chromoplast of the tomato fruit.

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Distribution of Protein within Sweet Potato Roots (*Ipomea batatas* L.)

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Distribution of protein within roots of three sweet potato cultivars was studied. End-to-end gradients of protein concentration were small but significant in Jewel and Centennial, with higher concentration toward the stem end. Circumferential protein gradients in Jewel and Centennial were consistent year to year but were not statistically significant. Cultivar 213×228-1 had no significant gradients. There was no evidence of radial gradients in any cultivar. All gradients were too small to suggest modified processing to obtain high protein products.

Sweet potato could be a significant source of protein with some varieties containing up to 9% protein (Purcell et al., 1972). Protein contents differ between cultivars and possibly from year to year (Purcell et al., 1976). Some of the reported variation might be due to sampling error caused by uneven distribution of protein in roots. Uneven distribution of starch and carotene in roots apparently has been recognized, since it was standard practice to cut a longitudinal section from the root as a sample (Anderson, 1956).

If protein were unevenly but consistently distributed within roots, sampling might be improved and processing modified to increase protein content of products from sweet potatoes. We have studied sweet potatoes to determine whether protein distribution does vary and whether variation is influenced by cultivar, root size, or

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total protein content. End-to-end, circumferential and radial distribution were studied.

MATERIALS AND METHODS

Sweet Potatoes. Samples selected were: 1972, Centennial and Jewel from the North Carolina Agricultural Experiment Station (NCAES) Farm near Clayton, N.C.; 1973, Centennial, Jewel, and an experimental cultivar, 213×228-1, from the NCAES farm at Clayton and other samples of Centennial and Jewel from a commercial packer near Wake Forest, N.C.; 1974, Jewel and Centennial from the same sources as 1973. Roots from the experimental farm were cured for 1 week at 30°C and 90% relative humidity and stored at 13°C and near 50% humidity; roots from the commercial packer were treated similarly. All samples were thoroughly washed in tap water and dried at room temperature for 2 hr before further handling.

End-to-End Sampling. In 1972, six U.S. No. 1 medium size roots were cut across the longitudinal axis one-fourth the length from the stem end and root end providing three samples: stem end one-fourth, center one-half, and root end one-fourth. Corresponding parts were composited, dried, ground to a powder, and analyzed in duplicate. In 1973, three roots representing the largest, medium, and smallest size of U.S. No. 1 of each variety and location were selected. Roots were cut across the longitudinal axis into six equal parts and numbered 1–6 starting at the stem end. Each section was weighed and cut into small pieces. The entire smaller sections or 20 g from larger sections were weighed to 0.1 g, dried, reweighed, and analyzed for protein. In 1974, 10 roots of each size, each cultivar, and each location were similarly sectioned. Like sections were composited, dried, ground, and analyzed.

Circumferential Distribution. In 1972, six roots of Centennial and six of Jewel within the medium size range of U.S. No. 1 were selected. Roots were peeled with a kitchen peeler and peelings were collected as sample 1. Each peeled root was weighed and a uniform layer consisting of one-fourth the weight of the root was removed with the peeler, sample 2. This procedure was repeated for samples 3 and 4. Sample 5 was the core remaining. Corresponding parts were composited, dried, ground, and analyzed. In 1973, one straight root was selected in each of three sizes of each cultivar and each location. Tapered ends of each root were removed to give a cylindrical center section, which was scraped to remove the brown outer peel estimated to be 0.1–0.3 mm thick, sample 1. An attempt was made to obtain visible gross anatomical layers as separate fractions. Since nomenclature of these layers is confusing (Artschwager, 1924; Hayward, 1938; McCormack, 1916; Wilson and Lowe, 1973), designation of the layers is described. Sample 2 was obtained by cutting along the outer ring of latex droplets which formed at the cut surfaces. Thickness was about 0.1 × maximum radius of the cylindrical section. Sample 3 was composed of the layer that appeared to have radial orientation of structure. Thickness of this layer was about 0.25 × radius of the original section and ranged from 5 to 9 mm. Samples 4 and 5 were obtained by removing subsequent layers equal in thickness to sample 3. Sample 6 was the remaining core. Sample 4 contained no latex droplets, indicating it had no areas of vascular cambium. Sample 5 contained variable numbers and sample 6, numerous latex droplets. Samples were weighed to 0.01 g, dried, and reweighed. In 1974, 10 roots of each size, each cultivar, and each location were prepared and divided as in 1973. Corresponding fractions were composited, dried, ground, and assayed.

