Protein Nutritional Value of Sweet Potato Flour

William M. Walter, Jr.,* George L. Catignani, Leslie L. Yow, and David H. Porter

"Jewel" and "Centennial" cultivars were stored until the nitrogen levels exceeded 1.8% dry basis (0.45% fresh basis). The roots were then peeled, cooked, and dehydrated by drum-drying (160 °C drum surface) and forced-air-drying (60 °C). The dehydrated flours were assayed for amino acid composition of an acid hydrolysate, nonprotein nitrogen, and available lysine (relative fluorescence assay; Goodno et al., 1981). The flours were then incorporated into diets for measurements of the protein efficiency ratio (PER). PER values (relative to a PER of 2.5 for ANRC casein) ranged from 2.2 to 1.3, depending upon the cultivar and dehydration treatment. Although amino acid analyses indicated little difference in levels of lysine (the first limiting amino acid for rat growth) between high- and low-PER flours, the value for available lysine correlated well with PER values. It appears that available lysine assays should be included in predicting the nutritional quality of heat-treated vegetable proteins where lysine is the limiting amino acid.

Although regarded in the United States as a high-energy, low-protein food, the sweet potato serves as fairly important protein source in parts of Asia. The biological value of sweet potato protein is quite good. Adolph and Liu (1939) reported that human beings can be maintained in nitrogen balance solely on nitrogen from sweet potatoes. Isolated sweet potato protein has a protein efficiency ratio (PER) equal to that of casein (Walter and Catignani, 1981).

Purcell et al. (1978) and Purcell and Walter (1980) found that in "Jewel" sweet potatoes, as much as 40% of the total nitrogen exists as nonprotein nitrogen (NPN). The NPN fraction (not precipitated by 12% trichloroacetic acid) contained mainly asparagine and aspartic and glutamic acids. Since NPN to N ratios are highly dependent on cultivar, determination of protein by the Kjeldahl method (percent total nitrogen × 6.25) may lead to overestimation of the actual amount of protein present.

Recently, Purcell and Walter (1982) found by amino acid analysis that the major protein nutritional change caused by heat processing is lysine destruction. There appeared to be a greater loss of this amino acid in canned or drum-dried material than in baked sweet potatoes. However, part of the lysine measured by amino acid analysis after acid hydrolysis may be biologically nonavailable (Carpenter, 1973).

The purpose of this study was to compare: (1) the PER of sweet potato cultivars containing different amounts of NPN and (2) the effect of heat processing on PER, amino acid patterns, and lysine availability.

MATERIALS AND METHODS

Sweet Potatoes. "Jewel" and "Centennial" sweet potatoes were grown at the Central Crops Research Station near Clayton, NC. They were cured 1 week at 30 °C and 80–90% relative humidity and stored at 13 °C and 60–70% relative humidity for 9–18 months before use.

Sweet Potato Flour. "Centennial" roots were washed, hand peeled, and sliced into strips, 1 × 5 × 0.2 cm thick. The strips were cooked in culinary steam at atmospheric pressure for 5 min. Half of the cooked strips were dried at 60 °C in a forced-draft oven for 24 h. The dried strips were milled into ≤60-mesh particles and stored under nitrogen at −20 °C.

The remainder of the cooked strips were comminuted and dried on a 30.5 × 48.2 cm double-drum dryer heated with steam at 80 psi and a retention time of 30 s. The flakes were milled into ≤60-mesh particles and stored under nitrogen at −20 °C. "Jewel" roots were handled in the same way except the entire sample was processed into oven-dried flour.

Nitrogen Analyses. The nitrogen content of the flour samples, casein, and all diets was determined by the macro-Kjeldahl method using copper and selenium catalysts. The protein content was calculated as $N \times 6.25$. The NPN content of the flours was measured by determination of the nitrogen content before and after exhaustive extraction with 70% aqueous methanol (Purcell and Walter, 1980).

Amino Acid Analysis. Samples of sweet potato flour, casein, and residues from extraction of flour with 70% aqueous methanol were acid hydrolyzed, and the amino acid content was measured on a Durrum Model D-500 with a 1.75 mm × 48 cm column packed with Durrum high-resolution cation-exchange resin (Miller and Young, 1977). Tryptophan content was not measured.

