EFFECTS OF AMYLOLYTIC ENZYMES ON "MOISTNESS" AND CARBOHYDRATE CHANGES OF BAKED SWEET POTATO CULTIVARS

INTRODUCTION

SWEET POTATOES have been grouped by cultivar into two major classes on the basis of the textural properties of the baked root. The "yam" type has a soft, syrupy texture and is a "moist" type; at the other extreme is the firm, mealy textured, "dry" type (Hayword, 1938). The terms "moist" and "dry" as used here designate organoleptic characteristics of the baked sweet potato and are not related to water content. There is no clear line of separation between "moist" and "dry" cultivars, so it is probably more realistic to consider a continuum of textural properties. All cultivars are "drier" at harvest than after curing and storage, thus a "moist" cultivar may have a wide range of textural properties depending upon the history of the roots.

A number of workers have studied "moist" and "dry" roots with the idea of determining their basic differences. Ali and Jones (1967) found no significant correlation between softness of baked roots and reducing sugar, maltose or dextrins in contradiction to at least two other groups. Hammett and Barrentine (1961) found that the cured Porto Rico, a "moist" type, had much higher amylopectin, dextrin and reducing sugar values than the intermediate type, Allgold. These differences became apparent only after baking. Swingle (1965), however, found no relationship between "moistness" and amylopectin content of cured baked roots and concluded that "moistness" did seem to be associated with starch content and insoluble pectins.

Sweet potatoes contain large amounts of starch which is largely converted during baking into maltose and dextrins (Ali and Jones, 1967). Gore (1920, 1923) demonstrated the presence of an active diastase in sweet potato reporting that slow cooking of the roots through a range of 60–100°C converted large amounts of starch into soluble carbohydrates. Maltose has been shown to be the sole sugar produced by cooking sweet potatoes (Sistrunk, 1954). Balls et al. (1948) crystallized the diastatic enzymes from sweet potatoes and observed that the amylolytic activity was almost entirely due to β-amylase. The presence of β-amylase in sweet potatoes and the production of maltose during baking indicates that starch conversion is due in part to this amylolytic enzyme.

The other major product of starch conversion, dextrins, are polysaccharides having a broad spectrum of molecular size formed by the action of α-amylase on starch. Ikemiya and Deobald (1966) isolated sweet potato α-amylase which had an optimum activity temperature of 70–75°C at pH 6.0. Hoover (1967) showed that in sweet potato puree, starch was not converted into maltose and dextrins until the temperature was above that for starch gelation. The object of this study was to determine the relationships among amylolytic enzyme activities, carbohydrate changes and differences in organoleptic properties in sweet potato cultivars.

MATERIALS & METHODS

FOR 1971 AND 1972, Centennial, Jewel, Porto Rico, Nuggett, Australian Canner and Pelican Processor sweet potatoes were obtained at the North Carolina Agricultural Experiment Station at Clayton, N.C. A representative sample of each cultivar was analyzed at harvest. The remainder were cured at 29–32°C and 85% relative humidity for 7 days, then stored at 16°C until used.

Random samples of about 2.5 kg were taken from each cultivar for analytical and baking tests. Only sound roots, about 1-7/8–3-3/8 in. in diameter and 3–9 in. in length, were used. About 75% of the sample was baked for organoleptic tests and the remainder used for enzyme assays. For 1972, carbohydrate analyses were also performed on raw and baked samples of Centennial, Jewel, Pelican Processor and Porto Rico cultivars.

Enzyme assays

Replicate samples of two or three roots were selected for each analysis. Roots were hand-peeled, grated and juice equivalent to 20–25% of the weight was pressed from the grated material in a hydraulic press. Enzyme assays of the juices were run in duplicate at 60°C. Substrates were prepared at the 2% level using as solvent 0.02M phosphate buffer (pH 6.0) containing 0.3% NaCl. Controls which contained heat-denatured samples were run with each set of samples.

α-Amylase

α-Amylase activity was determined by the chromogenic starch method (Walter and Purcell, 1973). Amylopectin Azure (Calbiochem.) served as substrate. Enzyme activity is expressed as APA amylase units per ml of sweet potato juice. The data were handled by analysis of variance (Snedecor, 1950).

β-Amylase

Activity of β-amylase was determined on the 1972 crop only using Lintner starch as the substrate. A 1.0 ml sample of juice or dilution was added to 15.0 ml of substrate. The reaction was continued for 5 min, then stopped with 0.2N NaOH. The amount of reducing sugar produced was determined as maltose (Hodge, 1964), and expressed as mg of maltose per ml of juice per min.