Radial Distribution. Samples of Jewel and Centennial roots from Wake Forest and 213×228-1 from Clayton were selected as for the 1973 end-to-end sampling. Efforts were made to obtain straight roots with circular cross sections. Roots were laid on a cutting board with the stem end toward the observer and cut along the longitudinal axis. Each half was again cut along the longitudinal axis. The quarters were designated ABCD in a clockwise direction. Each quarter was dried, ground, and analyzed.

Table I. Protein Content of End-to-End Fractions of Three Sweet Potato Cultivars (Means of Three Sizes and Two Locations), 1973[a]

Section	% protein (dry basis)		
	Centennial	Jewel	213×228-1
1	8.44[a]	4.91[n]	5.52
2	7.82[b]	6.10[m]	5.28
3	6.80[c]	5.11[no]	4.64
4	6.68[c]	5.65[m]	4.58
5	6.90[c]	4.47[o]	4.71
6	5.54[d]	5.72	5.03

[a] LSD, 0.05, 0.95. Figures with the same superscript letter are not significantly different.

Analyses. Material for protein analysis was dried in a forced air oven at 77°C for 8 hr and ground. Nitrogen in 2–2.5 g of dried material was determined by the Kjeldahl method using copper and selenium catalysts. Protein was calculated as N × 6.25.

Microscopic Examination. Hand sliced sections and tissue mashes from various sections or layers were fixed to gelatin coated slides by heating and drying at 65–70°C. Starch was removed by covering the slides with 1 *N* NaOH and holding at 20°C overnight. The alkali solution was carefully removed with filter paper wicks and the slides were dried in a desiccator over sulfuric acid, and coated with celloidon. Alkali remaining in the tissues was removed by soaking in water and the specimen was stained by periodic acid–Schiff's base and counter stained with fast green (Jensen, 1962).

RESULTS AND DISCUSSION

End-to-End Distribution. Data from 1972 suggested an end-to-end gradient in protein concentration, with slightly more protein in the stem end. Values for the stem end 1/4, center 1/2, and root end 1/4 were 6.07, 5.41, and 5.04% for Centennial and 5.29, 5.26, and 5.12% for Jewel. Statistical statements were not obtained.

Data from 1973 supported the observations of 1972 by showing significant end-to-end differences in Centennial and Jewel (Table I). The six fractions of 1973 showed some differences which were not evident in the 1972 samples. In Jewel and Centennial, protein content was significantly different in section 2 than in sections 1 and 3. In Centennial section 6, the root end contained significantly less protein than other sections. Section 1 showed considerable variation possibly because of shape; sections with small diameters were associated with low protein. Protein content in the root end was also variable, perhaps for the same reason. Weighted averages for sections 1 and 2, 3 and 4, and 5 and 6 showed essentially the same gradient as that noted in 1972. There was no significant gradient of protein concentration in 213×228-1. The pattern of distribution was essentially the same as those in 1973 but with less variance (Table II). The regression coefficient of protein content upon section number was −0.248 ($P \leq 0.001$) for Centennial in 1973 and −0.142 ($P \leq 0.001$) in 1974. Corresponding values for Jewel were −0.004 (NS) and −0.129 ($P \leq 0.001$). The coefficient for 213×228-1 in 1973 was −0.060 (NS).

Analysis of variance on protein content involving source, cultivar, size, and section indicated that size and source were not significant factors in the disribution of protein.

