# A Comparison of the Volatile Constituents and Sugars of Representative Asian, Central American, and North American Sweet Potatoes

Authors: Stanley J. Kays and R. J. Horvat, University of Georgia and USDA-ARS Russell Research Center, Athens, GA, 30602, USA.

## ABSTRACT

The volatile profiles and sugars of three cultivars of baked sweet potatoes representing an Asian, Central American, and North American center of selection were compared. Aromatic compounds were analyzed and identified by gas-liquid chromatograph-mass spectrometry.

Volatile components were identified from the North American cultivar Jewel and from the Central American cultivar Morado.

The volatile profiles between the three cultivars were distinctly different as were the aromatic properties, measured subjectively.

There were no qualitative differences in sugars between the cultivars. Maltose, sucrose, glucose, and fructose is decreasing order of concentration were isolated and identified by high pressure liquid chromatography. Significant quantitative differences were found in the concentration of total sugars (Jewel>Tainung> Morado) and in the concentration of free hexose sugars (Jewel> Morado>Tainung 57) between the cultivars tested.

We have proposed that the limited use of sweet potatoes as a preferred staple food for human consumption is due to a large extent to the intensity and dominance of the flavor (aromatic and taste) of the cooked product which minimizes its flexibility for use in cuisines. Based upon the significant variation in both the volatile compounds and concentration of sugars that appear to be present in the sweet potato gene pool, the integration of an analytical measure of flavor into future sweet potato breeding programs would be a highly desirable research approach.

The world's population of more than 4,000 million increases by up to 80 million people every year (Population Reference Bureau, 1976). At this rate the world's inhabitants will double in about 38 years and the demand for food will increase correspondingly. Consequently, increases in food production are needed to meet the growing caloric demand of our expanding population.

Greater food production can be attained through two primary means: by increasing yields per hectare, and/or by increasing the amount of land mass in production. For example, replacement of part of the acreage currently allocated to less efficient crops with higher yielding species is one readily accessible way to increase the per hectare yield. The sweet potato is a crop which is a likely candidate for increasing food production in this way. Along with high yields, it has the advantage of having both a relatively short growing season and a wide ecological range in which it can be successfully cultured. Sweet potatoes are grown from the tropics through the subtropics and into many areas of the temperate zone. It is currently one of the leading food crops in the world, ranking sixth in total yield (107,254,000 MT/year, 1980).

A persistent problem of the sweet potato in many of the major production areas, for example in the People's Republic of China which produces 81% of the world's sweet potatoes (FAO, 1981), is that one of its primary uses is for livestock feed rather than direct human consumption. This conversion of carbohydrate to animal protein (principally pork) results in an approximate 3.3 fold decrease in caloric value before consumption. Direct utilization of sweet potatoes would therefore elevate the net caloric yield of human food.

One may ask then, why are sweet potatoes not more widely consumed directly as a food? We propose that the primary reason is that the flavor of the cooked product is extremely dominant and as a consequence cannot be readily altered. The majority of the existing staple crops (rice, wheat, cassava, white potato, for example) act to a large degree as flavor carriers (products with low flavor impact) to which flavor is added during or after preparation. This both increases the flexibility of the product for preparation and increases its potential for introduction into new geographical areas, since distinctive "flavor principles" of the culture can be successfully added to increase its acceptability.

In a survey of sweet potato purchase and use in northeastern United States, it was shown that while 82.8% of the households surveyed were classed as users of sweet potatoes, only 10.4% purchased the product more than once a month (Law, 1977). A conclusion that emerges from the data is that the majority of the people like sweet potatoes, however, not sufficiently well to consume them with any regularity. In addition, upon making a cursory survey of selected North American cookbooks in the University of Georgia Library, we found that white potatoes have on the average six times as many recipes as sweet potatoes and a more diverse array of potential dishes. Both examples point toward the intensity, distinctness, and lack of flexibility of the flavor of sweet potatoes, characteristics not commonly associated with common staple foods.