Organoleptic evaluations

For each taste panel, at least four roots of each cultivar were washed, punctured to prevent bursting and baked in a pre-heated, 191°C oven for 70 min. After baking and cooling the flesh was removed and presented to the panel on a white plate scored into six equal coded wedges. Deep red filters were used in taste panel booths to prevent the influence of color (Nelson, 1973). Panelists were instructed to rank samples in increasing intensity of moist mouthfeel with six most moist. The scores were ranked and analyzed statistically as described by Kramer and Twigg (1966).

Carbohydrate analysis

At each sampling period in 1972, several raw roots of Centennial, Jewel, Porto Rico and Pelican Processor cultivars were hand-peeled, grated and homogenized with sufficient boiling ethanol to give an 80:20 ethanol-water ratio. The slurry was heated in a boiling water bath for 1 hr, cooled and filtered. Those baked roots used for taste panel evaluations were treated in the same manner. The resulting filter cake was extracted two additional times by heating with 80% ethanol for 1 hr followed by filtration. Filtrates were combined and assayed for total carbohydrate (Dubois et al., 1956) and for reducing sugars (Hodge, 1964). The filter cake containing the alcohol insoluble substances (AIS) was retained for starch and dextrin analyses. Dry matter content was determined on a separate portion of each sample by drying weighed samples at 110°C for 24 hr.

Dextrins. Dextrins were extracted with water-ethanol (9:1) from weighed samples of AIS by shaking on a rotary shaker for about 4 hr at 200 rpm. The pellet was dehydrated by washing successively with

[1] Present address: Southwest Texas State University, San Marcos, TX 78666

ethanol, ether and hexane. The dextrin-free material was air-dried and retained for measurement of starch content.

The supernatant, which contained the total dextrin extract (TDE), was diluted and carbohydrate content was measured by the phenol-sulfuric acid procedure (Dubois et al., 1956). Dextrin content was quantitatively measured on alcohol-free aliquots of the TDE solution with the amyloglucosidase-glucose oxidase procedure of Dekker and Richards (1971).

If viscosity measurements were to be made, the TDE was freeze dried on a Freeze-Mobile apparatus (Virtus Co., Gardiner, N.Y.). Where pure dextrins were needed, the TDE solution was treated with excess saturated lead acetate solution to remove co-extracted contaminants (e.g., pectins) and excess lead removed by shaking with IRC 50 (Na^+) ion exchange resin. The dextrin solution was freeze dried, extracted with ethanol to remove sodium acetate and finally solvent dehydrated and dried in vacuo. Viscosity measurements were obtained on solutions of this material.

Starch. Starch content of the dextrin-free material was measured by the amyloglucosidase hydrolysis method of Dekker and Richards (1971) except that the glucose formed from the starch was quantitated using the alkaline copper reagent (Hodge, 1964). The glucose concentration was multiplied by appropriate factors to give the amount of starch in the original sample.

Viscosity measurements. Intrinsic viscosity determinations were made with a #50 semi-micro Cannon Ubbelohde dilution viscometer (Cannon Instruments, State College, Pa.). The sample was dispersed in 0.1M potassium chloride, filtered, and adjusted to about 2% concentration. A 1.0-ml portion was charged into a calibrated viscometer, in a water bath at 25.1 ± 0.05°C, and equilibrated. Flow time was measured in triplicate. A measured amount of solvent was added, mixed, temperature equilibrated, and flow time again measured in triplicate. This procedure was continued until a fourfold dilution was obtained. The diluted sample was removed and the carbohydrate content measured using the phenol-sulfuric acid reagent (Dubois, 1957). Using the flow times and substrate concentrations, the intrinsic viscosity $[\eta]$ was obtained (Greenwood, 1964). Viscosities for all samples were measured on solutions of 0.65%–2.2% carbohydrate.

RESULTS & DISCUSSION

Amylase activities and moistness scores (Table 1)

For both years, Pelican Processor ranked lowest in "moistness," while Centennial and Porto Rico consistently ranked highest. Jewel ranked high in moistness early in the tests but declined in rank as the seasons progressed. Australian Canner ranked low in "moistness" early in the storage period and increased in rank toward the end of storage. In all cultivars and both years, α-amylase activities increased with storage time. For both years, roots of Pelican Processor had lowest, while Centennial and Porto Rico had highest α-amylase activity. In Australian Canner, enzyme activity increased late in storage corresponding to the shift in taste panel rankings. Alpha-amylase activity in Nugget and Jewel increased steadily, but was always less than in other varieties except Pelican Processor.

