5	117 ^d	73.8 ^d	24.3 ^d
Gly	130	7	2.2	0.1
Pro	300	2	9.1	4.0
Ser	150	118	6.4	-

^a Kirimura et al., 1969

^b Alabran and Ahmad, 1973

^c Solms and Wyler, 1979

^d Amino acid value exceeds the taste threshold in water.

The composition of these peptides is shown in Table 13. Research on the taste of peptides has been mostly centred on bitter-tasting peptides. Ney (1971) proposed that bitterness in peptides is related to average hydrophobicity (Q). According to Ney's rule, all peptides having low average hydrophobicities ($Q \leq 1,300$) are not bitter; all peptides having high hydrophobicities ($Q \geq 1,400$) have a bitter taste. Therefore, calculating the average Q value for the peptides extracted from the tubers will give an indication as to whether they are bitter or non-bitter. The Q value was calculated to be 894 indicating that the peptides were possibly non-bitter. Being non-bitter is not synonymous with no taste. Many peptides are described in the literature as having acid, sweet, brothy, or salty tastes. Bitter is just one taste quality of peptides. In addition to taste, the buffering capacity of peptides has been recognized as an important contributor to the complexity and favorable balance of taste in foods (Kirimura et al., 1969).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Sensory description revealed that the fresh Jerusalem artichoke have a grassy, earthy, woody aroma and a slightly sweet taste. For the dried Jerusalem artichoke, aroma was described as grassy, woody, earthy and nutty. The overall aroma intensity of the dried sample was stronger than the fresh. Taste of the dried Jerusalem artichoke was described as moderately to slightly sweet and also slightly bitter.

Geosmin, which was suspected to be the earthy component in Jerusalem artichoke (Romig, 1979) was not found in the tubers during this study. The major compound in both the fresh and dried Jerusalem artichoke was identified to be β -bisabolene by GLC-MS. The amount of β -bisabolene in the fresh and dried samples was 71 ppm and 16 ppm on a dry basis. The aroma of this compound has been described as a pleasant, balsam, woody odor (Givaudan, 1983). It is possible that β -bisabolene was responsible for the woody note that was detected in both the fresh and dried Jerusalem artichoke samples during sensory evaluation. Besides β -bisabolene, other major compounds identified in the fresh sample were: 1H-cycloprop(E)azulene, -decahydro-1,1,7-trimethyl-4-methylene; 2,6,9,11-dodecatetraenal, -2,6,10-trimethyl-(E,E,E); tetradecanal; and 11,14-eicosadienoic acid, methylester. The dried sample contained 2-furanacetaldehyde, α -propyl- in addition to those identified in the fresh tubers. Information regarding the aroma of these compounds

was not found in the literature. 2-Furanacetaldehyde, α -propyl- is possibly a compound derived from sugar degradation during dehydration. It would be useful to carry out further studies as to the flavor impact of these major volatile compounds. This would involve chemical synthesis of these compounds followed by aroma evaluation. Sensory techniques such as descriptive flavor profile analysis of the tubers using the major compounds as references might be helpful in this respect.

Ethanol extraction was employed to remove aroma compounds in the dried tubers and most the major peaks were removed as evidenced by the reduction of peak size on the chromatogram. However, one drawback of using 80% ethanol as the extracting solvent is that inulin and related polyfructans are partially soluble in ethanol. Thus, there will be losses in the yield of the final product after extraction. It may be valuable to investigate the ability of other solvents such as petroleum ether, methylene chloride, pentane or isopropyl alcohol to extract flavor compounds from Jerusalem artichoke.