Lysine Analysis. Available lysine of dried residues from extraction of the flours with 70% aqueous methanol (NPN free) was measured by the fluorometric assay of Goodno et al. (1981), except that the samples were incubated in 1% sodium dodecyl sulfate overnight at 38 °C prior to analysis to solubilize the protein. NPN-free material was used in this assay because the methanol extraction step removed most of the interfering β-carotene. The NPN fraction has been shown to contain less than 0.1% lysine (Purcell and Walter, 1980).

Protein Efficiency Ratios. Diets were formulated (AOAC, 1975) from oven-dried and drum-dried "Centennial" flours and oven-dried "Jewel" flour and the reference diet was formulated from ANRC casein. Using male Sprague-Dawley rats as the test animal, the feeding study was conducted as described by Walter and Catignani (1981). Protein efficiency ratios were calculated from protein intake and weight gain data for the 28-day test period.

Statistical Analysis. The effect of processing treatment on PER values was determined by analysis of variance and the Waller-Duncan K-ratio T test (SAS, 1979).

RESULTS AND DISCUSSION

The sweet potatoes used in this study contained insufficient nitrogen at harvest to do a PER study. Consequently, they were held at 13 °C and 65% relative hu-

U.S. Department of Agriculture, Agricultural Research Service, Southern Region, and North Carolina Agricultural Research Service, Department of Food Science, North Carolina State University, Raleigh, North Carolina 27650 (W.M.W.), and Department of Food Science, North Carolina State University, Raleigh, North Carolina 27650 (G.L.C., L.L.Y., and D.H.P.).

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Table I. Nitrogen Content of Whole and NPN-Free[a] Sweet Potato Flours

sample	% nitrogen	% NPN[b]
"Centennial" oven-dried		
whole flour	1.93	24.3
NPN free	2.55	
"Jewel" oven-dried		
whole flour	1.85	34.7
NPN free	2.81	
"Centennial" drum-dried		
whole flour	2.00	23.5
NPN free	2.62	

[a] Extracted with 70% aqueous methanol to remove nonprotein nitrogen. [b] Percent of total (Kjeldahl) nitrogen.

midity until sufficient starch had been metabolized to increase nitrogen levels of the flours to above 1.8% (Table I) (Purcell et al., 1978). The prolonged storage that was required to decrease the carbohydrate levels also resulted in increased NPN content, particularly for "Centennial", which normally has an NPN content below 15%. The normal range of NPN for "Jewel" is from 25 to 35%.

When the flours were formulated into diets and fed to rats, the PER values (corrected) ranged from 2.22 for "Centennial" oven-dried flour to 1.18 for "Centennial" drum-dried flour (Table II). The "Jewel" oven-dried flour was intermediate with a PER of 2.00.

Examination of the amino acid composition of the flours (Table III) revealed that "Centennial" oven-dried flour has the best balance of those essential amino acids required for rat growth. Lysine is the first limiting amino acid for both varieties, followed by the sulfur amino acids and isoleucine. Leucine also is limiting in "Jewel". "Centennial" oven-dried flour has higher levels of all limiting essential amino acids and thus has the highest PER of the three flours tested.

The basis for PER assays is that protein quality (i.e., amino acid composition plus bioavailability) is the limiting factor in rat growth. Sweet potato protein from many cultivars has been shown by chemical analysis (Purcell et al., 1972) to have similar amino acid patterns. "Jewel" and "Centennial" proteins have indistinguishable PER values (Walter and Catignani, 1981). However, "Centennial" oven-dried flour is nutritionally superior to "Jewel" oven-dried flour because "Jewel" flour has the higher NPN value. Purcell and Walter (1980) showed that most NPN is present as nonessential amino acids, thus lowering the amounts of essential amino acids as a percentage of the total nitrogen. This study has shown that sweet potatoes with a high NPN will be nutritionally inferior to those with low NPN values. Consequently, when new cultivars are being evaluated, it is incorrect to assume that Kjeldahl or other procedures for measuring total nitrogen give an accurate measure of the true protein content. In order to measure the true protein content, the NPN must be removed. Removal of NPN by solvent extraction prior to nitrogen determination has also been suggested for white potatoes (Li and Sayre, 1975).

