Fruit, Vegetable and Cereal Science and Biotechnology ©2012 Global Science Books

Food Uses and Nutritional Benefits of Sweet Potato

G. Padmaja[*] • Jaffer T. Sheriff • Moothandassery S. Sajeev

Central Tuber Crops Research Institute, Thiruvananthapuram-695017, India

***Corresponding author*: * padmajabn@yahoo.com**

ABSTRACT

Sweet potato (*Ipomoea batatas* (L.) Lam.) has high ability to convert solar energy in to carbohydrates and store it in the bulky roots that are recognised as one of the energy godowns of nature. Sweet potato is next to cassava (*Manihot esculenta* Crantz) in acreage, widespread cultivation, diversified uses etc., among the tuber crops in the world. With rapidly changing lifestyle and urbanization, the significance of sweet potato as a food is getting diminished. Nevertheless, its importance as a health food is being increasingly realised now. A number of novel food products with functional value are being developed worldwide. Sweet potato tubers with their low glycaemic index have additional value as a food for diabetics. There are a range of primary food products that could be made from sweet potato like chips, flakes, frozen products, French fries, puree, etc., while it is also the raw materials for a host of secondary products like noodles, sugar syrups, alcohol, pasta etc. The potential of sweet potato as a promising food crop is discussed.

Keywords: chips, canning, frying, noodles, pasta

Abbreviations: DSF, defatted Soy Flour; **fwb**, fresh weight basis; **MJ**, Mega Joules; **RSS**, restructured sweet potato sticks; **RTE**, ready to eat; **RWF**, refined wheat flour

CONTENTS

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) is cultivated throughout the tropics and warm temperate regions of the world for its starchy roots, which can provide nutrition, besides energy. The edible tuberous root is either long and tapered, ovoid or round with a skin colour ranging from white, brown, purple or red and the flesh colour ranging from white, pale cream, orange or purple. Besides, the plant is also much valued for its green tops, which are a concentrated source of many essential vitamins and minerals. Although China is the largest producer of sweet potatoes, accounting for more than 80% of the world supply, only 40% of the production is used for human consumption and industrial uses, while, the rest goes as animal feed. Sweet potatoes are considered as one of the most important food crops of man due to the health contributing principles in the tubers and leaves. Despite the fact that it is one the highest energy producing crops (152 MJ ha^{-1} day^{-1}), it seldom finds use as a starchy staple in countries other than China and Japan. The latter two countries have developed several value added products from sweet potato tubers and leaves, realising its nutritional attributes as well. Unlike the South-east Asian countries and India, China, which is the largest producer of sweet potato, also utilizes a major part of its production for animal feed purposes. With the introduction of a large number of orange fleshed varieties having high β-carotene content ranging even up to 20-30 mg 100 g^{-1}, there is a recent upsurge of interest in including sweet potato roots as a part of the food-based strategy to compensate vitamin A deficiency, especially in African countries and Bangladesh.

Received: 1 November, 2011. Accepted: 1 November, 2012.

Invited Review

PRIMARY FOOD PRODUCTS

Sweet potato is cultivated and utilized extensively in Asia and South east Asian countries, although processed products are more common in countries like Indonesia, Philippines, Thailand, Malaysia and Vietnam. The tubers are eaten after boiling or baking and increase in sugars during these processes makes the tubers sweet after cooking. The 'dry' type of tubers will be dry and firm but mealy after cooking, while the 'moist' type will be soft and watery as well as sticky after cooking (Rao *et al.* 1974).

A major problem in the utilization of sweet potato is the post harvest damage often triggered by the pathogen entry through cut surfaces. Curing at a relative humidity of 85% and temperature of 29-30°C is often practiced in the South Asian countries and India, which facilitates wound- healing and enhances the shelf life of the roots. Curing has been reported to induce the amylolytic enzymes in sweet potato, leading to the production of sugars and development of sweetness. Studies have been made by various researchers in India to develop many value added products from sweet potato. Sweet potato was processed into vermicelli and its nutritional quality studied by Thirumaran and Ravindran (1992). White fleshed sweet potato was made into flour by treating the slices with 0.1% sulfur dioxide to prevent browning, drying, powdering and sieving. Vermicelli was prepared by extrusion using 50% each of sweet potato flour and refined wheat flour (maida). Also fortified vermicelli was attempted by incorporating 10%, 20% and 30% of green gram, black gram and defatted soy flour (DSF) into the mix. They found that the protein content could be enhanced up to *ca.* 8% in gram added sweet potato mix and 14% in DSF blended mix. Acceptability studies showed that up to 20% incorporation of the legume flour or DSF was possible. A similar study for extrusion processing of sweet potato flour-maida-DSF mix into macaroni was made by Chellammal and Prema (1996), who found that the optimum level of incorporation of sweet potato flour was 50%, with 35% maida and 15% DSF. The product had a protein content of 11.53% and energy value of 307 kcal 100 g^{-1}.

