# Comparison of Carbohydrate Components in Sweet Potatoes Baked by Convection Heating and Microwave Heating[1]

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The carbohydrate fractions of sweet potatoes baked in a convection oven and in a microwave oven were compared. Samples baked in the microwave contained less total alcohol-soluble carbohydrates, reducing sugars, and dextrins and more starch than those cooked in the convection oven. Measurement of static stress of the samples suggested that samples cooked in the microwave oven would have a drier mouthfeel. As storage time increased, samples baked in the microwave oven became more dry, while those baked in the convection oven became more moist.

Previous studies have shown that sweet potatoes contain amylolytic enzymes that hydrolyze starch when the roots are cooked (Ikemiya and Deobald, 1966; Balls et al., 1957). Temperature of the tissues must reach about 80 °C before rapid hydrolysis begins (Hoover, 1967). Differences in the amount of $\alpha$-amylase appear to account for differences in moistness or dryness of mouthfeel (Walter et al., 1975), and the amount of $\alpha$-amylase varies with cultivar and storage history. The concentration of $\alpha$-amylase in a given cultivar increases during curing and the first 12–16 weeks of storage. $\beta$-Amylase remains nearly constant.

Sweet potatoes baked in a microwave oven have a drier mouthfeel than those baked in a convection oven (Nelson, 1973). The rapid heating with a microwave might cause less variation in mouthfeel than is found with convection heating.

This study compares the carbohydrates of sweet potatoes cooked in a convection oven and in a microwave oven. Samples were taken after various periods of storage to determine the effect of storage on carbohydrate changes.

## MATERIALS AND METHODS

Jewel sweet potatoes were grown at the North Carolina Agricultural Research Service Central Crops Research Station near Clayton, NC. Immediately after harvest, the roots were cured at 30 °C and near 100% humidity for 5 days. After curing, they were stored at 13 °C without controlled humidity. Roots were taken at harvest, after curing, and at designated times during storage.

At each sampling, six roots between 6.5 and 7.5 cm in diameter and 20–25 cm in length were selected. They were washed with warm water (ca. 27 °C), dried at room temperature for 30–60 min, and separated into three pairs on the basis of similarities in size and shape. One root of each pair was baked for 90 min at 190 °C in a preheated convection oven. The other member of each pair was cooked 3 min in a Litton Model 850 microwave oven at full power (6000 W). All roots were pierced before baking. The temperature at the center of the potatoes was measured by inserting a bimetallic dial thermometer. The temperature for both microwave and convectional baking treatments was ~100 °C.

**Sampling.** After cooking, the roots were cooled and the edible portions scooped out. Root contents were mixed to form composite samples from which samples were drawn for analysis.

Samples for dry-matter determination consisted of 25 ± 1 g weighed to 0.01 g in a Petri dish. Samples for measurement of static yield (24 g) were weighed into 50-mL beakers. For other samples, the mashed sweet potato was placed in a 50-mL syringe, and measured amounts were forced through a 12-gauge cannula into appropriate containers. For total alcohol-soluble carbohydrates, duplicate 4-g samples were placed in 100-mL volumetric flasks with 17 mL of $H_2O$ and made to volume with 100% ethanol, so the final ethanol concentration was 80%. Samples for dextrin and starch analyses (4 g in duplicate) were placed in 125-mL Erlenmeyer flasks with 96 mL of 83% ethanol, so the final ethanol concentration was 80%.

**Analyses.** Dry matter was determined as weight remaining after the samples had been heated to 105 °C for 16 h in a vented convection oven.

Static yield samples were mixed with 18 g of water to give a 4:3 (w/w) mixture of sweet potatoes and water. The samples were stirred to remove all lumps and allowed to stand for 2 h at room temperature, 23 ± 1 °C. A 1-cm-diameter, fluted, cylindrical rotor attached to a Brookefield Model RVT viscosimeter was immersed 2 cm into the puree. The rotor was started at 2.5 rpm, and the maximum scale deflection, which occurred as the rotor first began to turn, was recorded as static yield. Static yield is defined as the yield stress measured under static conditions and measures different flow characteristics from viscosity (DeMan, 1976). In previous unpublished laboratory studies, static yield was shown to correlate with viscosity and mouthfeel, as determined by Rao et al. (1975).