Table II. Protein Content of End-to-End Fractions of Two Sweet Potato Cultivars (Means of 10 Root Samples of Three Sizes and Two Cultivars), 1974[a]

Section	% protein (dry basis) Centennial	Jewel
1	7.67[a]	6.19[m]
2	7.09[b]	5.62[n]
3	6.45[c]	5.31[no]
4	6.28[c]	5.06[op]
5	6.31[c]	4.91[op]
6	6.18[c]	4.86[p]

[a] LSD, 0.05, 0.35. Figures with the same superscript letter are not significantly different.

Table III. Protein Contents of Two Sweet Potato Cultivars from Two Sources in 1973 and 1974

Sample used to study	% protein (dry basis) 1973 Clayton	1973 Wake Forest	1974 Clayton	1974 Wake Forest
End-to-end distribution				
Centennial	5.44	8.68	6.14	7.18
Jewel	4.17	6.18	3.99	6.65
LSD 0.05	0.34		0.27	
Circumferential distribution				
Centennial	6.64	8.80	6.25	6.12
Jewel	4.36	6.96	4.21	6.28
LSD 0.05	0.61		0.51	

Although roots from the two sources had very different protein concentrations (Table III), there was no evidence of differences in distribution due to source.

Circumferential Distribution. Protein distribution did not differ significantly in circumferential fractions, but was consistent within cultivars for all 3 years. Differences in 1974 approached significance suggesting that larger samples might show significance. Fraction 1, the brown outer peel, was not included in statistical analysis since it comprised less than 1% of the weight. Fraction 2 of 1972 was about equal to fractions 2 and 3 for the other 2 years. In 1973 and 1974 fraction 2 of Jewel and Centennial had a higher protein content than fraction 3. Protein concentrations in fractions 5 and 6 of Centennial were higher than in fractions 3 and 4. This was not so in Jewel. The 213×228-1 roots appeared to be nearly uniform.

As in end-to-end distribution, root size had no effect on protein distribution nor on mean protein content. Mean protein content differed significantly due to source (Table III) but had no effect on distribution.

Radial Distribution. There appeared to be no radial differences in protein content for any of the cultivars. When computed as the original data, the probability level for differences was 0.93. When the data were arranged so that the quarter highest in protein became number 1 and other quarters were numbered clockwise from number 1, probability of differences became 0.15. This arbitrary arrangement of data exaggerates any possible differences, but even with this arrangement significant differences were not found.

Microscopic Observation. Microscopic observations did not provide an obvious explanation for these gradients. Thinner parts of the root at each end contain relatively more vascular bundles and fewer enlarged starch cells, but differences between stem end and root end were not apparent. Protein content in a section may depend upon varying amounts of cambium, cellulosic fibers, and enlarged starch bearing cells. Circumferential fractions showed minor differences in shape of some cells but enlarged starch cells were dominant in all fractions. Microscopic examination did not reveal any protein bodies comparable to the aleurone grains of peanut. Apparently protein was distributed in cytoplasm and cell walls. There was no histological suggestion that any region contained more or less protein than others.

SUMMARY

Protein concentration in Centennial and Jewel sweet potatoes appeared to differ significantly end-to-end, with 20–30% higher concentration toward the stem end. The differences were not consistent from one cultivar to the other. There was no gradient in 213×228-1. The end-to-end gradients in Centennial and Jewel were sufficient to cause significant sampling error if small cross sections were taken at random. Circumferential gradients of protein concentration were not significant. The only consistency between cultivars was high protein in the outer layer, 0.1 radius thick layer. Sampling procedures which change the relative amounts of the circumferential layers would cause small errors. There was no evidence of radial gradients of protein concentration.

These data show that a sample consisting of a longitudinal section, as used by earlier workers (Anderson, 1956), is valid and indeed necessary if only part of the root is taken before homogenization.

Protein gradients were too small to suggest that sweet potato products with higher protein content would be obtained by selective processing. Peeling methods which remove only the brown outer peel are not wasteful of protein but methods which remove 0.1 × the radius of the root would remove a high protein layer.

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