Sweet potatoes are processed into dried cubes in the Philippines (Truong 1990). Cultivars of white, orange or purple flesh are used for the purpose and the dried cubes are sometimes mixed with cubes of cassava, cocoyam, jack fruit or banana and packaged in plastic bags. The cubes are cooked with rice, brown sugar, coconut milk and vanilla and it is a favourite Filipino dish.

Sweet potato (orange fleshed) has been processed into a 'dry fruit' type product by peeling, slicing into long pieces, soaking them in 2% (w/v) metabisulphite solution and cooking in a 60° Brix syrup containing 0.8-1.0% citric acid. This is then dried and packed (Truong 1987). The product had low fat (0.4%) and protein (1.2%) content, but was rich in β-carotene (7.8 mg 100 g^{-1}). Similar dried sweet potato products are available in Malaysia as well, where sweet potato is processed into an edible 'leather' or fruit roll. Orange fleshed sweet potato was used for making leather in Malaysia (Yaacob and Raya 1983), by cooking, mashing and sieving the pulp. The pulp is then mixed with 0.5% (w/w) carboxymethyl cellulose (CMC), 200 μg g^{-1} sodium bisulphite and 7% (w/w) sugar and made into a sheet of thickness (1 mm) and dried at 75°C to 10-17% moisture. The product could be eaten as such or could be deep fried and consumed.

Sweet potato contains water-soluble pectin, which enables its use in making jams and jellies. Due to the high starch content of sweet potato, compared to fruits, the jam has a slightly different consistency (Truong 1987). Differently coloured and flavoured jams were prepared in the Philippines using white, orange or purple fleshed sweet potato with fruits like orange, guava, pineapple, mango, etc. Jams from sweet potato have been prepared in India (Padmaja and Premkumar 2002) and Bangladesh (Chaudhury 1992). The orange fleshed variety 'Kamala Sundari' was used for making jam with either sugar or molasses (Chaudhury 1992). It was found that the high starch sweet potato varieties could be incorporated only up to 60% (Padmaja and Premkumar 2002).

Sweet potato pickles have been made from orange fleshed varieties in Bangladesh and Philippines and white variety in India (Chaudhury 1992; Padmaja and Premkumar 2002; Tan *et al.* 2005). Blanched sweet potato cubes were used in Philippines, while lightly fried cubes were used in Bangladesh (Chaudhury 1992; Golder *et al.* 2005). In India, the cubes were treated with 1.0% acetic acid solution for 1 h to prevent browning and then used for pickling. Golder *et al.* (2005) found that the best formula for sweet potato jam was sweet potato pulp (52.22%), sugar (46.90%), citric acid (0.53%) and pectin (0.26%). Microbe aided lactic acid fermentation of sweet potato for pickling purpose was also attempted in India. The sweet potato cubes, after blanching in boiling water for one minute were put to salt solution (10% w/w) and starter culture of *Lactobacillus plantarum* was added to this (Ray *et al.* 2005).

Sweet potato based composite flours have been used in many countries for making small baked goods like cakes, cookies, biscuits, doughnuts etc. There are experimental reports on cakes and biscuits made with 50% sweet potato flour-wheat flour mixes in India (Seralathan and Thirumaran 1990) and butter cakes and cookies in the Philippines (Montemayor and Notario 1982). Predominant sweet potato flavour has been cited as a factor for lower rating of baked goods made with it, making mashing of flavour with others necessary for better consumer acceptance. The flour from the orange- fleshed variety 'Merah Manis' was used in Malaysia to produce several baked goods viz., sweet buns, cakes, cookies and muffins. The sweet potato flour had around 7.5 mg 100 g^{-1} of β-carotene. Sweet potato flour was incorporated at 20% to wheat flour and supplemented with 6% gluten and 4% bread softener to produce good quality buns (Salma and Zaidah 2005). The flour could be used to substitute 60% wheat in cookies and 57% in muffins while 100% wheat substitution with sweet potato flour was possible in cakes.