Total alcohol-soluble carbohydrates (TASC) and reducing sugars were determined after samples had equilibrated in 80% ethanol for 7 days or longer. TASC were determined by the phenol–sulfuric acid method of Dubois et al. (1956). Reducing sugars were determined with arsinomolybdate reagent (Hodge, 1961).

Dextrins were determined as material insoluble in 80% ethanol and soluble in 10% ethanol. Samples were allowed to equilibrate in 80% ethanol for more than 24 h. The alcohol was decanted, and samples were again made to volume with 80% ethanol and allowed to stand more than 24 h. After three such changes of 80% ethanol, the samples were covered with 10% ethanol and allowed to stand for at least 7 days. The supernatant was diluted 1:4 with 0.02 M (pH 7) phosphate buffer and treated with amylo-

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**Table I. Carbohydrate Components and Rheological Properties of Sweet Potatoes Sampled at Different Dates and Baked by Two Methods: Microwave and Convection[a,b]**

| | % total alcohol-sol carbohydr | | % reducing sugars | | % dextrins | | % starch | | blue value of starch | | static yield | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sample | micro | conv | micro | conv | micro | conv | micro | conv | micro | conv | micro | conv |
| at harvest | 33.3 D | 43.0 D | 13.3 C | 18.9 C | 0.95 A | 1.23 C | 38.5 A | 26.5 A | 0.23 C | 0.15 B | 56.0 D | 37.0 B |
| 7 days (cured) | 45.4 A | 46.0 C | 13.6 C | 21.2 BC | 0.42 B | 2.89 C | 31.7 BC | 24.5 A | 0.23 C | 0.20 A | 65.0 C | 46.0 A |
| 24 days | 42.9 B | 57.2 A | 17.9 B | 23.7 AB | 0.94 A | 10.46 A | 34.2 B | 5.7 C | 0.24 C | 0.11 C | 60.0 D | 27.0 D |
| 36 days | 39.3 C | 53.1 B | 21.5 A | 26.2 A | 0.90 A | 10.23 A | 29.4 C | 9.1 B | 0.32 B | 0.12 C | 69.0 B | 33.0 C |
| 42 days | 40.3 C | 54.8 B | 21.0 A | 27.5 A | 0.81 A | 8.17 B | 40.4 A | 11.8 B | 0.32 B | 0.18 AB | 80.0 A | 35.0 BC |
| 63 days | 34.4 D | 55.1 AB | 6.1 D | 22.7 B | 0.81 A | 8.61 B | 36.6 A | 5.8 C | 0.40 A | 0.11C | 83.0 A | 28.0 D |

[a] Dry-weight basis. [b] Numbers in the same column with different letters are statistically different ($P \leq 0.05$).

**Table II. Regression Equations for Changes in Carbohydrate Components and Rheological Properties of Baked Sweet Potatoes Caused by Length of Storage[a]**

| | microwave | | convection | |
|---|---|---|---|---|
| component | A | B | A | B |
| TASC[b] | 0.058 | 40.8 | 0.158 | 47.3 |
| reducing sugars | 0.046 | 16.8 | 0.076 | 21.3 |
| dextrins | 0.001 | 0.78 | 0.103 | 4.17 |
| starch | 0.024 | 34.5 | −0.280 | 21.5 |
| blue value | 0.00287[c] | 0.207 | −0.000675 | 0.160 |
| static yield | 0.420[c] | 57.7 | −0.152 | 38.5 |

[a] Regression equation: % component = $A \times$ days + $B$. [b] Total alcohol-soluble carbohydrates. [c] Significant at the 0.05 level. Others are not significant.

glucosidase (Dekker and Richards, 1971). Glucose was measured by the glucose oxidase reaction. The residue remaining after dextrin extraction was dried with 100% ethanol, and lipids were extracted with a 1:1 mixture of diethyl ether–methanol. Starch was removed from the residue by equilibrating with 50 mL of dimethyl sulfoxide (DMSO) for 24 h and twice with 25 mL of DMSO for 24 h. The DMSO extracts were combined, made to 100 mL with DMSO, and added to 200 mL of absolute ethanol. After 24 h, the precipitated starch was recovered by filtration through a Whatman No. 1 filter, dried, and weighed. A sample of the starch, 0.1000 g, was dissolved by warming to 40 °C in 1.0 N NaOH. Blue value was determined as previously described (Walter et al., 1976).