On the basis of amino acid content (Table III), "Jewel" oven-dried and "Centennial" drum-dried flours should have similar PER values. However, the "Centennial" drum-dried flour is much poorer nutritionally (Table II). Sweet

Table II. Protein Efficiency Ratio (PER) for Sweet Potato Flours[a]

protein source	PER[b]	corrected PER[b,c]	wt gain, g	food consumed, g	initial group wt, g
casein (study no. 1)	2.32 ± 0.19^{A}	2.50^{A}	89.1 ± 12.0	386.1 ± 31.0	76.5 ± 2.1
"Centennial" oven-dried flour	2.06 ± 0.11^{B}	2.22^{B}	86.2 ± 9.3	417.9 ± 27.4	76.5 ± 2.0
"Centennial" drum-dried flour	1.18 ± 0.15^{D}	1.27^{D}	38.7 ± 6.2	328.6 ± 26.8	77.0 ± 2.2
casein (study no. 2)	2.25 ± 0.17^{A}	2.50^{A}	75.8 ± 12.9	334.2 ± 47.2	70.3 ± 3.8
"Jewel" oven-dried flour	1.80 ± 0.17^{C}	2.00^{C}	56.8 ± 7.5	313.4 ± 13.4	70.0 ± 3.8
LSD_{05}	0.11	0.12			

[a] Mean and standard deviation calculated from data on 10 rats per diet group. [b] Numbers with different letter superscripts are different at the $P \leq 0.05$ level. [c] Converted by adjusting test diets to 2.5 for casein (AOAC).

Table III. Amino Acid Analysis of Flours from "Jewel" and "Centennial" Sweet Potatoes

	whole flour			NPN extracted			
	oven-dried		drum-dried,	oven-dried		drum-dried,	
	"Jewel"	"Centennial"	"Centennial"	"Jewel"	"Centennial"	"Centennial"	rat[b]
essential[a]							
threonine	5.32	5.57	5.58	6.29	5.78	5.81	4.6
valine	6.67	7.55	7.82	8.95	8.59	8.42	5.1
methionine	0.97	1.19	1.32	1.54	1.38	1.25	4.6
half-cystine	1.22	1.37	1.41	2.02	1.83	1.75	
isoleucine	3.94	4.38	4.86	5.22	5.08	4.99	5.0
leucine	5.85	6.51	6.60	7.72	7.48	7.44	6.3
tyrosine	3.97	3.52	4.12	5.70	5.27	5.13	6.6
phenylalanine	5.94	6.33	6.70	7.23	6.91	6.84	
lysine	3.82	4.47	3.80	5.09	5.28	4.69	8.2
nonessential[a]							
aspartic acid	22.43	18.17	19.42	18.85	16.60	17.17	
serine	5.47	5.75	5.92	6.50	6.24	6.66	
glutamic acid	10.98	12.41	12.40	12.52	11.76	11.60	
proline	2.54	4.26	2.95	5.64	4.40	4.03	
glycine	4.29	4.73	4.92	5.57	5.22	5.15	
alanine	3.56	4.42	4.54	5.04	4.70	5.04	
histidine	3.09	3.30	3.50	3.70	3.34	3.50	1.9
NH_3	1.83	1.51	1.65	1.67	1.30	1.39	
arginine	4.17	4.47	4.66	5.70	5.18	5.17	

[a] Grams of amino acid per 16 g of nitrogen. Means of duplicate analyses. Tryptophan not measured. [b] Amino acid pattern for rat growth (Said and Hegsted, 1970).

Table IV. Relative Fluorescence of Sweet Potato Flours[a]

sample	relative fluorescence[b,c]
"Centennial" oven-dried flour	4.21^{A}
"Jewel" oven-dried flour	3.71^{B}
"Centennial" drum-dried flour	3.14^{C}
LSD_{05}	0.13

[a] All flours extracted with 70% aqueous methanol to remove β-carotene and nonprotein nitrogen. [b] Mean of four replicates for each sample. [c] Numbers with different superscript letters are different at the $P \leq 0.05$ level.

potatoes processed by drum-drying are subjected to much higher temperatures. A common problem associated with such treatment in high carbohydrate foods is the reaction of the ε-amino group of lysine with reducing groups of carbohydrates which causes the lysine to become nutritionally unavailable. In some cases, acid hydrolysis prior to amino acid analysis can liberate nutritionally unavailable lysine. Subsequent amino acid analysis would indicate that the lysine content is higher than it actually is from a nutritionally standpoint (Carpenter, 1973).