French fry type products have been prepared from sweet potato in Thailand. The roots after slicing to 7.5 cm long strips were dipped in sodium acid pyrophosphate (0.25% w/w) and $CaCl_2$ (0.25% w/w) to prevent browning and blanched for 3 min at 100° C. The chips on cooling were deep fried at 180°C for 20 s dried in a hot air oven for 4 min at 180°C, cooled, packed and frozen. The fries were again fried for 2 min before use (Reungmaneepaitoon *et al.* 2005). These workers found that white or yellow flesh varieties gave a firmer French fry product than the purple or orange fleshed sweet potato.

Sweet potato (orange flesh variety) flour was used to prepare a popular Malaysian snack food 'Keropok', in which sweet potato flour was mixed with cassava/sago flour and supplemented with fish, prawn or squid pastes. Ready-to-eat (RTE) breakfast food and snacks have also been made from sweet potato (Lee 2005). Sweet potato flour was blended with cassava flour (30-50%), tempered to 15% moisture and extruded using a 1.90 cm diameter laboratory extruder. The barrel length-to-diameter ratio was 20:1 and screw compression ratio was 3:1. Higher levels of incorporation of sweet potato flour were found to affect the expansion of the RTE product (Lee 2005).

Restructured sweet potato sticks (RSS) are another product similar to French fries made in Malaysia (Utomo *et al.* 2005). The blanched sweet potatoes were mashed, mixed with 0.3% Carboxy methyl cellulose (as binder). Utomo *et al.* (2005) observed that the RSS made from yellow cultivar had the lowest firmness and hardness. White cultivar generated RSS having elastic or chewy texture.

Curd is a popular food item for the Asians and is usually made from milk by natural lactic fermentation. Sweet potato (anthocyanin and carotene rich varieties) was used to prepare curd having high nutritive value. The process consisted in making sweet potato puree and mixing it with milk at levels of 8-12% (w/v). Starter culture (homemade curd) was then added (2-3%) and incubated at room temperature for 18-24 h. The product had a pH of 3.50 and lactic acid content of 0.60%. The β-carotene rich variety yielded curd with a carotene content of 2.6 mg 100 g^{-1} (Ray *et al.* 2005). Lacto juice was made from orange fleshed sweet potatoes by fermenting the mash with *Lactobacillus plantarum* at 28 ± 2°C for 48 h and expressing the juice. The sensory evaluation gave high scores for taste, aroma and texture (Panda and Ray 2007).

Hard candies contain flour and starch as texture modifiers, besides the usual ingredients like milk, fat, sugar, glucose syrup and emulsifiers. Sweet potato was attempted as a replacer of flour and starch in candy making (Samsiah *et al.* 2005). Sweet potato mash prepared from steamed/baked roots was added to the basic ingredients viz., coconut milk, sugar and glucose syrup. The basic ingredients were boiled, filtered and concentrated. Skimmed milk powder and sweet potato mash were added, mixed and solidified with stirring. The mass was then kneaded, tempered and cut into candies. These workers obtained a high quality product from 10% steamed sweet potato mash. Sweet potato flour was utilized to make a 'nutrigulab jamun mix' by mixing it with refined wheat flour and milk powder. The sweet gulab jamuns, a popular dessert of India had good soft texture and taste (Padmaja and Premkumar 2002).

Sweet potatoes are consumed at home level, mainly after cooking, baking or converting into fried chips. The roots are often converted to canned or pureed form, to enhance the shelf life. Sweet potato based baby foods are preferred in many countries as the first solid food for infants.

Baking sweet potatoes in country ovens has been an old mode of processing of roots in countries viz., China, India, Japan, Bangladesh, Indonesia, Kenya, Papua New Guinea etc. Traditional baking has now been replaced in many countries by microwave baking. A comparison of the carbohydrate components in sweet potatoes, baked by convection heating and microwave heating was made by Purcell and Walter (1988). They found that the samples baked in microwave contained less total alcohol soluble, carbohydrates, reducing sugars and dextrins and more starch than the roots baked in convection oven.

Reddy and Sistrunk (1980) observed that baked or microwave cooked sweet potato roots had more reducing sugars, total sugars and pectins than boiled or steamed roots. Microwave baked roots had higher hemi-cellulose and cellulose than the boiled roots, probably due to increased solubility of these components in the latter process. The percentage of starch conversion to maltose was reported to be around 54% in 'dry' cultivars, as compared to 63-69% in 'moist' cultivars (Martin 1986). Cooking has also been reported to increase the digestibility of starch. Cooked sweet potato starch was more susceptible to enzymic hydrolysis than raw starch. Bradbury *et al.* (1985) reported significant increase in the dietary fibre in boiled and steamed sweet potatoes, resulting probably from the conversion of part of the starch to 'resistant starch'.