## RESULTS AND DISCUSSION

The carbohydrate composition of sweet potatoes baked in the microwave oven was similar to that of the dry types (low $\alpha$-amylase) studied by Walter et al. (1975; Table I). Apparently, microwave cooking was too rapid to allow significant starch degradation by the $\alpha$-amylase. It was previously shown that $\alpha$-amylase activity increased during storage (Ikemiya and Deobald, 1966; Walter et al., 1975). However, for microwave-cooked roots, TASC, reducing sugars, dextrins, and starch did not change linearly with storage time, while starch blue value and pure$\alpha$cue static yield were positively correlated with storage time (Table II). An increase in blue value is caused by an increase in the average linear chain length of the starch. It is unlikely that the relative amounts of linear and branched components changed during the postharvest period encompassed by this study. A possible explanation is that due to a combination of the postharvest $\alpha$-amylase activity increase and heating rate peculiar to the microwave oven the branched component (amylopectin) was degraded to expose additional linear regions that participated in iodine binding.

For sweet potatoes baked in the convection oven, increases were observed in alcohol-soluble carbohydrates, reducing sugars, and dextrins. Simultaneously, decreases were noted for percent starch, blue value, and static yield (Table I). The only significant linear trends from harvest until 63 days of storage were the changes in blue value and static yield of roots cooked by microwave heating. Significant changes occurred for all other variables during the first 24 days after harvest. Comparison of the values for microwave and convectionally baked sweet potatoes indicated that those factors associated with a moist sweet potato (i.e., high sugar and dextrin content and decreased starch content and static yield) are lower in the microwave-baked roots than in the convection-oven-baked roots. Static yield increases observed for microwave-baked sweet potatoes indicated that intermolecular binding of the baked material increased. Enhanced intermolecular binding is usually caused by a rise in macromolecular size or effective concentration. It is possible that the trend observed with the microwave-cooked material is caused by the interaction of rapid heating and compositional changes in macromolecules such as pectins and hemicelluloses during postharvest storage.

**Table III. Correlation Coefficients Relating Function of Component on Static Yield**

| component | correln coeff | component | correln coeff |
|---|---|---|---|
| TASC[a] | 0.817[b] | starch | 0.880[b] |
| reducing sugars | 0.652 | blue value | 0.964[b] |
| dextrins | 0.120 | starch × blue value | 0.978[b] |

[a] Total alcohol-soluble carbohydrates. [b] Significant at the 0.05 level. Others are not significant.

Static yield was correlated with TASC, starch, and blue value (Table III). The correlations were similar to those obtained by Walter et al. (1975, 1976) between the carbohydrates and viscosity. The product of percent starch and blue value was more closely correlated with static yield than either value alone. On the basis of previous correlations between starch and mouthfeel, it appears that static yield may be a useful means of predicting mouthfeel.

We conclude from these studies that microwave cooking at full power will yield a consistently dry type of baked sweet potato. It is possible that a schedule of cooking could be devised such that the sweet potato would be heated to 80–85 °C, maintained at that temperature for about 7 min, and then finish-cooked at full power. Such a regime could result in a microwave-baked root of quality similar to that prepared by convection baking.