Humans exhibit distinct patterns in the foods which they select to consume and flavor is known to be a primary criterium in this selection. Most flavors are comprised of a combination of both taste and odor. Our perception of taste is generally thought to be limited to four basic tastes: sweet, salty, sour, and bitter. This is contrasted with the potential perception of up to 10,000 distinct odors by the olfactory epithelium. This difference in potential perception is also seen in the number of taste receptors for an individual which are in the thousands, versus odor receptors which are thought to be in the millions. Characteristic combinations of flavors (called "flavor principles") are often added to many foods in most of the worlds cuisines (Rozin, E., 1973). Thus the ability to manipulate the flavor of a food product can greatly enhance a new product's acceptance into a cuisine (Rozin, P., 1977).

Foods can be classed into four general groups based on their characteristic flavor volatiles (Nursten, 1978).

1. Those whose aroma is composed primarily of one character impact compound (CIC).
2. Those whose aroma is due to a mixture of a small number of compounds, of which one may be a character impact compound.
3. Those whose aroma is due to a large number of compounds, none of which are character impact compounds and with a careful combination of these components the odor can be reproduced.
4. Those whose aroma is made up of an unreproducible complex mixture of compounds.

Examples of character impact compounds would be 2-isopropyl-3-methoxypyrazine in raw white potato tubers or isopentyl acetate in banana fruit. Examples of foods whose aroma is made up of a small number of compounds are boiled white potatoes [2-ethyl-3-methoxypyrazine (CIC) and methional], apple [ethyl-2-methylbutyrate (CIC), hexanal and trans-2-hexenal] and boiled cabbage [dimethyl disulfide (CIC) and 2-propenylisothiocyanate].

Little is known about the flavor of sweet potatoes. The aromatic flavor components of cooked sweet potatoes have not been identified although part of the volatile constituents of one North American cultivar have been described (Purcell et al., 1980). The principal taste sensation is sweetness and appears to be due primarily to maltose (Sistrunk et al., 1954) and sucrose. The degree of variation in these parameters between local cultivars and cultivars from diverse centers of selection has not been measured.

The development of the sweet potato into a staple for human consumption appears to be in part dependent upon the integration of an analytical measure of flavor (aroma and taste) into breeding programs for new cultivars. As a preliminary step in this process we describe the volatile profiles of three diverse cultivars of sweet potatoes from different centers of selection, and identify a number of the volatile and sugar constituents.

## Materials and Methods

Three sweet potato cultivars (Jewel, Morado and Tainung 57) representing North American, Central American, and Asian centers of selection were used in our investigation to characterize the volatile compounds and sugars from baked storage roots. The cultivars selected differed significantly in both the physical and aromatic properties of the baked roots (Table 1). Morado, a dry white fleshed type, had very little aroma which was described as a starchy odor. The flavor was often described as similar to a baked dry fleshed white potato (*Solanum tuberosum* L.) that was sweet. Tainung 57, a yellow dry fleshed type, had a slightly stronger aroma than Morado which was also characterized as principally starchy in nature. The flavor was described as somewhat similar to roasted chestnuts (*Castanea sativa*, Mill). Jewel, a moist orange fleshed cultivar, exhibited a strong sweet, caramel aroma. The aromatic properties of this cultivar were much more pronounced than those of either Morado or Tainung 57.

The cultivars were grown at the University of Georgia Horticultural farm, near Athens, Georgia, on a Cecil sandy loam soil. After harvest, the roots were cured at 29.4°C, 98% RH for 7 days and stored until use at 12.8°C, 85% RH. Seven individual roots, 7 to 9 cm in diameter, of each cultivar were baked in an electric oven for 60 minutes at 204°C. The skin was removed and the individual roots of each cultivar composited and mashed. A 300 gm aliquot was removed and blended in a Waring blender with 300 ml of distilled water. The resulting slurry was placed in a 3-l round bottomed flask with an additional 300 ml of distilled water added. The flask was then connected to a steam distillation, continuous pentane extraction apparatus (Nickerson and Likens, 1966) and the pentane and sweet potato macerate boiled for 8 hours. After cooling, the flask containing the 120 ml of pentane was removed, cooled to ca 40°C, and concentrated to 0.5 ml with a gentle stream of high purity nitrogen.

