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REVIEWS

Sweet Potato Protein: A Review

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The sweet potato supplies protein to a large segment of the world population. There appears to be considerable latitude to increase the protein content of the sweet potato and improve protein nutritional quality by exploitation of the natural genetic variability and by manipulation of certain production and postharvest handling practices. From 60 to 85% of the nitrogen is proteinaceous, and approximately 90% of that is amino or amide nitrogen. Isolated protein has a protein efficiency ratio equal to that of casein. Sulfur-containing amino acids are first limiting. In some cases lysine and/or tryptophan may also be limiting. Heat processing can cause a decrease in bioavailable lysine, the amount being dependent upon the severity of the heat treatment.

The sweet potato [*Ipomoea batatas* (L.) Lam.], a thickened root, is grown throughout the world. In 1981 the estimated harvest was 107 million metric tons with a dry matter content of about 31 million metric tons (FAO, 1981). An estimate of the potential worldwide yield of protein from this crop can be obtained by using the U.S. mean yield for sweet potatoes of 13 108 kg/ha (USDA, 1980), a mean dry matter content of 28% (Crosby, 1964), and a mean crude protein content of 5% (dry basis). When these figures are used, the expected yield of protein is 184 kg/ha. This value compares favorably with the yields for wheat (200 kg/ha) and rice (168 kg/ha) (FAO, 1981). Sweet potato, as the sixth largest plant food crop, has the potential to provide about 2 million metric tons of protein worldwide.

Root and tuber crops such as the sweet potato and white potato have long been recognized as a significant contributor to worldwide caloric needs. Because of its importance in the diet of the more developed nations, the nitrogenous constituents of white potato have been throughly investigated (Knorr, 1978). However, until recently, very little was known about the nitrogenous components of the sweet potato. It is the purpose of this review to provide an overview of present knowledge.

Nitrogenous Compounds of Sweet Potato. The crude protein content of sweet potato (Kjeldahl nitrogen × 6.25) has been reported to range from 1.3 >10% (dry basis) (Li, 1974; Purcell et al., 1972; Splittstoesser, 1977; Splittstoesser et al., 1973). Significant genetic variability in available germ plasm has been shown to exist (Collins and Walter, 1982). The potential for increasing protein content by breeding has been explored (Dickey et al., 1984)

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and appears to be a fruitful area for further research. Sweet potatoes have responded quite well to selection for other traits when genetic variability is present. Thus, efficient breeding methods are already available (Collins, 1983).

Variations in crude protein content within cultivars have been studied by several groups. Purcell et al. (1978b) reported that variation in crude protein content among roots taken from a single plant (hill) was smaller than the variation found between hills. These authors also noted high within-cultivar variability form field to field. The "Jewel" cultivar contained 4.1% crude protein at one location and 8.8% at another (LSD = 1.23 at $P \leq 0.05$). Other workers have reported large within-cultivar variability in crude protein content (Constantin et al., 1974; Li, 1976a,b).

Collins and Walter (1982) reported on crude protein variability resulting from the interaction of genotype with environment over a 3-year period at 6 locations (18 environments) for 6 genotypes. Analysis of variance of the data showed that crude protein content varied by genotype, environment, and interaction of genotype × environment ($P \leq 0.01$).

Water availability (Constantin et al., 1974) and the amount of nitrogen fertilization have been shown to influence root nitrogen content. Purcell et al. (1982) showed that for "Jewel" and "Centennial" an increase in rate of nitrogen application from 0 to 112 kg/ha increased protein content without adversely affecting yields. Potassium and sulfur had no effect on protein content. Other workers have shown that sweet potato crude protein content can be increased through cultural management practices (Li, 1975; Yeh et al., 1981). Thus, optimization of cultural practices also appears to offer a means to increase protein content in sweet potatoes.

It is important to realize that the crude protein content (Kjeldahl N × 6.25) of sweet potatoes includes all nitrogenous compounds present in the analysate. Sweet potatoes at harvest contain from 15 to 35% nonprotein nitrogen (NPN). The main components of the NPN fraction for the "Jewel" cultivar after 107 days of storage were asparagine (61%), aspartic acid (11%), glutamic acid (4%), serine (4%), and threonine (3%) (Purcell and Walter, 1980). An additional 5.5% of the NPN fraction was shown to contain small amounts of the other amino acids and ammonia. The remaining 11.5% of the NPN fraction remains unidentified. White potato has been shown (Schreiber, 1961) to contain as much as 50% NPN with asparagine and glutamic acid comprising 46% of the NPN fraction. From a nutritional standpoint, most of the sweet potato NPN is available to satisfy the requirement for total utilizable nitrogen but provides only small amounts of essential amino acids.