Beta-amylase activities (Table 1) of the cultivars changed erratically as the season progressed. Centennial, Porto Rico and Pelican Processor were highest in β-amylase. Jewel was intermediate and Nugget and Australian Canner had the lowest activity.

Correlation coefficients between β-amylase and taste panel scores were very low and are not reported. Although α-amylase activities and "moistness" scores were not significantly correlated in the early part of the season, there was a trend toward significance as the season progressed (Table 2). In 1971, α-amylase activities were significantly correlated with "moistness" scores at 45 ($P < 0.01$) but not at 20 days. In 1972, the correlation increased between 31 and 48 days and was significant ($P < 0.05$) at 71 days. For two testing dates for 1971 and three for 1972, correlations were significant at the 0.01 and 0.05 levels, respectively. Values "at harvest" were not included. These correlations suggested that α-amylase influenced the textural properties of baked sweet potatoes.

Amylase activities and carbohydrate changes

Numerous workers have reported the conversion of starch into maltose and dextrins during baking of sweet potatoes (Southern Cooperative Series, 1970). In general, our data are similar to those reported for other cultivars; the content of sugars in raw and baked roots increased with storage. Sugar concentration in baked roots was similar for all cultivars within any sampling period, although increases with time of storage tended to be erratic. Sugar in raw roots increased during storage from about 2.0g per 100g fresh weight at harvest to about 6.0 per 100g after 71 days.

Starch and starch transformation products are shown in Table 3. Even in freshly harvested roots large amounts of starch were converted into maltose during baking. For Centennial, Jewel and Porto Rico, ranges of conversion were 63–69% at harvest and 91–95% at 71 days. Pelican Processor, a typical "dry" variety, converted only 63% of its starch when the 71-day sample was baked.

Beta-amylase levels did not seem to directly affect the amount of maltose produced during baking. For example, Jewel has significantly less activity than any of the other varieties and yet baking produced very similar amounts of maltose in all varieties. We concluded, therefore, that factors other than juice β-amylase levels control conversion of starch into maltose.

Dextrins, as well as maltose, are produced from starch during baking of sweet potatoes. The dextrin content of raw sweet potatoes is less than 0.1g per 100g fresh weight. All varieties have similar amounts and no increases are noted during storage. In all varieties, the percent of starch converted to dextrins by baking (Table 3), was lowest at harvest, and for Centennial, Jewel and Porto Rico, increased sharply during storage, and was about 27% at 71 days. For Pelican Processor, conversion into dextrins was only about 9% at 71 days.

The relationship between α-amylase activity (Table 1) and dextrin formation (Table 3) appears to be complex. Within each variety, dextrins produced by baking and raw juice α-amylase increased simultaneously with storage time of the raw roots. In Pelican Processor, enzyme levels show very little change until after 48 days of storage. Dextrin formation follows an identical path. Centennial, Jewel and Porto Rico were alike in amounts and rate of increase in formation of dextrin during baking but differ in their levels of α-amylase. Alpha-amylase was related to starch conversion but not in a simple linear fashion.

Alpha-amylase activity is also characterized by the range of dextrin molecular sizes produced. Increasing enzyme activity causes reduction in the average molecular size. Changes in molecular size can be estimated by comparing intrinsic viscosities (INV). Table 4 indicates that INV of the TDE decreases steadily with length of storage before baking, indicating decreases in molecular size. This steady decrease in the INV from stored roots occurs concurrently with increases in α-amylase activity. However, the enzyme levels are not linearly related to changes in molecular size.

The INV values for purified dextrins are inconsistent with the 48-day values for all varieties being greater than those for the 31 days. This apparent anomaly might have been caused by the procedure used to isolate the purified dextrins. We have found, in agreement with others (Diemair and Koelbel, 1963), that 10–30% of the dextrins could have been removed by co-precipitation during removal of contaminants with lead acetate. Moreover our study shows that the dextrins of highest molecular size are selectively removed. Thus a leveling effect would occur with observed INV for purified dextrins being shifted to lower values and differences between cultivars becoming smaller.