Table 1. Description and origin of the sweet potato cultivars used to characterize the aromatic components and sugars of the baked roots.

| | Cultivar | | |
|---|---|---|---|
| | Morado | Tainung 57 | Jewel |
| Geographical origin | Central America | Asia (Republic of China) | North America (United States) |
| Skin color* | | | |
| Description | red | yellowish beige | copper |
| L | 40.5 | 55.5 | 44.7 |
| a | 17.9 | 11.6 | 14.7 |
| b | 11.5 | 22.9 | 17.5 |
| Flesh color* | | | |
| Description | white | yellow | orange |
| L | 85.9 | 76.7 | 65.4 |
| a | -1.7 | 12.8 | 32.5 |
| b | 17.9 | 31.8 | 29.7 |
| Description of baked flesh texture | dry | dry | moist |
| Description of aroma of baked roots | little aroma, starchy | weak aroma, starchy | strong aroma, sweet, caramel |
| % dry matter of baked roots | 32.02 | 32.21 | 29.05 |

*Uncooked

GLC-MS Volatile Analyses

Analyses were performed with a Perkin-Elmer Model 900 gas-liquid chromatograph (GLC) on samples ranging from 1.0 to 1.7 µl in volume. The chromatograph was connected by means of an effluent splitter to a DuPont 21-490B mass spectrometer equipped with differential pumping on the analyzer section. Separations were made on a 50 m x 0.05 cm glass capillary column coated with Superox 4 (Alltech Associates). GLC conditions were: carrier gas inlet pressures, 0.6 kg/cm$^2$; injector and manifold temperature at 250°C; and column held at 55° for 6 min then programmed to 200°C at 1.5°/min.

Table 2. The sugar composition of three cultivars of baked sweet potatoes.

| | Sugars (% dry weight) | | | | | |
|---|---|---|---|---|---|---|
| Cultivar | Unkown | Fructose | Glucose | Sucrose | Maltose | Total sugars |
| Jewel | 0.46 | 2.68 | 3.02 | 15.96 | 27.12 | 49.24 |
| Morado | 0.53 | 0.91 | 0.97 | 10.25 | 19.05 | 31.71 |
| Tainung 57 | 0.33 | 0.61 | 0.66 | 13.98 | 25.05 | 40.63 |

Mass spectrometer conditions were: ion source temperature, 200°C, scan rate, 10 s per decade; ionizing voltage, 70 ev; and ion source pressure, $2 \times 10^{-5}$ Torr. Compounds were identified by comparison of their mass spectra and GLC retention times with those of known standards. Compounds were considered to be positively identified when their mass spectra and GLC retention times agreed with those of a known standard. Compounds identified solely on the basis of comparison of their mass spectra with standards in the literature are designated "tentatively identified."

## HPLC Sugar Analyses

Samples of the baked sweet potatoes were also collected and freeze dried for sugar and dextrin analysis by high pressure liquid chromatography (HPLC). Two gm samples of ground (40 mesh) freeze dried sweet potatoes were blended in a Virtis mixer for 7 minutes with 25 ml of distilled water. The solution was then vacuum filtered through #2 Whatman filter paper and then through a 0.45 μm Millipore filter. Samples (50 μl) were then separated on an Alltech 600 CH 30 cm x 4.1 mm ID column using either 7:3 or 8:2 ratio of degassed acetonitrile and deionized water as the mobile phase (3 ml/min). The 7:3 ratio was used for separation of the component dextrins, which gave only fair resolution of individual sugars. As a consequence, the 8:2 acetonitrile-water solvent was used on separate samples for more precise sugar analysis. A Whatman CO:Pell pac precolumn was used with an Altex pump, Waters differential refractometer and Hewlett Packard 3380A integrator. Individual peaks were identified and quantified using known standards.