DEHYDRATED CHIPS AND FLOUR

Sweet potato roots are dehydrated to enhance the shelf life of stored roots. The chips are further powdered to flour and used for making many snack foods. The roots are either peeled or unpeeled and sliced for drying. Discolouration of dried chips is a problem with certain cultivars having high activity of polyphenol oxidases and higher levels of phenols. Walter and Purcell (1980) found that the browning tendency of sweet potato was correlated only with the phenolic content, while others found that PPO activity was also correlated with browning potential of sweet potato (Scott and Kattan 1957). Walter *et al.* (1979) found that the principal phenolics of sweet potato viz., chlorogenic acid and its isomers were effectively oxidized by sweet potato PPO, resulting in browning in the processed product. Extensive drying of sweet potato is practiced in China to produce dried chips for its further use in starch, noodle and alcohol factories. Damp weather and prolonged drying periods can cause microbial contamination of the chips.

Dried sweet potato cubes have been developed in the Philippines, using a fabricated sweet potato slicer (Truong 1990). The cubes can be cooked either alone or with other ingredients like coconut milk, rice, sugar and vanilla to make a traditional dish called 'guinata an'. Orange fleshed sweet potatoes have been diced into long strips and soaked in 2% metabisulphite (w/v) prior to cooking in 60°C Brix sugar syrup containing citric acid (0.8-1.0%). These were then dried and packed to make a product like sweet potato candy. Data and Operario (1992) found that processing operations for dry chip production only slightly affected the chemical constituents of sweet potato. Polyethylene sacks were found to be the best packing material, permitting 6 months storage without microbial or insect damage.

CANNED SWEET POTATOES

Canning of sweet potato is widely practised in the United States, to enhance the storage life and ensure round the year availability of the product (Walter and Hoover 1986). Canned sweet potato is also widely available in countries like Australia, Taiwan and the Netherlands (Mason 1982). The pre-processing steps in the production of canned sweet potato are grading, cleaning, pre-heating, peeling and trimming (Bouwkamp 1985). Pre-heating is adopted by immersing the roots in heated water or live steam for small periods, which helps in driving off the intercellular gases, to facilitate good vacuum build up in cans (Bouwkamp 1985). Scott (1952) found that 40 second pre-heating in live steam can prevent the enzyme linked browning of sweet potato. Peeling and trimming are essential stages in the preparation of canned sweet potato. Several methods are available for peeling of sweet potato roots, including manual peeling and the peeling losses vary from 15-60% (Bouwkamp 1985). Exposing the roots to 7-10% (w/w) boiling lye for 6 min followed by washing with a high pressure spray was found to be the best method, with a peeling loss of only 20-35%. Hand trimming is done to remove surface imperfections in the lye peeled roots (Walter and Schadel 1982).

The discoloration in canned sweet potato has been correlated with the initial levels of phenol and phenol oxidizing enzymes in raw roots. While enzymic browning leads to discoloration during canning process itself, non-enzymic browning, resulting from the reaction of quinones with iron or tin of the metal cans, is responsible for the discoloration observed after the opening of cans. Pre-heating the roots prior to peeling has been reported to reduce the discoloration of the canned product (Scott 1952). Pre-heating also facilitated rapid inactivation of the phenolases during the lye peeling stage (Walter and Schadel 1982).

FROZEN SWEET POTATOES

Low temperature storage of sweet potato is practiced in developed countries only, as the cost is prohibitive for adoption. Sweet potatoes are frozen as whole roots or sliced cubes, pieces or as pastes. The roots are often blanched in water or with steam at 10 psi pressure (116°C) to inactivate the enzymes associated with browning, off flavor development, etc. Steam blanching was reported as the best method, as it does not lead to a soggy product (Woodroof and Atkinson 1944). The slices/cubes are packed in plastic bags and blast frozen at 40°C. The washed roots are sometimes steamed, crushed, mixed with 35% sugar (w/w) and filled to plastic bags under pressure before blast freezing at -40°C. Frozen sweet potato products are widely popular in Japan Woolfe 1992).