Apparently, "moistness" scores are significantly and negatively related to INV of the total dextrin extract (Fig. 1). The

Table 1—Taste panel scores and amylase activities for sweet potato varieties after baking

Variety	1971 Crop			1972 Crop			
	Harvest[a]	20-Day	45-Day	Harvest[a]	31-Day	48-Day	71-Day
	Panel "moistness" scores[b]						
Centennial	5.7t	5.3t	4.4v	5.0t	4.4t	4.8t	4.9t
Porto Rico[c]	4.3u	4.9t	5.5t	4.3u	3.4u	3.7u	4.5t
Jewel	4.5u	4.3u	2.9w	4.0u	4.5t	3.6u	3.3u
Nugget	2.2v	2.7v	2.2x	3.9u	2.6v	4.0u	3.1u
Australian Canner	2.5v	2.9v	4.9u	2.9u	4.0u	4.0u	4.3t
Pelican Processor	1.3w	1.0w	2.3y	1.0v	1.0w	1.0v	1.0v
	Alpha-amylase activity[d]						
Centennial	2.8	13.6	35.3	1.5	27.7	45.9	61.8
Porto Rico[c]	4.9	26.6	46.3	1.9	27.5	24.2	35.6
Jewel	1.2	1.9	5.6	0.6	6.5	10.9	22.7
Nugget	2.8	9.3	11.4	2.5	9.7	14.0	18.5
Australian Canner	1.9	6.6	31.3	1.5	11.8	29.2	53.1
Pelican Processor	0.7	2.9	1.5	0.8	3.3	3.1	10.3
LSD at 0.05 confidence level	1.4	9.2	5.6	1.5	3.2	4.5	12.1
	Beta-amylase activity[e]						
Centennial				32.1	28.9	32.4	22.6
Porto Rico				30.5	35.3	27.2	23.3
Jewel				9.6	11.9	11.2	10.6
Nugget				4.2	5.1	3.3	4.3
Australian Canner				8.0	8.8	6.8	7.1
Pelican Processor				19.7	22.4	16.9	21.3

[a] Not cured
[b] High score means large degree of moist "mouthfeel." Scores in same column not followed by a common letter are different at the 0.05 confidence level.
[c] Porto Rico Mutant used in 1972 crop
[d] Activity in APA units per ml of sweet potato juice at 60°C during a 15 min reaction period
[e] Activity in milligrams of maltose per ml of sweet potato juice per min at 60°C X 100

Table 2—Correlation coefficients between taste panel scores and α-amylase in baked sweet potato varieties

	Simple correlation	N
1971 Study		
20 Day	0.570	6
45 Day	0.949**	6
Both testing dates	0.714**	12
1972 Study		
31 Day	0.476	6
48 Day	0.775	6
71 Day	0.861*	6
All testing dates	0.663*	18

* $P < 0.05$
** $P < 0.01$

Table 3—Changes in starch and starch conversion products during baking of cultivars of sweet potatoes[a]

			Maltose produced[b]		Dextrins produced[d]	
		% of Total starch converted	Amount[c]	% of Converted starch	Amount[c]	% of Converted starch
Centennial	At Harvest	68.5	14.6	99.0	0.2	1.0
	31 Day	75.1	11.4	79.8	2.9	20.2
	48 Day	82.7	9.8	73.8	3.5	26.2
	71 Day	95.4	10.8	73.5	3.9	26.5
Jewel	At Harvest	62.9	14.2	99.2	0.1	0.8
	31 Day	84.8	13.6	80.8	3.2	19.2
	48 Day	81.0	9.3	71.5	3.7	28.5
	71 Day	92.0	9.9	71.9	3.9	28.1
Porto Rico Mutant	At Harvest	65.4	13.8	99.1	0.1	0.9
	31 Day	62.6	9.8	85.6	1.7	14.4
	48 Day	84.8	10.4	73.8	3.7	26.2
	71 Day	91.4	11.8	72.4	4.5	27.6
Pelican Processor	At Harvest	53.8	15.5	99.0	0.2	1.0
	31 Day	49.5	13.3	98.6	0.2	1.4
	48 Day	42.0	9.9	97.3	0.3	2.7
	71 Day	63.4	13.6	90.7	1.4	9.3

[a] In 100g of raw sample
[b] Sugar in baked root less sugar in raw root
[c] Grams in 100g of a raw sample
[d] Dextrin in baked root less dextrin in raw root

Table 4—Intrinsic viscosity (INV)[a] for total dextrin extract (TDE)[b] and purified dextrins[c] in baked sweet potato varieties