## Raw Product Color

The external and internal color of representative fresh storage roots of each cultivar were measured using a Gardner XL 20 colorimeter against a white chromatic reference standard (L = 92.0, a = -1.2, b = 1.1).

## Results and Discussion

Comparing the chromatographic profiles of the volatile compounds collected from each of the three cultivars indicated distinct differences. These differences were reflected in both the number of volatile compounds present and in the concentration of specific molecules (Figure 1). Jewel had substantially more compounds present and generally a greater concentration when there were similar molecules in either of the other cultivars. We have thus far identified pentene-2, acetone, 2,3-butanedione, hexane, pentane-2-one, methylbenzene, 2-pentanol, methylacetate, dimethylbenzene, pyridine, 2-phenyl-2-methylbutane, furfural, 2-furylmethylketone, benzaldehyde, 2-propenylfuran, 2-methyl-6-ethylpyridine, α-terpinol, heptylbenzene, hexadecanol, heptadecanol, 1-isopropyl-4-isopropenyl benzene, tetradecanol, a monoterpene and several sesquiterpenes as volatiles of Morado. In Jewel, pentene-2, acetone, acetaldehyde, methanol, hexane, toluene, xylene, pyridine, benzaldehyde, i-butyronitrile, 2-phenyl-2-methylbutane, furfural, 2-acetyl furan, 2-pyrone, n-propylbenzene, limonene, 2,4,6-trimethyl pyridine, β-ionine, several monoterpenes and a number of sesquiterpenes were found. There appear to be a number of alcohols in the higher molecular weight compounds possessing high retention times in the chromatogram (Figure 1). Because of high column bleed at the upper temperatures used, we have not yet been able to get good spectra for these compounds in the Jewel cultivar. A number of these volatiles are known to have distinctive aromatic properties and may therefore be significant components of the characteristic aroma of the respective cultivars. For example, furans, pyridines and pyrones are heterocyclic compounds known to be involved in the aromas of other food products (Figure 2). In addition, terpenes such as the monoterpene limonene and the sesquiterpene cadinene are also distinctive aromatic compounds (Figure 2). We have yet to identify a character impact compound in sweet potatoes. It is probable, however, that if there is a character impact compounds present, it will differ between the moist fleshed highly aromatic Jewel and the weakly aromatic Morado and Tainung 57.

The qualitative composition of specific sugars between the three cultivars was identical, however, the relative amounts and ratios of individual sugars within a cultivar varied considerably between cultivars. The sweet flavor of the sweet potato was found to be due to maltose, sucrose, glucose, fructose and an unknown sugar (possible a pentose) in decreasing order of concentration. The identification of furfural among the volatiles of two types of sweet potato supports the pentose structure for the unknown sugar. Jewel had the greatest concentration of total sugar in the baked product, over one-third greater than Morado which had the lowest concentration. Maltose is believed to be the predominant sugar formed during baking (Sistrunk et al., 1954). Its final concentration is known to vary due to both postharvest factors and cooking technique; both factors which were held constant in this study. The ratio between the concentration of sucrose and maltose was relatively similar between cultivars (1:1.7 - Jewel, 1:1.9 - Morado, 1:1.8 - Tainung 57) which would suggest that differences in the final maltose concentration were due to inherent differences within the respective cultivar rather than any variation in treatment. Differences in free hexose sugars (fructose and glucose) represented a significant point of separation between Jewel and the dry fleshed cultivars. Jewel had 3 to 4.5 times more free hexose sugars than Morado and Tainung 57.

