Protein Quality and Quantity of Tropical Roots and Tubers

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The U.S. National Academy of Sciences issued a report in 1966 (1) stressing the need for research on the principal food plants of the world. Although about 3,000 different species are utilized by humans as food, only about 150 are commercially important. Of these, wheat, corn or maize, rice, potato, various beans, sugar cane, sweet potato, sugar beets and cassava feed the majority of the world population. Four are root and tuber crops: sugar beets, cassava, sweet potato and potato. In the temperate areas potatoes, and to a somewhat lesser extent sweet potatoes, are important foods. In the tropics, various other root and tuber crops are also considered staples and zealously cultivated and preserved (18).

Production of potatoes is over 260 million metric tons (2); other tropical roots and tubers are produced and consumed at an annual rate of 150 million metric tons (17). These crops supply an important portion of worldwide caloric needs and many people depend upon these crops for their sustenance. However, nutritional values are poorly understood which makes it difficult to assign priorities for development and to assess future roles.

It is well known that roots and tubers vary widely in nutrient content. Light intensity, photoperiod, location, planting date, harvest date, fertilizer, growing season temperature, and cultivar all influence nutrient content. Frequently environmental influences exceed the cultivar differences; thus variations within a cultivar are often greater than between cultivars. Storage practices after harvest also influence nutritive value of the product. This variation occurs even though the plants are propagated vegetatively. Hammett (10) concluded that for legislation and regulation purposes, it was highly questionable to establish a nutrient content range as most vegetables, including roots and tubers, deviate by more than 20% in their nutrient contents.

High-protein contents of tropical roots and tubers could be important in eliminating marasmus and reducing kwashiorkor, the most serious human deficiency disorders. The protein content of various crops is compared to the reference protein of the Food and Agricultural Organization of the United Nations (FAO) (9, 28). This reference protein is a tentative "ideal" protein containing adequate amounts of all of the essential amino acids required in human nutrition. Thus, the quantity of a crop required to satisfy the human protein requirement is an arbitrary number because this protein may still be deficient in essential amino acids (protein quality). This review summarizes the protein content and the amino acid quality of a number to tropical roots and tubers, and assesses the future potential for improving protein quality and quantity.

Cassava

Cassava (Manihot esculenta Crantz), also called tapioca, yuca or manioc (Fig. 1) is grown in all tropical countries for its starchy roots (5, 19). Cassava production amounts to 57% of the tropical root and tuber production while utilizing 54% of this acreage (24). Cassava provides about 50% of the calories required by people in the tropics (21). The "bitter" types of cassava have more of the cyanogenic glycoside linamarin, than the "sweet" types (23). This glycoside is hydrolyzed to hydrogen cyanide (HCN) by enzymatic action (5). Therefore, a wide variety of food preparation techniques are used to reduce the HCN content either by its solution in water or by volatilization but substantial residual quantities often remain (5).

Cassava roots contain from 1.5—5.2% protein on a dry weight basis as estimated by the Kjeldahl method (17, 35, 36). Cassava also contains a considerable amount of non-protein water-soluble amino acids (17) and these would be removed during food preparation procedures to remove HCN. Thus, the actual protein content ranges from 1.2—2.7% on a dry weight basis.

All cassava cultivars were deficient in many amino acids, namely methionine, half-cystine, tyrosine, isoleucine and tryptophan (17, 33, 35, 36). In addition, some cultivars were also deficient in lysine, valine, leucine, threonine and phenylalanine (17) compared to the FAO reference protein (9, 28). When measured on a protein basis, cassava contains about 65% of the FAO tryptophan minimum (33) but the total protein content is so low that over 6 kg (fresh wt) would need to be consumed to ingest the FAO minimum.

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Cassava is used primarily as a source of starch and produces more starch per unit area per year than any known crop. Most breeding programs have not emphasized protein quality or quantity. Breeding for increased protein content has not been successful (14, 21), but within the species there is a large pool of genetic variability which has just recently been investigated. From this gene pool at least one protein-rich cultivar has been discovered (14). Once the existing plants are studied in more detail and the protein content of the roots determined, it is probable that other high protein types will also be found.

Potato

The potato is the only "vegetable" among the 5 principal world food crops (12). The most popular cultivated species is Solanum tuberosum L. although over 75 wild and cultivated species are maintained in the potato collection (29). The numerous potato cultivars available around the world differ in skin color, earliness, shape of tuber, adaptation, depth of eye, cooking quality, and yielding ability. American-grown cultivars are generally white fleshed while Europeans favor yellow-flesh tubers for food and white-flesh tubers for feed and processing (2).