Study of taste compounds was done only on the fresh Jerusalem artichoke. Three sugars were identified - sucrose, glucose and fructose, making up 1.43% of fresh tuber weight. It is known that the content of sucrose will increase with storage time due to metabolic breakdown of inulin and high DP fructans. It would be interesting to investigate whether panelists can perceive an increase in sweetness over increasing storage time. If the results indicate that stored Jerusalem artichoke are sweeter than freshly harvested Jerusalem artichoke,

then further studies as to how sweetness of the tubers affects acceptance and what level is most appealing to consumer could be useful to the marketing of the product. Besides sugars, sixteen free amino acids were identified in the tubers. Arginine, glutamic acid and asparatic acid were the three major amino acids exceeding their respective taste thresholds in water. Vegetables are usually rich in glutamic acid and aspartic acid. Their flavor enhancing property may be important to the overall taste of the tubers. Several phenolic acids have been reported to be present in Jerusalem artichoke by Paupardin (1965). However, this group of taste compounds was not included in the study. Further research as to quantitation of phenolic acids and analysis of their contribution to the tuber taste will be helpful to achieve a more complete understanding of Jerusalem artichoke flavor.

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APPENDICES

APPENDIX A

EVALUATION FORMS

AROMA EVALUATION OF JERUSALEM ARTICHOKE TUBERS

The two samples presented are for aroma evaluation. Remove the cover carefully and hold the container close to your nostrils. Take three short sniffs and describe the following:

- i) overall odor intensity - strong
 - moderate
 - weak

- ii) Describe the odor. Terms on the odor list might be of help. If not, use your own words.

Please smell samples in the following order. Rest 30 seconds between samples.

SAMPLE CODE	OVERALL ODOR INTENSITY	ODOR DESCRIPTION

Terms related to odor

Cardboard-like

Caramel-like

Pine-like

Earthy

Floral

Fruit

Grassy or leafy-like

Medicinal

Musty

Woody

Spicy

Nutty

Garlic or onion-like

TASTE EVALUATION OF JERUSALEM ARTICHOKE TUBERS

The three samples presented are for taste evaluation.
Describe the taste note(s) that you can detect in each sample
and the intensity of each of the taste note(s). Rinse mouth
with distilled water between samples.

Intensity - strong
 - moderate
 - weak

Taste samples in the following order.

SAMPLE CODE	TASTE NOTE AND INTENSITY	AFTER-TASTE

APPENDIX B

SENSORY EVALUATION OF JERUSALEM ARTICHOKE TUBERS

AROMA EVALUATION OF FRESH JERUSALEM ARTICHOKE

- musty, woody, slightly onion-like (weak) ^a
- earthy (weak)
- grassy, earthy, raw egg-plant (moderate)
- floral (weak)
- earthy, damp leaf (strong)
- sweet, fruity (moderate)
- sweet, grassy, musty (weak)
- grassy, fruity (moderate)
- banana-stalk (weak)
- grassy (weak)
- earthy (weak)
- grassy (moderate)
- earthy, green, woody (weak)
- woody, musty (moderate)
- sweet (weak)

AROMA EVALUATION OF DRIED JERUSALEM ARTICHOKE

- leaf-like smell (strong)
- woody, medicinal (strong)
- earthy, woody, nutty (strong)
- grassy, fruity (moderate)
- grassy, caramel, earthy, slightly nutty (strong)
- earthy, woody (strong)
- earthy, woody, potato-like (moderate)
- leafy (moderate)
- grassy (strong)
- earthy, green (moderate)
- rancid butter (strong)
- earthy, woody, green
- woody, musty (moderate)
- sweet, nutty (moderate)
- woody, grassy (strong)

^a The overall aroma intensity of the sample is put in brackets.

TASTE EVALUATION OF FRESH JERUSALEM ARTICHOKE

- very slight potato-like taste
- weak fruity and sweet taste
- moderately sweet
- moderately sweet like carrots, slightly bitter
- taste like carrots but not as sweet
- weak taste, bland
- sweet
- moderately sweet
- bland
- slightly sweet, very bland in general
- weak sweet and muddy taste
- very bland, slightly sweet
- slightly sweet, coconut-like
- slightly sweet, vegetable-like
- slightly sweet