We did not find significant levels of dextrins, although one unidentified peak (Figure 3) probably represents an intermediate chain length dextrin. This would indicate that in the cultivars tested, β-amylase represented the primary active enzyme in the hydrolysis of starch during baking and α-amylase had only a very limited role.

## Summary

We have demonstrated that there is a substantial variation between existing sweet potato cultivars in both the volatile constituents of the baked roots and the concentration and ratios of specific sugars. It is anticipated that a much more extensive range of variation in these parameters will be found in the world sweet potato gene pool and between Ipomoea batatas, Lam. and other storage root and tuber forming Ipomoea species.

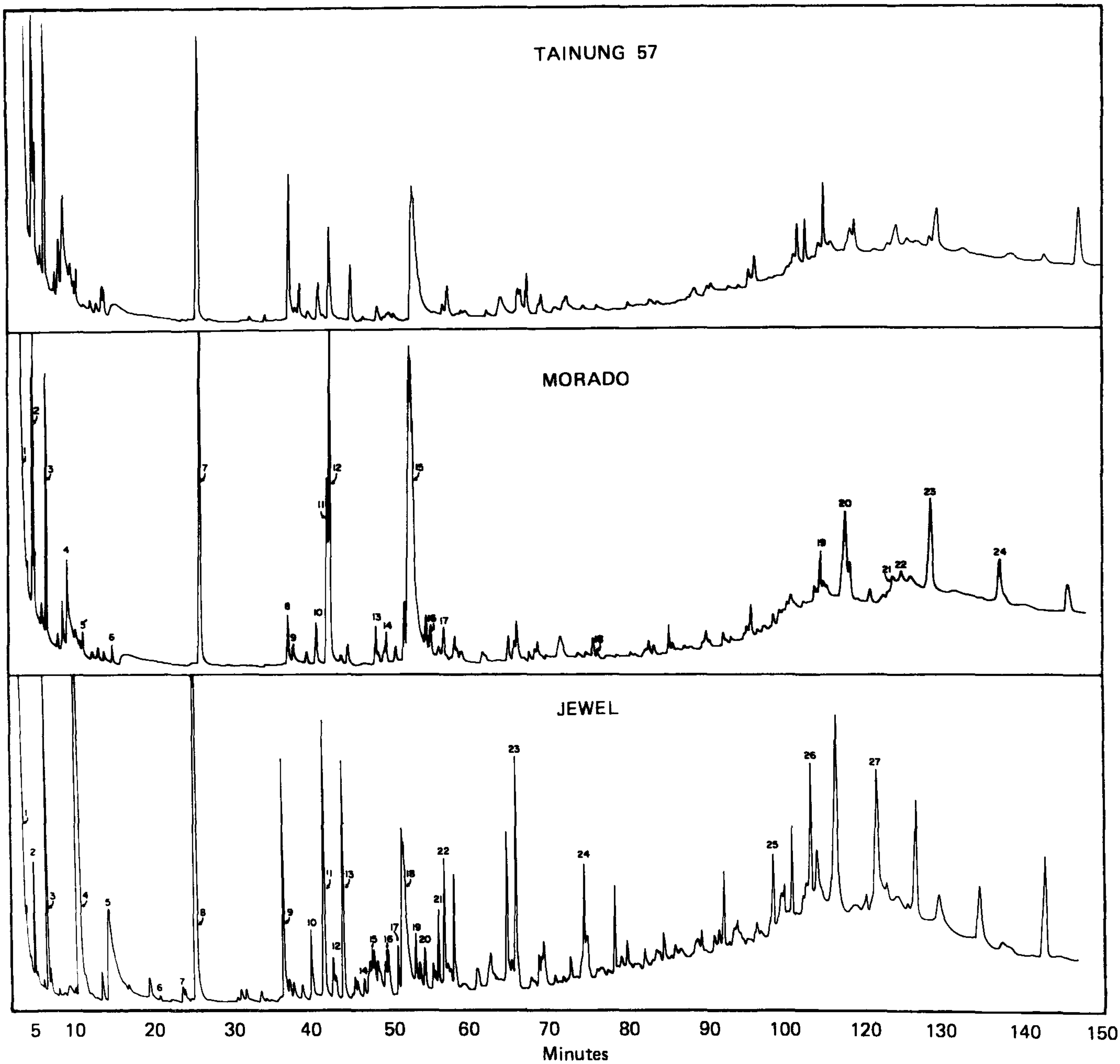


Figure 1. Volatile profile chromatograms of a North American (Jewel), Central American (Morado), and Asian (Tainung 57) cultivar of baked sweet potatoes.