FRIED SWEET POTATO PRODUCTS

Sweet potato roots are transformed into more stable edible products like fried chips, crisps, French fries etc., which are very popular in Japan, USA, China, Netherlands, Peru etc. The roots are peeled, sliced into thin chips and deep fat-fried to obtain fried chips. Discoloration during frying at high temperature due to Maillard reaction is very common with cultivars having high amino acid and sugar contents. Sugar coated fried chips are popular in Japan, while salted or spicy chips are preferred in Papua New Guinea, Bangladesh and Peru. The quality is improved through treatments like blanching for 2 min at 93°C in boiling water or a solution of sodium acid pyrophosphate (0.5-0.75% w/w) or diffusion extraction of sugars to eliminate the problem of browning, etc. Picha (1986) reported that the glucose and fructose content of the sweet potato slices determined the extent of browning of fried chips, rather than the sucrose content.

The length of frying is influenced by the moisture content of the chips and the temperature of cooking oil. Fresh/ blanched chips having around 50% moisture takes approximately 4.5 min at 138°C (Hoover and Miller 1973). The yield of chips is around 40% of the weight of precooked peeled root (Kelly *et al*. 1958). Higher temperature of frying has been reported to result in dark coloured chips (Martin 1987). High moisture and low dry matter content in the fresh slices leads to higher oil retention in the fried chips. Hoover and Miller (1973) reported reduction in the oil retention in fried chips made from partially dried blanched chips. Blister formation has been reported to lead to chip hardness and lack of crispness (Baba *et al.* 1981). Blanching and/ or freezing and thawing of the sweet potato slices could reduce the hardness of chips (Baba and Yamamura 1981). Packaging of fried chips in moisture proof packs is essential to prevent leatheriness in the chips.

Frozen French fry type products were developed from sweet potato by deep-frying the slices, cooking and freezing the fries (Kelley *et al*. 1958). The frozen fries are cooked in an oven prior to eating. The process for frozen French fry making was subsequently modified by other workers (Walter and Hoover 1986; Schwartz *et al*. 1987). In this process, the lye peeled roots are made into long strips (1.9 cm × 6.4 cm) blanched in boiling water containing 1% (w/v) sodium acid pyrophosphate, partial drying and freezing at 34°C. Deep frying is done immediately before eating. Reungmaneepaitoon *et al*. (2005) reported that good quality French fries with low oil content could be made by blanching sweet potato strips for 3 min in boiling water at 100°C, containing 0.25% sodium acid pyrophosphate and 0.25% calcium chloride and then partially frying at 180°C for 20 s.

SWEET POTATO PUREE

Sweet potato puree, is a primary processed product from the roots, which is used directly as a baby food or used for mixing various food items like patties, flakes, reconstituted chips, etc. High quality puree can be made from white, cream or orange fleshed sweet potatoes and also from tubers of any size or shape (Bouwkamp 1985; Woolfe 1992). Puree making also ensures round the year availability and better storage life. The initial process involved more cooking of the roots, peeling and then mashing. The process was subsequently modified through a controlled alpha-amylase process, where commercial alpha-amylase was added to a portion of the puree for enabling partial hydrolysis of starch. The enzyme treated fraction was then treated with the remaining puree (Szyperski *et al*. 1986). This process resulted in puree with better rheological characteristics. Controlled heat processing of sweet potatoes (Jewel variety) for puree making was investigated by Walter and Schwartz (1993). They prepared puree from 0.5 cm thick sweet potato slices by pre-cooking at 100, 125 or 150°C for varying periods; finish cooking for 15 min at 150°C and pureeing.

The textural quality of puree has been studied by several workers and was found to be influenced by cultivars, storage period as well as length of time given for puree hydrolysis. Ice *et al*. (1980) found that pH of the puree affected the rheology of the stored puree and lower and higher pHs were found to lower the puree viscosity. Fasina *et al*. (2003) studied the thermal and dielectric properties of sweet potato puree within a temperature range of 5-80°C. Increase in temperature was reported to increase the specific heat, thermal conductivity and diffusivity of the puree while the density decreased. Sweet potato puree, prepared under aseptic conditions has been reported to have a storage life of up to 9 months and flash heating at 123°C was suggested as the best method for aseptic can filling of puree (Smith *et al*. 1982).