**Registry No.** Starch, 9005-25-8; dextrin, 9004-53-9.

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# Degradation of Pectic Substances in Carrots by Heat Treatment

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Changes in the pectic substances of carrots were studied after heat treatment. Differences in soluble pectin and calcium pectate were observed after ion-exchange chromatographic separation on DEAE (diethylaminoethyl) cellulose. Different "fingerprints" were found in both pectic fractions after heat treatment. The ratio of neutral sugars to uronic acids was almost unchanged in the soluble pectin fraction, but the relative amounts of glucose and rhamnose increased after heat treatment by about 10- and 3-fold, respectively. The ratio of neutral sugars to uronic acids in the calcium pectate increased after heat treatment from 0.11 to 0.27. On the average, all the neutral sugars increased about 3-fold while rhamnose increased about 8-fold. The increase in the relative amount of the rhamnose compared with other sugars in the heated tissue indicates possible degradation of pectins in the "hairy region".

Pectin is a polysaccharide responsible for the texture of fruits and vegetables (Jarvis, 1984). The cohesion of the pectin gel is probably the critical factor in determining fruit texture (Williams and Knee, 1980; Jarvis, 1984). The structure of the cell wall polymers of the carrot root was studied intensively by Stevens and Selvendran (1984). Results of their investigation showed that the preponderant polymers in the cell wall were pectic polysaccharides with associated arabinans and galactans. Changes in the noncellulosic cell wall polysaccharides of the carrot during growth in suspension culture were studied by Asamizu et al. (1983). The polyuronoid polymers, unlike other carbohydrates, are very susceptible to degradation by $\beta$ elimination upon heating at neutral or weakly acidic pH (Albersheim et al., 1960; Doesberg, 1965). This reaction is catalyzed by several cations and anions (Ben-Shalom et al., 1982). Unsaturated compounds, formed by the trans-elimination reaction, result from the removal of the hydrogen atom at C-5 and of the glycosidic residue at C-4 of the galacturonic acid molecule (Albersheim et al., 1960). Heat-induced degradation by $\beta$ elimination was found after isolation of cell components in potato (Keijbets et al., 1976) and in cherry (Thibault, 1983). In this study we characterized the changes found in the pectic substances after heating of the carrot tissue (blanching).

## MATERIALS AND METHODS

A 10-kg batch (for each treatment) of baby carrot (var. Amsterdam Forcing) that was obtained from the Sunfrost freezing plant in Israel was hand-peeled and divided into two samples, one of which remained untreated while the other was steam heated (blanching) for 4 min, the time found necessary to inactivate the pectin esterase (PE). Alcohol-insoluble solids (AIS) were prepared from the untreated and the blanched tissue by repeated extractions with 70% and 96% alcohol. Soluble pectin was prepared by sequential extraction of the AIS with water at room temperature until no galcturonic acid appeared in the extract. Calcium pectate was extracted from the washed pellet of the soluble pectin with 0.2% EDTA and Tris-HCl (0.02 M, pH 6.2), dialyzed against water, and freeze-dried.

The soluble pectin and calcium pectate (20 mg of galacturonic acid) were solubilized, dialyzed with sodium phosphate buffer (1 mM, pH 6.2), and applied to a column of DEAE-cellulose (Whatman) (1.6 × 20 cm), which had been equilibrated previously with the same buffer. Elution was done initially with 1 mM sodium phosphate (150 mL) and then with the same buffer, in a linear gradient of 0–0.8 M (300 mL). Fractions (3–4 mL) were collected and monitored for galacturonic acid by the *m*-hydroxyphenol method (Blumenkrantz and Asboe-Hansen, 1973) and for total carbohydrate by reaction with phenol–sulfuric acid (Dubois et al., 1956). Total neutral sugars were estimated from the difference between the two reactions based on galacturonic acid and glucose standards. Appropriate fractions eluted from the column were combined, dialyzed, and freeze-dried. The composition and the amount of individual neutral sugars were obtained by hydrolysis in trifluoroacetic acid. The respective alditol acetates were analyzed by gas chromatography as described by Albersheim et al. (1967). Methanol derived after demethylation was converted to methyl nitrite and determined by gas chromatography according to the method of Litchman and Upton (1972), as modified by Versteeg (1979). Molecular weight of the pectic fractions was determined by viscometric measurements according to Christensen (1954).

## RESULTS AND DISCUSSION

The chromatogram of soluble pectin and calcium pectate (Figures 1 and 2) on the DEAE column showed three main fractions: nonabsorbed material, which was washed with

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