	Intrinsic viscosity	
	Total extract	Dextrins
At Harvest		
Centennial	72.7	—[d]
Jewel	73.1	—[d]
Porto Rico Mutant	54.5	—[d]
Pelican Processor	—[d]	—[d]
31 Day		
Centennial	32.1	12.8
Jewel	33.1	17.1
Porto Rico Mutant	39.2	16.1
Pelican Processor	78.4	—[d]
48 Day		
Centennial	28.8	14.6
Jewel	35.8	20.5
Porto Rico Mutant	35.4	18.2
Pelican Processor	56.6	—[d]
71 Day		
Centennial	27.6	11.8
Jewel	33.8	18.5
Porto Rico Mutant	31.1	13.7
Pelican Processor	38.4	25.3

[a] Grams per ml in 0.1M KCl. Viscosities measured in the same concentration range for all samples.
[b] Material extracted with 10% aqueous ethanol freeze dried and reconstituted before viscosities were measured.
[c] Purified by lead acetate removal of contaminants
[d] Insufficient material for viscosity studies

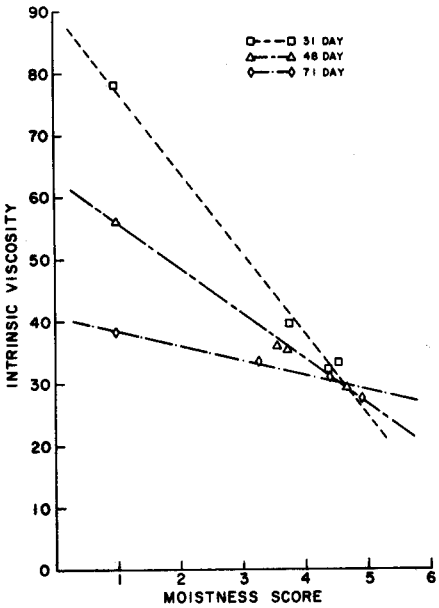

Fig. 1—Relation between organoleptic "moistness" score and intrinsic viscosity of the total dextrin extract for four baked sweet potato cultivars. Data are for three storage times at 16°C.

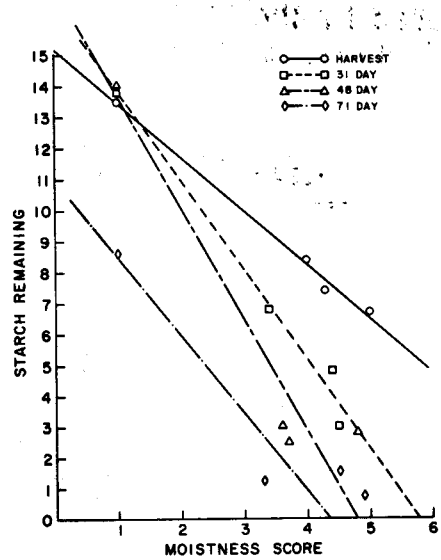

Fig. 2—Relation between organoleptic "moistness" score and starch remaining after baking for four sweet potato cultivars. Data presented are for four storage times.

combined correlation coefficient for all varieties for three panel dates is -0.793 ($P < 0.01$). Moistness scores were more highly correlated with INV than with α-amylase activities. This relation suggests that dextrins, pectins and, possibly, other components of TDE interact and thereby influence the textural differences described as "moistness" or "dryness." Others (Chen and Joslyn, 1967a, b) have reported that mono- and disaccharides or chemically-prepared dextrins added to pectin solutions interact to cause changes in the flow characteristics of the pectin solutions. Changes in this property have an impact on what humans perceive as textural properties.

A part of the mouthfeel could also be contributed by that starch which is not converted during baking. Possibly, as starch is removed by enzymatic action, the "dryness" decreases or "moistness" increases. A plot of "moistness" scores versus unconverted starch (Fig. 2) indicated that the two variables are negatively related. The combined correlation coefficient for four varieties and four panel dates is -0.859 ($P < 0.01$). Thus, both INV and starch remaining are significantly correlated with "moistness" scores.

The textural property of "moistness" or "dryness" in sweet potatoes is a complex organoleptic sensation. No one factor appears to be more important than all others. Our data indicate that mouthfeel depends on the amount of starch remaining after baking, the amounts and molecular sizes of dextrins and possibly on the amount of sugar present. All of these properties are affected by amylolytic enzymes. In addition, the unconverted starch probably had been partially degraded by amylolytic enzymes and might have contributed to the overall property of moist mouthfeel. Very probably the presence and state of pectin and cellulose fibers also exerted important influences. The effects of small changes in these variables upon mouthfeel is not known.