SWEET POTATO FLAKES

A procedure for the production of sweet potato flakes was first described by Taubenhaus (1923), consisting of washing, cooking, mashing and drying on steam heated drum dryers. The process underwent several steps for refining the technology and a much advanced process is now available. The dehydrated flakes can be reconstituted to mashed sweet potato or incorporated into various food products like pastries, cakes, bread, biscuits, etc. Hoover (1966) reported that the ratio of soluble to the insoluble solids in sweet potato puree decided the final quality of the flakes produced. The high content of soluble solids in the sweet potato flakes resulted in low water requirement to rehydrate the flakes. Further, the flavour also improved with increase in the proportion of enzyme treated puree in the mash. The earlier process was further modified for puree preparation using added alpha-amylases to partially hydrolyse the starch and increase the soluble solids content of puree. The hydrolyzed puree was then added to the control puree and subjected to drum drying. Spadaro and Patton (1961) observed that the quality of dehydrated sweet potato flakes depended on the variety of sweet potato and for each variety, the process parameters have to be optimized. The procedure was subsequently modified by adding amylase and/ or sucrose after cooking and pureeing, leading to a more acceptable product. Curing of tubers and storage were reported to affect the amount of amylase required to produce acceptable flakes (Bertoniere *et al*. 1966). The extraneous addition of alpha-amylase was further eliminated by activating the endogenous amylases during processing (Hoover 1967). The process consists of heating the puree almost instantaneously by steam injection to 160-185°F. The pre-heating helped to activate the endogenous amylases in sweet potato and a holding period of 2-6 min was sufficient to achieve the required conversion of starch to sugars. The partially cooked puree is then passed through a second steam injector, where high temperature in activation of the amylases is achieved at 200°F. The treated puree was then drum dried to form dehydrated flakes. The modified process enables the use of freshly harvested and/ or high starch cultivars also for the production of flakes with acceptable quality.

Fortified sweet potato flakes were made through the incorporation of soy flour, cottonseed flour and wheat gluten flour into the puree. Although the protein levels could be elevated through fortification, the water holding capacity of the reconstituted flakes was reduced (Walter *et al*. 1978). Development of off flavours in sweet potato flakes has been reported during storage, resulting mainly from the autoxidation of carotene and lipid fractions (Purcell and Walter 1968). The fragmentation of β-carotene during autoxidation was studied using radioactive β-carotene and it was found that the major fractions of β-carotene remained unaffected. The 'hay-like' flavor of stored sweet potato flakes has been reported to be due to the formation of monocarbonyls especially aldehydes or due to the decrease in the unsaturation ratio of fatty acid (Lopez *et al*. 1976). The shelf life of sweet potato flakes could be extended through the addition of antioxidants to sweet potato puree, prior to dehydration (Deobald and McLemore 1964).

Spray drying of amylase hydrolyzed sweet potato puree was attempted by Grabowski *et al*. (2006). The effect of viscosity reduction of sweet potato puree with alpha-amylase, maltodextrin addition and inlet air temperature on the physicochemical characteristics of spray dried powder was investigated. A steam jacketed mixer was used to elevate the temperature of the puree as well as for blending it with alpha-amylase. After a reaction period of 30 min, the temperature was raised to 90°C and maltodextrin was added as a drying aid and the mixture was spray dried. Maltodextrin significantly increased the powder solubility, altered the hue value and raised the glass transition temperature of the powder. Alpha-amylase treatment could reduce the glass transition temperature and decrease the particle size of the powder. The spray dried powder was further characterized for nutritional value and rheological properties by Grabowski *et al*. (2007). Spray drying significantly reduced the β-carotene and ascorbic acid contents. The all *trans* form of β-carotene was found to be transformed into *cis*-isomers during the spray drying. The viscosity of the reconstituted solution was found to be much lower than that of puree and was rheologically similar to pre-gelatinized starch solution.

SECONDARY FOOD PRODUCTS

Noodles and other extruded foods

Sweet potato is processed into noodles in many countries of the Far East viz., China, Japan, Taiwan and Korea. A major part of sweet potato starch produced in China and Korea is utilized for the production of noodles (Hong 1982; Wiersema *et al*. 1989). There are many home scale and cottage level processing units in China, which make traditional noodles from sweet potato starch. The process consists in gelatinizing sweet potato starch slurry in a big vessel at 80°C, treating with sulphate to prevent discoloration and mixing with native dry sweet potato starch (5%) to form a dough. The dough is then filled to long cylindrical column (30 cm × 40 cm) and pressed to extrude the dough into strings into hot water. This is then separated manually to prevent adhesion. The strings are then suddenly put to cold water, when the outside hardens and stickiness is reduced. The noodles are then dried slowly so that both inside and outside get dry (Wiersema *et al*. 1989). In the Korean method, sweet potato starch is used to replace part of the wheat flour. The noodles are made from sweet potato starch, wheat flour and salt. Steam cooking of wet sweet potato starch, over boiling water is adopted in Vietnam. The extruded starch is then dried in bamboo racks and semi dried material is cut into strips. Noodles are often dark coloured due to phenol oxidation, which limits its marketability.