Table III shows that the lysine content is higher in oven-dried "Centennial" flour than in drum-dried "Centennial" flour. This is as expected because some of the lysine is irreversibly destroyed. However, lysine levels are essentially identical in drum-dried "Centennial" flour and oven-dried "Jewel" flour. Since levels of other essential amino acids are somewhat higher in the drum-dried flour, one would expect that PER value for "Centennial" drum-dried would be somewhat higher than that of "Jewel" oven-dried flour. The PER for "Jewel" oven-dried flour is much higher than the PER for "Centennial" drum-dried flour.

In an attempt to determine if nutritionally unavailable acid hydrolysable lysine was responsible for this discrepancy, we performed the flourometric procedure for available lysine (Goodno et al., 1981) on methanol-extracted flours. Solvent extraction was necessary to remove β-carotene, which has a λ_{max} very close to the emission maximum for the lysine–phthalaldehyde reaction product.

From relative fluorescence data (Table IV), the available lysine decreases in the same order as the PER values, that is, "Centennial" oven-dried > "Jewel" oven-dried > "Centennial" drum-dried. Our study indicates that for drum-dried vegetable products containing high carbohydrate levels, the relative fluorescence assay is a better measure of nutritionally available lysine than is the acid hydrolysis–amino acid analysis procedure.

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LITERATURE CITED

Adolph, W. H.; Liu, H.-C. *Chin. Med. J. (Peking, 1932–1966)* **1939**, *55*, 337.
AOAC "Official Methods of Analysis", 12th ed.; Association of Official Analytical Chemists: Washington, DC, 1975; p 857.
Carpenter, K. J. *Nutr. Abstr. Rev.* **1973**, *43*, 404.
Goodno, C. C.; Swaisgood, H. E.; Catignani, G. L. *Anal. Biochem.* **1981**, *115*, 203.
Li, P. H.; Sayre, K. D. *Am. Potato J.* **1975**, *52*, 341.
Miller, J.; Young, C. T. *J. Agric. Food Chem.* **1977**, *25*, 653.
Purcell, A. E.; Swaisgood, H. E.; Pope, D. T. *J. Am. Soc. Hortic. Sci.* **1972**, *97*, 30.
Purcell, A. E.; Walter, W. M., Jr. *J. Agric. Food Chem.* **1980**, *28*, 842.
Purcell, A. E.; Walter, W. M., Jr. *J. Agric. Food Chem.* **1982**, *30*, 443.
Purcell, A. E.; Walter, W. M., Jr.; Giesbrecht, F. G. *J. Am. Soc. Hortic. Sci.* **1978**, *103*, 190.
Said, A. K.; Hegsted, D. M. *J. Nutr.* **1970**, *100*, 1363.
SAS "SAS User's Guide"; SAS Institute, Inc.: Raleigh, NC, 1979.
Walter, W. M., Jr.; Catignani, G. L. *J. Agric. Food Chem.* **1981**, *29*, 797.

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Pectic Substances in Raw and Cooked, Fresh or Processed Spanish Vegetables

Concepción Vidal-Valverde,* Manuel Perez Lopez, and Enrique Rojas-Hidalgo

The content of pectic substances (PS) (as anhydrogalacturonic acid) (AGA) was determined on samples of 19 fresh vegetables (raw and cooked), 8 fresh vegetables (raw), 5 frozen vegetables (raw and cooked), and 5 canned vegetable products (3 of which were also analyzed after frying). The PS content of fresh vegetables ranged between 0.19% (mushroom) and 2.5% (potato). The culinary process produces a decrease in the PS content that is most pronounced in the case of frying. Frozen vegetables had a PS content similar to that found in fresh vegetables. The PS content of canned vegetables, however, was lower than those observed in fresh or frozen vegetables. Cooking of processed vegetables produces effects on the PS content that are similar to the effects observed in cooking fresh vegetables.

The beneficial effects of pectic substances upon the human physiology have been demonstrated by different authors in numerous publications. These compounds slow down the absorption of soluble carbohydrates, causing a lesser increase of postprandial blood sugar in normal individuals, as well as in type I and type II diabetics (Jenkins et al., 1976, 1977b, 1978; Kay and Stitt, 1978). They eliminate or reduce the dumping syndrome of gastrectomized subjects (Jenkins et al., 1977a; Labayle et al., 1980). They decrease the level of cholesterol in the blood

Nutrition Department, Clinica Puerta de Hierro, Centro Nacional de Investigaciones Médico-Quirúrgicas de la Seguridad Social, Faculty of Medicine, Universidad Autónoma, S. Martin de Porres 4, Madrid-35, Spain.

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