TASTE EVALUATION OF DRIED JERUSALEM ARTICHOKE

- moderately potato-like, slightly sweet
- slightly sweet, strong sharp bitterness
- strongly sweet, slightly earthy and caramel; slightly bitter and astringent after-taste
- strong off-flavor; terrible after-taste
- sweet syrupy taste and bitter
- moderately sweet and medicinal; sickly after-taste
- strong grassy taste; bitter after-taste
- strong bitter-sweet taste; musty after-taste
- slightly sweet, very earthy; earthy after-taste
- moderate sweetness, "mouldy-taste"; both taste notes lingered as after-taste
- moderately sweet, strong green taste; weak bitterness
- green/pulpy, sweet, astringent
- moderately sweet, earthy and nutty
- strongly muddy and sweet; unpleasant after-taste
- moderately sweet and green

APPENDIX C

COMPOUNDS IDENTIFIED IN FRESH JERUSALEM ARTICHOKE
TUBERS BY GLC-MS

9-Oxabicyclo[6.1.0] nonane
 1-Pentanol, 3-methyl-
 Nonanal
 6-Nonenal, (E)-
 Cyclohexane, 1-(Ethoxymethyl)-4-methylene-
 Cyclohexene, 4-(1,5-dimethyl-1,4-hexadienyl)-1-methyl-
 1-Hexanol, 2-ethyl-
 1-Dodecanol
 1,6-Octadien-3-ol, 2,7-dimethyl-
 2,6-Octadienal, 3,7-dimethyl-, (Z)-
 1H-Cycloprop [E] azulene, decahydro-1,1,7-trimethyl-4-methylene
 Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-
 [1S-(1.alpha.
 Bicyclo[2.2.1] heptane, 2-methyl-
 Bicyclo [3.1.0] hexan-3-ol, 4-methylene-1-(1-methylethyl)-
 [1S-(1.alpha.,
 2,6-Octadienal, 3,7-dimethyl-(Z)-
 Hexadecane
 1H-3A,7-methanoazulene, 2,3,4,7,8,8A-hexahydro-3,6,8,8-
 tetramethyl-, [3R
 Naphth [2,3-B] oxirene, decahydro-
 Benzeneethanol, .alpha., .alpha.-dimethyl-
 Cyclohexene, 1-methyl-4-(5-methyl-1-methylene-4-hexenyl)-, (S)-
 Bicyclo [3.1.1] heptane, 6-methyl-2-methylene-6-
 (4-methyl-3-pentenyl)-, [1
 Eicosane
 Heptadecane
 Benzene, 1-ethyl-3-methyl-
 Benzene, diethylmethyl-
 Bicyclo [3.1.1] hept-2-ene-2-methanol, 6,6-dimethyl-
 Bicyclo [2.2.1] heptan-2-ol, 1,7,7-trimethyl-, endo-
 1-Heptyne
 1-Hexadecyne
 2-Cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl)-, trans-
 Hexadecane

Benzeneethanol

1,2-Benzisothiazole

1H-Cycloprop [E] azulene, 1A, 2, 3, 4, 4A, 5, 6, 7B-octahydro-1, 1, 4, 7-tetramethy

1H-3A, 7-methanoazulene, octahydro-1, 4, 9, 9-tetramethyl-

2, 6, 9, 11-Dodecatetraenal, 2, 6, 10-trimethyl-, (E, E, E)-

4A, 8A-Ethenonaphthalene, 1, 4, 5, 8-tetrahydro-

Tetradecanal

Tetradecanoicacid

2-Azacyclopropa [CD] pentalene, octahydro-2-methyl-

8, 11, 14-Eicosatrienoicacid, (Z, Z, Z)-

Cholesta-8, 24-dien-3-ol, 4-methyl-, (3.beta., 4.alpha.)-

1-Butanol, 3-methyl-, benzoate

Atis-16-ene, (5.beta., 8.alpha., 9.beta., 10.alpha., 12.alpha.)-

Tetradecane, 1-chloro-

Tricyclo [4.3.1.13, 8] undecane-1-carboxylicacid, methylester

8A(2H)-Phenanthrenol, 7-ethenyldodecahydro-1, 1, 4A, 7-tetramethyl-, acetat

Phenanthrene, 7-ethenyl-1, 2, 3, 4, 4A, 4B, 5, 6, 7, 8, 10, 10A-dodecahydro-4A, 7-D

11, 14-Eicosadienoicacid, methylester

Ethanone, 1-(1, 3A, 4, 5, 6, 7-hexahydro-4-hydroxy-3, 8-dimethyl-5-azulenyl)-

Naphthalene, octahydro-1, 6-dimethyl-4-(1-methylethyl)-didehydroderiv.