REFERENCES

Ahmed, E.A. and Scott, L.E. 1957. Pectin constituents of the fleshy roots of the sweet potato. Proc. Amer. Soc. Hort. Sci. 71: 376.
Ali, M.K. and Jones, L.G. 1967. The effect of variety and length of storage on the carbohydrate contents and table quality of sweet potatoes. Pakistan J. Sci. Ind. Res. 10: 121.
Balls, A.K., Walden, M.K. and Thompon, R.R. 1948. A crystalline β-amylase from sweet potato. J. Biol. Chem. 173: 9.
Chen, T.-S. and Joslyn, M.A. 1967a. The effect of sugars on viscosity of pectin solution. 1. Comparison of corn syrup with sucrose solutions. J. Colloid. Interface Sci. 23: 399.
Chen, T.-S. and Joslyn, M.A. 1967b. The effect of sugars on viscosity of pectin solution. 2. Comparison of dextrose, maltose and dextrins. J. Colloid. Interface Sci. 25: 346.
Dekker, R.F.H. and Richards, G.N. 1971. Determination of starch in plant material. J. Sci. Fd. Agric. 22: 441.
Deobald, H.J., Hasling, V.C., Catalava, E.A. and McLemore, T.A. 1969. Relationship of sugar formation and sweet potato alpha-amylase activity during processing for flake production. Food Technol. 23: 118.
Diemair, W. and Koelbel, R. 1963. Detection and determination of dextrins from dilute solutions; Wines. Z. Lebensm.-Untersuch-Forsch. 124: 1.
Dubois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A. and Smith, F. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28: 350.
Gore, H.C. 1920. Occurrence of diastase in the sweet potato in relation to the preparation of sweet potato syrup. J. Biol. Chem. 44: 19.
Gore, H.C. 1923. Formation of maltose in sweet potatoes on cooking. Ind. and Eng. Chem. 15: 938.
Greenwood, C.T. 1964. "Methods in Carbohydrate Chemistry," Vol 4, p. 179, Ed. Whistler, R.J. Academic Press, New York.
Hammett, H.J. and Barrentine, B.F. 1961. Some effects of variety curing and baking upon the carbohydrate content of sweet potatoes. Proc. Amer. Soc. Hort. Sci. 78: 421.
Hayword, H.E. 1938. "The Structure of Economic Plants." Macmillan Co., New York.
Hodge, J.E. 1964. "Methods in Carbohydrate Chemistry," Vol 1, p. 386, Ed. Whistler, R.J. Academic Press, New York.
Hoover, M.W. 1967. An enzyme-activation process for producing sweet potato flakes. Food Technol. 21: 322.
Ikemiya, M. and Deobald, H.J. 1966. New characteristic alpha-amylase in sweet potatoes. J. Agr. Food Chem. 14: 237.
Jenkens, W.T. and Geiger, W. 1957. Curing, baking time and temperatures affecting carbohydrates in sweet potatoes. Proc. Amer. Soc. Hort. Sci. 70: 419.
Kramer, A. and Twigg, B.A. 1966. "Fundamentals of Quality Control for the Food Industry." Avi Publishing Co., Inc., Westport, Conn.
Nelson, A.M. 1973. Shear press testing to define mouthfeel characteristics of baked sweet potatoes. M.S. thesis, N.C. State University, Raleigh, N.C.
Sistrunk, W.A., Miller, J.L. and Jones, L.G. 1954. Carbohydrate changes during storage and cooking of sweet potatoes. Food Technol. 8: 223.
Snedecor, G.W. 1950. "Statistical Methods." Iowa State College Press, Ames, Iowa.
Southern Cooperative Series. Bull. No. 159. 1970. "Thirty Years of Cooperative Sweet Potato Research — 1939—1969," p. 36.
Swingle, H.D. 1965. "The Relation of Pectin Substances and Starch to Consistency and Moistness of Sweet Potatoes." University Microfilms, Inc., Ann Arbor, Mich., Order No. 66-10923.
Walter, W.M. Jr. and Purcell, A.E. 1973. Alpha-amylase in sweet potatoes. A comparison between the amyloclastic and chromogenic starch methods of analysis. J. Food Sci. 38: 548.

Ms received 9/4/74; revised 11/12/74; accepted 11/17/74.

We thank Dr. Daniel T. Pope of the Dept. of Horticultural Science, North Carolina State University, for the sweet potato cultivars. We thank Dr. Pope and Dr. Leaton J. Kushman of the U.S. Dept. of Agriculture for constructive advice while this study was in progress.

Paper No. 4378 of the Journal Series of the North Carolina Agricultural Experiment Station, Raleigh.