In most cases, sweet potatoes are stored after harvest. During storage, respiration continues, and as a result, both dry matter and nitrogen are lost. Purcell et al. (1978a) demonstrated that during storage an apparent increase in crude protein content was due to the fact that loss in dry matter occurred twice as rapidly as did nitrogen loss. For the three cultivars examined ("Centennial", "Jewel", and NC 317), NPN decreased during the early part of the storage period and then increased. No data are available for other cultivars.

The protein of sweet potato is not evenly distributed throughout the root. The crude protein content is slightly higher at the proximal (stem) end than at the distal (root) end and much higher in the outer layer, 0.1 radius thick (Purcell et al., 1976). Bradbury et al. (1984) also reported that there is an elevated level of crude protein in the tissue close to the skin. They found that peel removed by scraping (2.5% of the total weight) contained 87% more protein per unit weight than the peeled material, while the peel removed by a deep peeling (8.9% of the total weight) contained 47% more crude protein per unit weight than the peeled material. Thus, a vigorous peeling process that removes 8.9% of the total weight can reduce the protein content of the remaining material by about 12%, while removal of 2.5% of the weight as peel by scraping can reduce the protein content 4.4%. The above data show that although the protein-rich tissue has a much higher percent protein, it is present in rather small amounts.

Most of the protein of sweet potato is reported (Jones and Gersdorff, 1931) to be a globulin, "ipomoein". Upon storage of the root, the ipomoein is partially converted into a polypeptide, which is considerably different from the parent globulin in its physical and chemical properties.

Protein Nutritional Quality. *Isolates and Concentrates.* A limited number of reports are available concerning the nutritional quality of isolated sweet potato protein. Amino acid analyses that are available indicate that total sulfur is first limiting and lysine is the second limiting amino acid in sweet potato protein (Table I; FAO/WHO, 1973; Nagase, 1957; USDA, 1980; Walter and Catignani, 1981). For the "Jewel" cultivar (Table I), Walter and Catignani (1981) reported total sulfur to be first limiting and lysine to be second limiting, while Purcell et al. (1972) reported total sulfur to be limiting for "Jewel". Nagase (1957) reported no limiting amino acids for a Japanese cultivar. The data in the table indicate that there is some amino acid variability both between cultivars and within the same cultivar. In addition, the data of Purcell et al. (1972) for five other cultivars showed total sulfur to be limiting in all cases and that there was considerable between-cultivar variability in the content of several amino acids.

Several animal feeding studies have been published. Horigome et al. (1972) reported a protein efficiency ratio (PER) of 1.9 for protein recovered from an industrial sweet potato starch operation. The PER was increased to 2.5 by the addition of lysine and methionine to the diet. Apparently, during isolation of the protein these amino acids were partially destroyed or made biologically unavailable. Walter and Catignani (1981) found PER values of heat-precipitated concentrates and isolates from "Jewel" and "Centennial" cultivars to be equal to PER values for casein (milk protein).

Whole Sweet Potatoes. The sweet potato contributes very little to the overall protein nutriture of the United States. It is a very important food crop in tropical, subtropical, and half of the temperate zones (Splittstoesser, 1977). In parts of New Guinea the crop provides 41% of the crude protein consumed (Hipsley and Kirk, 1965). Most of the sparse literature reports concerning the role of the sweet potato in the maintenance of human protein nutriture are based on dietary recall or food consumption patterns and age–weight–height determinations (Hipsley and Kirk, 1965; Guzman et al., 1976; Bailey and Whiteman, 1963) rather than on carefully monitored nutritional studies. There is one report in which the sweet potato was used to maintain humans in nitrogen balance (adolph and Liu, 1939). This scarcity of data is in contrast to those studies involving white potato (Splittstoesser, 1977).