The protein content as determined by Kjeldahl varies from 1.2–19.1% (31, 37, 38) although most cultivars are around 5%. Potatoes may contain 37–64% of their nitrogen as non-protein nitrogen and as much as 32–46% as amide nitrogen (37). Consequently the use of the standard Kjeldahl method often leads to high estimates of tuber protein and a modified procedure is recommended (37).

FIG. 1. Cassava roots grown in Puerto Rico.

Compared to other plant proteins, potato protein and non-protein nitrogen have a high nutritional value (11). The protein is partially deficient in sulfur amino acids and tryptophan, but about 3 kg (fresh weight) of tubers consumed daily would provide enough protein to sustain health (11).

Breeding programs for increased nutrition in potato tubers have existed for a longer period of time than for any of the other tropical roots and tubers. This has resulted in potato tubers which are presently high in protein quality and quantity. However, research has shown that a number of potato seedlings produce tubers with substantial differences in amino acid composition, particularly the sulfur amino acids, and in total protein. One selection, obtained from South America, has double the protein content of the current cultivars. Breeding could lead to tubers with a balanced amino acid composition and a high total protein content. These potatoes would yield more total protein per unit area than soybeans.

Sweet Potato

Sweet potato (Ipomoea batatas (L.) Lam.) is grown in all parts of the world and is one of the most important food crops throughout the tropical; subtropical and at least half of the temperate zone. It is an excellent source of vitamins, particularly beta-carotene (in orange-flesh types), and ascorbic acid.

Protein content of sweet potatoes range from 1.7 to 11.8% on a dry weight basis (17, 20, 26, 27, 35) but most cultivars contain between 4.5–7% (26). Sweet potato protein is deficient in sulfur amino acids and tryptophan (26, 33, 35) compared to the FAO reference protein, but other amino acids are in excess. Sweet potato protein may supplement other plant proteins and it has been used to maintain nitrogen balance in humans (3) and sustain humans for several generations (30). About 3 kg of sweet potato consumed daily would satisfy the minimum FAO protein requirement (11) but this protein would be deficient in several essential amino acids.

Research programs have been established to produce sweet potatoes with substantially increased protein contents (26, 27). Enough variation in protein content of sweet potatoes presently exist (12) to show considerable promise to anticipate an increase in total protein content through either breeding or selection.

Yams

Yams (Dioscorea spp.) (Fig. 2) are commonly grown in many parts of the tropics (6, 13). Tubers (Fig. 3) are used similar to sweet potatoes but are not as palatable to most tastes and they have not become popular in areas where cassava or sweet potatoes grow well (19). However, the yams provide about 12% of the caloric needs in the tropics and the quantities of yam normally eaten in West African diets can supply the entire Vitamin C requirement.

When yam tubers were separated into younger and older sections, the various parts did not differ significantly in protein content (15). When yams were boiled, 25 to 59% of the non-protein water-soluble amino acids were removed from the tubers and Kjeldahl N x 5.44 correlated well with the total amino acid content remaining after boiling in water (32).

Tubers of 26 cultivars of D. alata L. from Puerto Rico, Barbados, Trinidad, India, and the Philippines contained from 6.6 to 11.2% protein on a dry weight basis (16, 17, 35, 36). Tubers of 6 cultivars of D. bulbilera L. from Puerto Rico, India, Ivory Coast, and Hawaii contained 6.7–11.1% protein (17, 35, 36). Tubers from 6 cultivars of D. esculenta Burkhill from Puerto Rico, India, and Trinidad contained 7.9–13.4% protein (17, 35, 36). Tubers of 5 cultivars of D. rotundata Poir from Puerto Rico, Ivory Coast, Jamaica, and Guadeloupe contained from 6.3–8.1% protein and tubers of 3 cultivars of D. trifida L. from Puerto Rico and Guadeloupe contained 6.7–7.6% protein on a dry weight basis (17, 35, 36). Since foods containing 5% utilizable balanced protein would be deficient in several essential amino acids.

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Fig. 2. Yams growing under staked conditions to produce higher yields.

The protein content of yam tubers (15, 34, 35) approaches the level found in cereal grains, and diets comprised largely of these tubers should be only marginally deficient in protein (22). However, when the protein composition was analyzed (17, 33, 34) all yams were found to be deficient in methionine and half-cystine, the sulfur containing amino acids, and in tryptophan. Since all cultivars are deficient in these essential amino acids, balanced diets must depend upon protein supplementation from other sources.