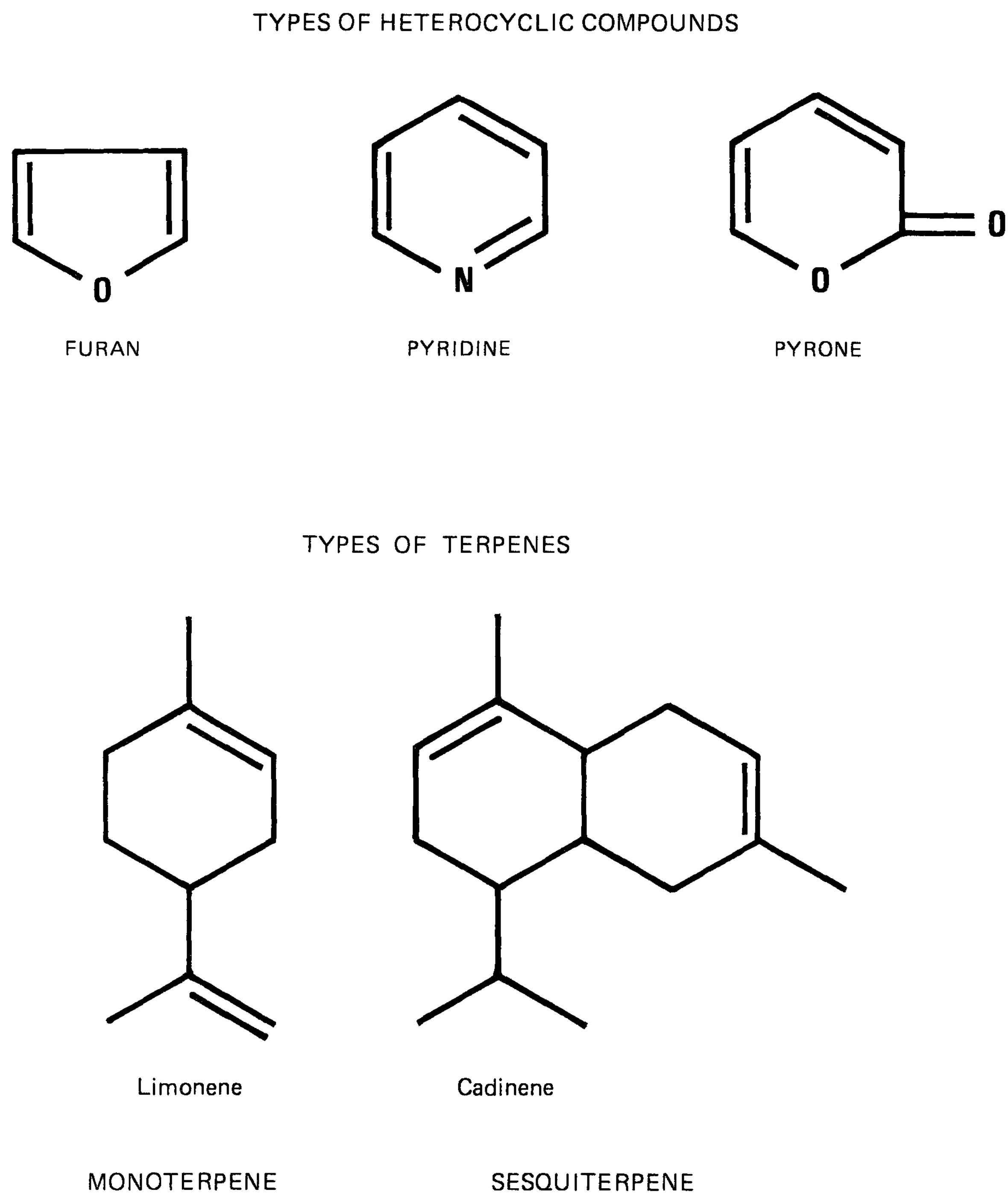


Figure 2. The basic structure of three general types of heterocyclic compounds and two types of terpenes found in the volatiles of baked sweet potatoes that have been associated with the aromatic flavor of other food products.