Sweet potatoes have been shown to contain trypsin inhibitors (Lin and Chen, 1980; Sugiura et al., 1973). These findings are of some concern due to the antinutritional activity of the inhibitors. It has been suggested that the

Table I. Amino Acid Composition of Protein Isolates (g of Amino Acid per 100 g of Protein)

	Walter and Catignani (1981)[a]	Purcell et al. (1972)[a]	Nagase (1957)[b]	FAO/WHO (1973)
essential				
threonine	6.4	5.5	4.6	4.0
valine	7.9	6.8	7.9	5.0
methionine	2.0	2.6	2.5	
total sulfur	3.1	3.0	4.1	3.5
isoleucine	5.6	5.3	5.3	4.0
leucine	7.4	7.8	8.7	7.0
tyrosine	6.9	5.2	3.6	6.0
phenylalanine	8.2	6.7	6.0	
lysine	5.2	6.8	6.5	5.5
tryptophan	1.2[c]	1.1[c]	1.8[c]	1.0
amino acid score[d,e]				
total sulfur	88	86	100	
lysine	95	100	100	
nonessential				
aspartic acid	18.9	14.4	13.1	
serine	6.6	5.1	5.5	
glutamic acid	9.6	8.6	11.8	
proline	4.2	5.4	4.3	
glycine	5.3	4.3	2.6	
alanine	5.4	4.6	6.1	
histidine	2.7	2.4	4.2	
NH_3	1.6	-[f]	-[f]	
arginine	5.9	6.0	6.4	

[a] "Jewel" cultivar. [b] Cultivar unknown. [c] Tryptophan content measured colorimetrically on enzyme-hydrolyzed material. [d] Grams of amino acid in 100 g of test protein/g of amino acid in FAO/WHO reference pattern × 100. [e] All other essential amino acids exceeded FAO/WHO values. [f] NH_3 not reported.

Table II. Amino Acid Composition of Whole Sweet Potato (g of Amino Acid per 100 g of Crude Protein)

	Ooman et al. (1961)[a]	Meredith and Dull (1979)[b]	Purcell and Walter (1982)[c]	Walter et al. (1983)[d]	FAO/WHO (1973)
essential					
threonine	3.14	4.10	4.50	5.32	4.0
valine	4.30	4.85	6.83	6.67	5.0
methionine	1.02	2.55	2.69	0.97	
total sulfur	1.31	2.55	3.25	2.19	3.5
isoleucine	3.84	3.58	4.57	3.94	4.0
leucine	4.85	5.38	7.47	5.85	7.0
tyrosine	2.37	3.06	5.81	3.97	6.0
phenylanine	3.49	4.32	7.32	5.94	
lysine	2.62	3.96	6.60	3.82	5.0
tryptophan	1.66		0.44		1.0
amino acid score[e]					
threonine	79	100	100	100	
valine	86	97	100	100	
total sulfur	37	73	93	63	
isoleucine	96	90	100	99	
leucine	69	77	100	84	
lysine	52	79	100	76	
tryptophan	100		44		
nonessential					
aspartic acid	27.97	28.32	20.22	22.43	
serine	3.94	4.43	3.83	5.47	
glutamic acid	8.02	8.04	7.41	10.98	
proline	3.09	2.69	3.99	2.54	
glycine	2.94	4.33	4.19	4.29	
alanine	4.70	5.16	6.24	3.56	
histidine	0.72	1.73	2.75	3.09	
NH_3				1.83	
arginine	5.08	3.47	4.28	4.17	

[a] Genjem-1 cultivar. [b] Jasper cultivar. [c] "Jewel" cultivar. [d] "Jewel" cultivar. [e] Grams of amino acid in 100 g of test protein/g of amino acid in FAO/WHO pattern × 100.

disease *enteritis necrotians* (Lawrence, 1979) is caused in part by this antinutritional factor. Dickey and Collins (1984) recently demonstrated that cooking in boiling water or baking destroyed most of the inhibitory activity. This being the case, the trypsin inhibitors could cause nutritional problems for humans only where roots are consumed raw. A recent study (Bradbury et al., 1984) was not able to demonstrate any relationship between the incidence of *enteritis necrotians* and trypsin inhibitor activity of the sweet potato cultivars prevalent in those areas of high disease frequency.