The physicochemical properties of sweet potato starches and their applications in noodle making were studied by Chen (2003). The process consisted of gelatinizing 5% sweet potato starch with water (1:9 w/v) and then mixing with 95% native starch. The mixture was made into dough at 40°C (moisture content 55%) and then extruded through a lab scale extruder to strips of 1.5 cm diameter, directly into hot water (95-98°C). The noodles were kept for 50-70 s at this temperature and then transferred to cold water. Precooling was done at 40° C for 6 h and then frozen at 5°C for 8 h followed by drying. Chen (2003) reported varietal differences in the cohesiveness of sweet potato starch noodles. Freezing was found to be an important step in noodle manufacture as this could considerably reduce the cohesiveness.

Sweet potato flour (white fleshed varieties) was used for extrusion into vermicelli by Thirumaran and Ravindran (1992). The process consisted of mixing sweet potato flour with refined wheat flour (50:50) or with added legume flour also (10-30%), steaming the dough, extruding, drying and packaging. Although the energy values of sweet potato flour: wheat flour vermicelli was high (234 kcal 100 g^{-1}), protein was low (6.1%), and this could be enhanced through legume fortification. In Japan, sweet potato flour is mixed in varying proportions with other cereal flours and extruded into noodles. Orange coloured noodles prepared from orange fleshed sweet potato and green noodles with sweet potato leaf incorporation are sold in Taiwanese markets. Chang and Lee (1974) reported that addition of sweet potato flour beyond 20% to wheat flour affected the organoleptic quality of the noodle. Sweet potato flour enriched with soy flour utilized for replacing part of the wheat flour in noodle making (Collins and Pangloli 1997). Combinations of sweet potato and defatted soy flour (DSF) increased the protein and dietary fibre content of the noodles. Orange fleshed sweet potato increased the β-carotene (5.0 mg 100 g^{-1}) as compared to 0.2 mg 100 g^{-1} in wheat flour-based noodles. Although cooking loss was increased by 12%, the product had acceptable flavour and reduced stickiness. Lee (2005) developed extruded ready-to-eat breakfast food and snack foods from sweet potato. The sweet potato flour was either used alone or blended with cassava flour and extruder through the Brabender extruder. A screw compression ratio of 3:1 and round die with i.d. of 2 mm was used.

Restructured sweet potato sticks were made from cooked and mashed sweet potato using extrusion technology (Utomo *et al*. 2005). White, yellow and orange varieties of sweet potato were blanched, mashed and mixed with 0.3% carboxymethyl cellulose as binder. The mash was then mixed with 5% sweet potato flour and extruded through a tube to produce sticks of 1.0 cm diameter and 5.0 cm length. The sticks were deep fried in oil at 163°C for 1 min and frozen at 20°C till use. Further frying was done at 175°C for 2 min, prior to eating. The product from yellow varieties had the lowest values for firmness, hardness and shearing force, while that from the white variety was more cohesive and chewy. Response surface analysis of the color of single screw extruded blends of soy sweet potato flour was done by Iwe *et al*. (2000), who found that the whiteness decreased with increase in the level of incorporation of sweet potato in the blends. While redness increased as the content of sweet potatoes increased, yellowness increased especially as a result of die diameter. The effect of extrusion cooking of soy sweet potato mixtures on available lysine content and browning index were studied by Iwe *et al*. (2004). Increase in screw speed and a reduction in die diameter enhanced lysine retention in the product and increased the browning index.

SUGAR SYRUPS

Both glucose syrup and HFS are commercially made from sweet potato starch in China (Wiersema *et al*. 1989). Sweet potato starch is converted to glucose syrup or high fructose syrup for use in confectionery industries, pharmaceutical applications, etc. Microbial enzymes with high conversion efficiency are available to effect the liquefaction and saccharification reactions, which have advantages of the earlier acid linked hydrolysis.

The optimum temperature for liquefaction using liquezyme X was standardized as 90°C for 1 h. Viscosity profile analysis during liquefaction of sweet potato starch indicated that small amount of liquezyme X (6.0 mg 100 ml^{-1} slurry) could bring down the viscosity of a suspension (1:10 w/v) from 3653 cP to 972 cP. Approximately 96% conversion of sweet potato starch to glucose could be obtained with 48 h of action by the saccharifying enzyme, Dextrozyme X on liquefied sweet potato starch slurry. Glucose isomerase (Sweetzyme T) could then convert glucose to HFS at 80ºC and pH 7.0 (Regy Johnson *et al*. 2011).