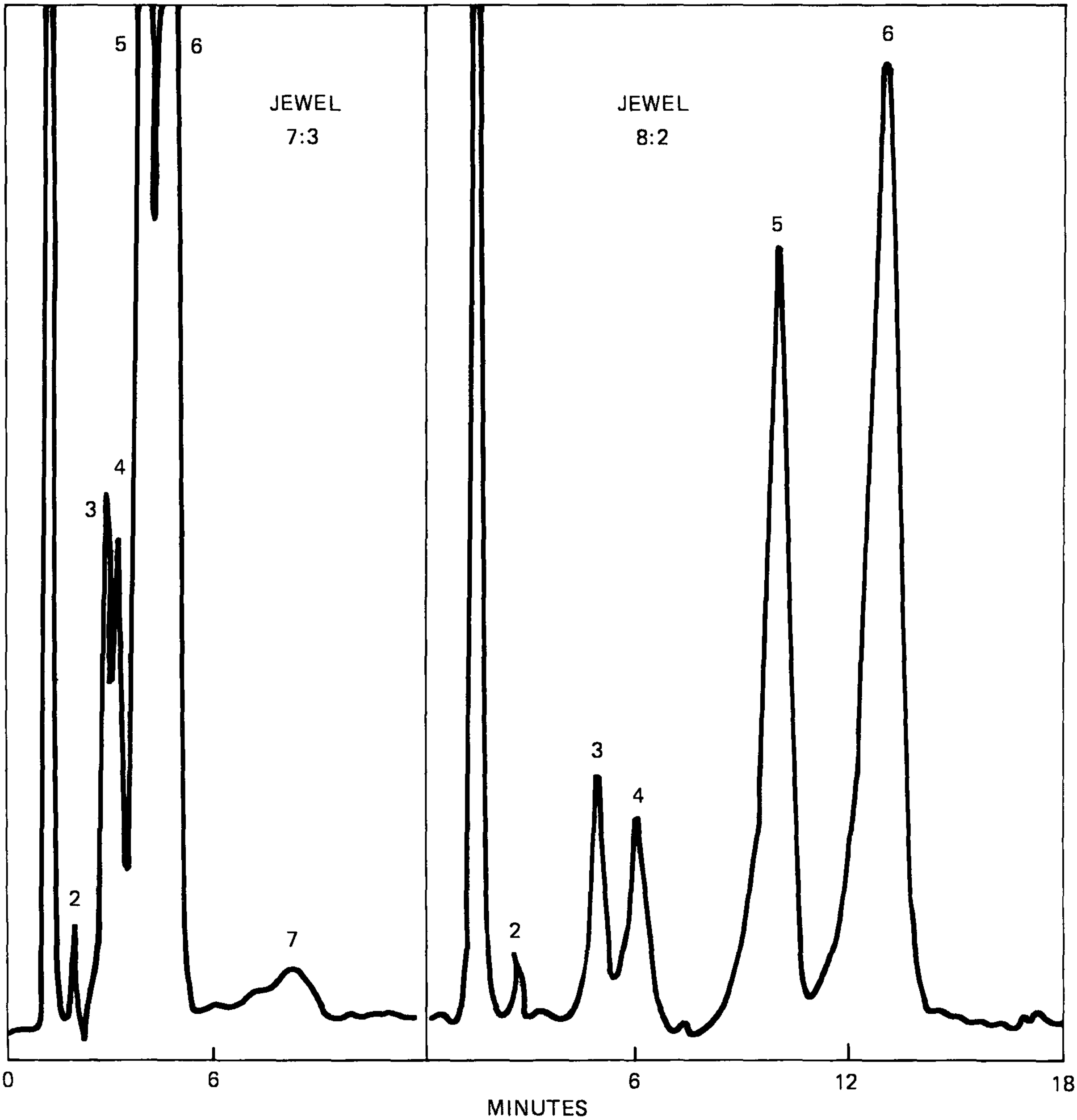


Figure 3. Chromatograms of sugars isolated from baked storage roots of the cultivar Jewel. Solvent ratios of 7:3 and 8:2 (acetonitrile and deionized water) were used to separate component dextrins (7:3) and specific sugars (8:3). Peaks present represent: (1) water, (2) an unknown, possibly a pentose sugar, (3) fructose, (4) glucose, (5) sucrose, (6) maltose, and (7) possibly an intermediate chain length dextrin.

The high yields and ecological flexibility of the sweet potato point toward its potential as a preferred human "staple", i.e. a food which is consumed on a frequent basis in an ethnic or social group's diet, providing a major amount of the nutrition of that group. However, the intensity and distinctness of the flavor of currently existing cultivars appears to decrease the product's flexibility for use and level of acceptance as a preferred staple. With the wide range of variation in the flavor of the sweet potato that appears to be present, the integration of an analytical technique for the rapid screening of genetic crosses for flavor would enhance the rate at which flavor quality could be altered. This could: (1) increase the level of acceptance of sweet potatoes as a human food, (2) increase its potential integration into new geographic areas and social groups, and (3) elevate world food production through its use in preference to lower yielding crop species.

Acknowledgements