Octadecane

1-Heptadecanol

Tridecane

Phenol, 4-(1, 1, 3, 3-tetramethylbutyl)-

9-Octadecen-1-ol, (Z)-

Propanoicacid, 2, 2-dimethyl-2, 4, 6-trimethylphenylester

Ethanone, 1-(2, 3-dihydro-1, 1-dimethyl-1H-inden-4-yl)-

Phosporicacid, trioctylester

Acetamide, N-(2, 6-dimethylphenyl)-

Tricyclo [4.3.1.13, 8] undecane, 3-bromo-

1-Phthalanol, 1, 3, 3-trimethyl-

Phenol, 4-nonyl-

Phenol, dodecyl-

Cyclohexane, 1,1,4,4-tetramethyl-2,6-bis(methylene)-
Acetamide, N-(2-methylphenyl)-
1,2-Benzenedicarboxylic acid, dipropylester ^a
Phenethylalcohol, .alpha.-butyl-.beta.-methyl
2H-Pyran, 2-(7-heptadecynyloxy)tetrahydro-
Pentadecanoic acid
1,2-Benzenedicarboxylic acid, diisooctylester ^a
Kaur-16-ene, (8.beta., 13.beta.)-
Podocarpa-6,13-diene, 13-isopropyl-
Hexadecanoic acid
1,2-Benzenedicarboxylic acid, butyl 2-methylpropylester ^a
2,5-Octadecadiynoic acid, methylester
Octadecanoic acid
3,7,11-Tridecatrienitrile, 4,8,12-trimethyl-
Aspidofractinine-3-methanol, (2.alpha., 3.beta., 5.alpha.)-
Heptane, 5-ethyl-2-methyl-
10-Undecenoic acid, octylester
Benzenamine, 4-chloro-
1,2-Benzenedicarboxylic acid, dioctylester
2-Butenedinitrile, 2,2'-(1,2-ethanediylidenedinitrilo)-
bis[3-amino-
2-Naphthalenamine, 5,6,7,8-tetrahydro-
Hexane, 3,3,4-trimethyl-
Quinoxaline
9-Octadecynoic acid, ethylester
5(4H)-Indanone, 3A, 7A-dihydro-7A-methyl-, trans-

^a The compound is possibly a contaminant from the steam distillation apparatus.

APPENDIX D COMPOUNDS IDENTIFIED IN DRIED JERUSALEM
ARTICHOKE TUBERS BY GLC-MS

Formicacid, cyclohexylester
1-Hexanol
Naphth[2,3-B] oxirene, decahydro
Nonanal
2-Isononenal
1-Undecanol
Phenol, 3-(dimethylamino)-
1,4-hexadiene, 3-ethyl-
3-Butenenitrile
Heptane, 1-bromo-
2-Octanone
1,3-Oxathiolane, 5-methyl-
6-Nonenal, (E)-
7-Octen-4-ol
9,12,15-Octadecatrienal
1-Hexanol, 2-ethyl-
3-Heptanol, 6-methyl-
1-Octene, 3,7-dimethyl-
Benzeneacetaldehyde
1-Nonanol
2-Pentadecyn-1-ol
Cyclohexene, 1-methyl-4-(5-methyl-1-methylene-4-hexenyl)-, (S)-
Cyclohexane, cyclopropyl-
Nonane, 5-butyl-
2-Furanacetaldehyde, .alpha.-propyl-
2-cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl)-, trans-
Octacosane
Benzeneethanol
Benzothiazole
Cholesta-8,24-dien-3-ol, 4-methyl-, (3.beta., 4.alpha.)-
1H-cycloprop(E)azulene, decahydro-1,1,7-trimethyl-4-methylene
2,6,9,11-Dodecatetraenal, 2,6,10-trimethyl-, (E,E,E)-
Tetradecanal
2-Azacyclopropa[CD]pentalene, octahydro-2-methyl