There are some amino acid analyses available for whole sweet potato (Table II; Meredith and Dull, 1979; Ooman et al., 1961; Purcell and Walter, 1982; Walter et al., 1983). With the exception of the aromatic amino acids, every essential amino acid has a score of less than 100 in one or more of the cultivars. Similar results were reported by Bradbury et al. (1984) from an investigation of the amino

Table III. Essential Amino Acids of Flours from "Jewel" and "Centennial" Sweet Potatoes[a,b]

amino acid	"Jewel"	"Centennial"	rat growth requirements[c]
threonine	5.3	5.6	4.6
valine	6.7	7.6	5.1
total sulfur	2.2	2.5	4.6
isoleucine	3.9	4.4	5.0
leucine	5.6	6.5	6.3
tyrosine	4.0	3.5	6.6
phenylalanine	5.9	6.3	
lysine	3.8	4.5	8.2
total	37.7	40.8	

[a] From Walter et al. (1983). [b] Grams of amino acid in 100 g of protein. [c] Said and Hegsted (1970).

acid composition of 21 cultivars from Papua, New Guinea. These workers found that sulfur-containing amino acids are limiting in all cultivars and are first limiting in 66% of cultivars. Leucine and lysine are limiting in 90% of the cultivars, threonine is limiting in 48% of the cultivars, isoleucine is limiting in 38%, aromatic amino acids are limiting in 24%, and valine is limiting in 14% of the cultivars. Thus, for whole sweet potato, total sulfur is always limiting and leucine and lysine are limiting in most cultivars. Insufficient data are available to make any statement regarding the abundance of tryptophan. These data are in contrast to the data for isolated protein in which total sulfur and lysine were the only deficient amino acids (Table I). For whole sweet potatoes the inclusion of NPN with protein nitrogen has the effect of lowering the chemical score because of the preponderance of nonessential amino acids in the NPN fraction. Table II data as well as those of Bradbury et al. (1984) show that there is a large amount of variability in the amounts of individual amino acids between cultivars. This variability is observed even for the same cultivar (Purcell and Walter, 1982; Walter et. al., 1983), reflecting the effect of environment conditions and postharvest handling history.

Walter et al. (1983) stored "Jewel" and "Centennial" sweet potatoes until sufficient carbohydrate had been metabolized that flours containing >1.8% nitrogen could be prepared. Analysis of the two flours showed that "Jewel" contained 34.7% NPN, while "Centennial" contained 24.3% NPN. The essential amino acid (EAA) patterns reflected the differences in NPN (Table III). "Jewel" has less EAA than "Centennial" because of the diluting effect of the NPN. Total sulfur, isoleucine, and lysine are less than the growth requirement for the rat (Said and Hegsted, 1970; the test animal) for both cultivars; however, "Centennial" (the lower NPN containing cultivar) contains more of these amino acids than does "Jewel". In addition, leucine is limiting for "Jewel" but nonlimiting for "Centennial". The PER values of these flours (Table IV) are lower than those from isolated protein, mirroring the lowered EAA values. In addition, the PER value for oven-dried "Centennial" flour (lowest NPN flour) is higher than the PER for "Jewel" oven-dried flour, again reflecting differences in the essential amino acid levels.

Effect of Processing on Protein Nutritional Quality. Purcell and Walter (1982) reported that for "Jewel" sweet potatoes which were baked, canned in 30% sucrose syrup, or processed into precooked dehydrated flakes, baking caused less amino acid loss than either of the other processing methods. Destruction of lysine appeared to be the major change caused by canning and flaking of sweet potatoes. Both canned and flaked samples contained 26% less lysine than did baked sweet potatoes. In addition, canned sweet potatoes contained 25% less total nitrogen than baked or flaked sweet potatoes. This loss is a result of leaching of part or all of the NPN fraction into the syrup. Since the syrup is usually discarded prior to consumption of the canned product, this represents a serious loss of nitrogen. Compositional analysis of canned sweet potato cultivars from different areas has shown that the protein content ranges from 3.8 to 4.2% (dry basis) (Collins, 1981) instead of the expected 4.5–7% (USDA, 1980). The explanation is very likely that the differences in protein content between canned and raw sweet potatoes are due to the leaching NPN into the syrup.