Practically no systematic selection and multiplication of improved cultivars has been done, and essentially no breeding. Recently scientists at the International Institute of Tropical Agriculture in Nigeria (W. M. Stele, personal communication) have begun a systematic collection of existing yam cultivars with an intent to nutritionally improve the crop. Principal component analysis of the amino acids found in yam tubers have shown that they are inherited independently of each other (34), and this should allow improvement in the amino acid composition through breeding. The conventional method of propagation has been to use the planting sets from one tuber. This results in, at best, a 5- or 6-fold increase in one year. However, vine cuttings have been used with the drug Dioscorea and this should allow a 20- or 30-fold increase per year. The protein quality and quantity of yams should be improved substantially in the near future.

Dasheen or Taro

Dasheen or taro (Colocasia esculenta (L.) Schott) are grown throughout the tropics (25). Some cultivars are aquatic or sub-aquatic in habit (Fig. 4) while others can be grown in fields with good drainage. Their major use is as a subsistence food crop although it is a staple food of rain forest dwellers in many parts of the tropics (19).

The protein content of edible corns range from 1.0–4.5% (4, 7, 17) and become progressively lower after 6 months of growth. 'Martin', a cultivar selected from unnamed types found in the mountains of Puerto Rico, contains 11.7% protein (17), making it the only one I know which meets the FAO protein minimum. The dasheen or taro are below the FAO minimum in methionine, cysteine, tyrosine, isoleucine and tryptophan (17, 33, 35). 'Martin', however, contains about 65% of the FAO minimum of these amino acids indicating that nutritionally improved tropical crops are feasible through selection. Few of these crops have been improved using population mating, and selection among existing cultivars appears promising as a means to improve the amino acid balance.

Tannier

Tannier or tanier (Fig. 5) (Xanthosoma sagittifolium (L.) Schott) is also called tannia, cocoyam or yautia and is...
grown in many areas of the Pacific (19). The tanniers closely resemble the dasheens/taro and are often confused with them. In southern Florida, Xanthosoma caracu Koch & Bouche (called cocoyam or malanga) is grown for export to the West Indies, Latin America and Oriental communities in the U.S. (39).

Tanniers contain 5–8.9% protein on a dry weight basis (17, 35) although older corms may contain as little as 2% protein (7). Most corms contain above minimum FAO levels of protein. Within the protein, all cultivars were below FAO minimum levels of the amino acids, lysine, methionine, half-cystine, tyrosine, isoleucine and tryptophan. However, a number of cultivars contained 90% of the FAO minimum level of these amino acids (17, 35), and they would be only marginally deficient as a protein source (22).

No systematic breeding programs exist for the improvement of protein quality and quantity. However, there appears to be enough variability in existing cultivars to improve the protein content through selection; some in fact, contain as much or more protein as yam.

**Future potential**

It is usually accepted that the most serious problem in the less developed countries is protein-calorie malnutrition. Although tropical roots and tubers do not constitute the major source of protein for most people, in some countries they supply a substantial portion of the total protein consumed. Research is under way in a number of countries to improve the protein quality and quantity of tropical roots and tubers, and hopefully substantial improvement will be made in these nutritional factors over the next decade.

**Arrowroot**

Queensland arrowroot (Canna edulis L.) or purple arrowroot is grown principally as a vegetable or for a flour in Australia (8). The pointed rhizome of West Indian arrowroot (Fig. 6) (Maranta arundinacea L.) is the arrowroot of commerce (19). The Queensland arrowroot contains 1.7% protein while the West Indian arrowroot contains 4.6% (17). Both are below the FAO minimum recommended protein levels to sustain health. In addition, they both lack minimal levels of the amino acids, methionine, cysteine, tyrosine and tryptophan (17, 33). Frequently, only traces of cysteine were found in protein isolated from Queensland arrowroot (17). Both of these are minor crops whose production in many areas is on the decline (19) and little research emphasis has been given to these two crops.

**Literature Cited**

The tremendous success of the fruit and nut breeding programs in this country has been largely due to the accessibility of a wide range of germplasm. Much of this germplasm was brought in from other countries since most fruit and nut crops are not indigenous to the U.S. Each breeder made his own arrangements and provided for his own program needs. There has been no national plan for coordinating the introduction, evaluation, maintenance, and preservation of this germplasm which requires distinctly different propagation methods than those used for seed crops. This paper describes a plan to establish a national fruit and nut germplasm repository system.

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**A Plan for National Fruit and Nut Germplasm Repositories**

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