The authors acknowledge the excellent technical assistance of Ms. Roxanne Jones during part of this research.

References

FAO. 1980 FAO Production Yearbook. Food and Agric. Organization of the United Nations. Vol. 34, 1981. 296 pp.

Law, J.M. Factors affecting the purchase and use of sweet potatoes. Louis St. Univ. Agric. Expt. Sta. Bul. 706, 1977. 36 pp.

Nickerson, G.B. and Likens, S.T. Gas chromatographic evidence for the occurrance of hop oil components in beer. J. Chromatogr. 21, 1966. 1-5.

Nursten, H.E. Why flavor research? How far have we come since 1975 and where now? In Progress in Flavor Research, D.G. Land and H.E. Nursten, eds., Proc. 2nd Weurman Flavor Res. Symp., Applied Science Pub., London, 1978. pp. 337-355.

Population Research Bureau. World Population Data Sheet. Washington, D.C., Population Reference Bureau, 1976.

Purcell, A.E., Later, D.W., and Lee, M.L. 1980. Analysis of the volatile constituents of baked, Jewel sweet potatoes. J. Agric. Food Chem. 28, 1980. 939-941.

Rozin, E. The Flavor Principle Cookbook. Hawthorn, N.Y., 1973.

Rozin, P. The use of characteristic flavorings in human culinary practice. In Flavor: Its Chemical, Behavioral and Commercial Aspects, Proc. A.D. Little Flavor Symp., C.M. Apt, ed., Westview Press, Boulder, Colorado, 1977. pp. 101-127.

Sistrunk, W.A., Miller, J.C., and Jones, L.G. 1954. Carbohydrate changes during storage and cooking of sweet potatoes. Food Tech. 8, 1954. 223-226.