Table IV. Protein Efficiency Ratio (PER) for "Jewel" and "Centennial" Sweet Potato Flours[a]

protein	PER[b]
casein	2.5^{A}
"Centennial" flour (oven-dried)	2.2^{B}
"Centennial" flour (drum-dried)	1.3^{D}
"Jewel" flour (oven-dried)	2.0^{C}

[a] From Walter et al. (1983). [b] Corrected to a casein PER of 2.5. Numbers with different letter superscripts are different at $P \leq 0.05$.

Meredith and Dull (1979) measured the amino acid content of canned "Jasper" sweet potatoes and the syrup removed from the roots. They reported that canned sweet potatoes contain ~45% less amino acids than did the roots prior to processing. Their data show that appreciable amounts of nitrogenous constituents leach into the canning liquor and are lost if the liquor is discarded.

Walter et al. (1983) reported that the method of dehydration may have a profound effect on protein nutritional quality. In this study, "Centennial" sweet potatoes were dehydrated either in a forced-draft oven (60 °C) or on a double drum dryer (160 °C). The oven-dried flour had a PER of 2.0, while for the drum-dried flour the PER value was 1.3 (Table IV). The amino acid analysis indicated that lysine was slightly decreased in the drum-dried flour. There did not appear to be enough of a quantitative difference to account for the differences in the PER values. Measurement of biologically available lysine by reaction of free ϵ-amino groups with *o*-phthalaldehyde followed by fluorometric assay of the resulting lysine-phthalaldehyde reaction product indicated that a large part of the lysine in dehydrated flakes was not biologically available. Apparently, the ϵ-amino groups of lysine reacted with the reducing groups of carbohydrates, thus causing the lysine to become nutritionally unavailable. Acid hydrolysis prior to amino acid analysis cleaves amino–carbohydrate bonds and thereby releases nutritionally unavailable lysine, which is measured along with available lysine, giving an erroneously high lysine content (Carpenter, 1973).

Conclusion. The sweet potato provides protein to a large segment of the world population. There appears to be considerable latitude to increase the protein content and improve protein nutritional quality by exploitation of the natural genetic variability and by manipulation of certain production and postharvest handling practices. Available data indicate that from 60 to 85% of the nitrogen is proteinaceous. Of the remainder, approximately 90% is amino or amide nitrogen and as such is available to satisfy some of the requirements for amino acid synthesis in vivo. The PER for isolated protein is equal to the PER for casein. Total sulfur is limiting, and in some cases, lysine and/or tryptophan are limiting also. Human beings have been maintained in nitrogen balance with all nitrogen supplied by sweet potato. When sweet potatoes are canned, a large part of the nonprotein nitrogen leaches into the syrup, thereby lowering the nutritional value. Depending upon its severity, any heat-processing technique

can cause a decrease in bioavailable lysine.

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Chemical Phosphorylation of Food Proteins: An Overview and a Prospectus

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Chemical phosphorylation of proteins may be useful for changing the functional properties of food proteins. The use of various reagents to phosphorylate proteins is reviewed. Attention is also given to covalent attachment of low molecular weight organophospho compounds to proteins. The nature of the phosphate linkages involved and the effects of phosphorylation on the functional properties, as well as on the in vitro and in vivo digestion of the proteins, are discussed. Phosphorylation of proteins with phosphorus oxychloride ($POCl_3$) improved the gel-forming properties, particularly in the presence of Ca^{2+}. Incubation of soybean proteins with sodium trimetaphosphate (STMP) improved a number of functional properties, including water solubility, emulsifying activity, and foaming properties. Conflicting data exist as to whether or not STMP is covalently bound to the soybean proteins. In vitro and in vivo digestibility studies of phosphorylated proteins indicate that the nutritional value of the proteins was not reduced to a significant extent by the phosphorylation. Of the phosphorylating reagents tested so far, only $POCl_3$ and STMP might prove economical and practical reagents for large-scale application.

The feasibility of using alternative sources of proteins (e.g., trash fish, grain, microbes, and leaf) as food proteins is often limited due to their low biological value, undesirable organoleptic properties, toxic constituents, and poor functional properties in large part due to insolubility. These problems may be overcome by physical or mechanical treatment or by microbial, enzymatic, or chemical modification.

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