1-Butanol.3-methyl-, benzoate
 Ethanone, 1-(1,3A,4,5,6,7-hexahydro-4-hydroxy-3,8-dimethyl-5-azulenyl)-
 Pentadecanoicacid, 14-methyl-, methylester
 Furan, 3-(4,8-dimethyl-3,7-nonadienyl)-, (E)
 Eicosane
 Hexadecanoicacid, ethylester
 1H-3A,7-methanoazulene, octahydro-1,4,9,9-tetramethyl-
 11,14-Eicosadienoicacid, methylester
 1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, [S-(Z)]-
 11,14,17-Eicosatrienoicacid, methylester
 1-Heptadecanol
 9,12,15-Octadecatrienoicacid, methylester, (Z,Z,Z)-
 Propanoicacid, 2,2-dimethyl-, 2,4,6-trimethylphenylester
 5,8,11-Heptadecatriynoicacid, methylester
 Acetamide, N-(2,6-dimethylphenyl)-
 Tricyclo [4,3,1,13,8] undecane, 3-bromo-
 1H-Indene-4-methanol, 2,3-dihydro-1,1-dimethyl-
 Phenol, 4-nonyl-
 Tricyclo [3.3.1.13,7] decan-2-one, 4-iodo-, (1.alpha., 3.beta., 4.alpha., 5.A)

 Phenol, 4-(1,1,3,3-tetramethylbutyl)-
 Acetamide, N-(3-methylphenyl)-
 1,2-Benzendicarboxylicacid, dipropylester ^a
 Phenethylalcohol, .alpha., -butyl-.beta.-methyl-
 Pentadecanoicacid
 1,2-Benzenedicarboxylicacid, diisooctylester ^a
 8A(2H)-Phenanthrenol, 7-ethenyl dodecahydro-1,1,4A,7-tetramethyl-, acetat
 Podocarpa-6,13-diene, 13-isopropyl-,
 Hexadecanoicacid
 1,2-Benzenedicarboxylicacid, butyl 2-methylpropylester ^a
 2,5-Octadecadiynoicacid, methylester
 Aspidofractinine-3-methanol, (2.alpha., 3.beta., 5.alpha.)-
 1,12-tridecadiene
 Aziridine, 1-(phenylmethyl)-

^a The compound is possibly a contaminant from the steam distillation apparatus.

1,3-Isobenzofurandione,5-nitro-

1,2-benzenedicarboxylicacid,dioctylester ^a

Grandidentatin,pentaacetate

1-Butanone,1-(2,4,6-trihydroxy-3-methylphenyl)-

1,2-Benzenedicarboxylicacid,dipentylester ^a

Heptane,5-ethyl-2-methyl-

Hexane,3,3,4-trimethyl-

1,2-Benzenedicarboxylicacid,dibutylester ^a

^a The compound is possibly a contaminant from the steam distillation apparatus.

APPENDIX E

AMINO ACID ANALYSIS

Amino acid	Run 1 ^a (mg/100 g) ^d	Run 2 ^b (mg/100 g)	Run 3 ^c (mg/100 g)
Arg	332.1	347.6	644.0
Asp	46.1	114.5	361.3
Glu	24.3	151.8	495.8
Phe	14.6	13.5	66.0
His	13.2	14.4	54.0
Leu	8.4	9.9	89.3
Lys	8.1	11.6	109.2
Thr	7.9	9.2	70.8
Trp	6.9	-	-
Ile	5.9	6.9	61.1
Pro	4.0	4.3	299.6
Val	3.6	4.9	73.4
Tyr	2.4	2.6	37.0
Ala	1.6	2.3	90.3
Gly	0.1	2.5	69.5
Met	trace	trace	17.2
Ser	} 104.6	5.0	65.3
Gln		-	-
Asn		-	-
% N recovered	78.72	95.51	87.17
% N in sample	82.60	82.60	0.57

^a Run 1 = Free amino acids

^b Run 2 = Free amino acids + ethanol-soluble peptides

^c Run 3 = Total amino acids

^d Amount of the amino acid in mg per 100 g of Jerusalem artichoke