COMMODITY CHEMICALS FROM STARCH

Sweet potato starch is commercially utilized for the production of a number of commodity chemicals like citric acid, mono sodium glutamate, microbial enzymes etc. which are used in the food industry. Most of these are produced on small scale in China and Japan where sweet potato starch is industrially produced. The starch is first converted to sugars and fermented to citric acid by *Aspergillus niger* (Wiersema *et al*. 1989).

Monosodium glutamate, a flavour enhancer for various foods is manufactured from sweet potato starch in China. Sweet potato starch is first hydrolysed using enzymes to glucose, which is then converted by *Brevibacterium glutamicus* to glutamic acid. Monosodium glutamate is produced using alkali treatment of glutamic acid (Wiersema *et al*. 1989).

NON-ALCOHOLIC AND ALCOHOLIC BEVERAGES

Non-alcoholic beverages have been prepared in the Philippines and India from sweet potatoes. A fruity sweet potato beverage developed from sweet potato contains in addition to mashed sweet potato (variety VSP-1), sugar, citric acid and ascorbic acid (Truong and Fementira 1990). Orange fleshed sweet potatoes yielded beverages with pleasant color and aroma. Truong (1992) observed that the aroma could be further enhanced by adding pulp of fruits like guava, pineapple, lemon, etc. at 0.6-2.4% w/v. The sweet potato beverage was found to have an acidic pH of 3.2 with a solids concentration of 13° Brix and insoluble solids content of 9.4 mg 100 ml^{-1}. An intake of 8 ounces of the fruity sweet potato beverage (VSP-1) could provide the daily requirement of vitamin A for adults (Truong 1992).

Non-alcoholic beverage has been prepared from cream or orange fleshed variety of sweet potato by mixing the cooked and mashed pulp of sweet potato with pulp of ripe mango or fruit juices from orange, lemon, pineapple etc in India (Padmaja and Premkumar 2002).

Alcoholic beverages

'Shochu' is traditional distilled liquor made from sweet potato or other sources like rice, barley, buckwheat, etc. The process consists in first preparing a fermentation broth from rice by crushing white rice, steeping in water for 3-4 h, steaming, cooling and then adding seed 'Koji' to the steamed rice, as a starter. The starter 'Koji' contains *Aspergillus niger* or *A. Kewachii* and the mould growth is facilitated at 38-40°C for 24 h followed by 18 h fermentation at 34-36°C. The 'Koji' is then mixed with traditional yeast, *Saccharomyces cerevisiae* and adequate water. The seed mash after 5-7 days of incubation at 25-30°C is added to steamed sweet potato slurry. Further incubation at 30°C for 10-12 days yields a broth having 13-15% alcohol, which is distilled and blended to form 20-40% alcohol.

The 'Koji' process for 'Shochu' making has been hitherto improved using microbial enzymes, which helped to improve the quality and reduce the reaction time (Ogawa *et al*. 1982). Kudo *et al*. (1979) reported vacuum distillation as a better method, compared to steam distillation, as the former reduces the content of furfural, acetaldehyde etc., in the alcohol, contributing to off flavours. The presence of the furanoterpenoid compound, ipomeamarone has been detected in Shochu, made using weevil damaged sweet potato roots. This being a lung toxin has to be removed by treatment of Shochu with 0.03% activated carbon for 5 h (Kudo and Hidaka 1984). Ohtai *et al.* (1990) characterized the flavour components of 'Shochu' and found that it contains several monoterpene alcohols, like linalool, α-terpineol, citronellor, nerol and geraniol.

FLOUR-BASED FOOD PRODUCTS

The possibility of replacing part of the wheat flour with sweet potato flour for making baked foods was investigated by many workers (Montemayor and Notario 1982; Seralathan and Thirumaran 1990). Most of these studies showed that acceptability is reduced due to dominant sweet potato flavor, when higher substitution was attempted. Replacement of wheat flour up to 30% was acceptable for cakes, biscuits, muffins, etc. Collins and Aziz (1982) reported that up to 21% sweet potato flour addition to wheat flour did not affect the quality of doughnuts.

Sweet potato flour has been used for the production of sauce, a product similar to soy sauce in the Philippines (Datta *et al.* 1986). The process consists in mixing steamed soybeans with roasted sweet potato flour (50:50) and spreading the mix on trays, mixing with starter culture of *A. oryze* or *A. sojae* and incubating for 4-5 days at room temperature. The culture broth was stirred to permit aeration and the 'Koji' was then transferred to plastic containers and mixed with salt and water. Further incubation for 3 months followed by straining to extract the sauce yielded slightly thin sauce. Color and viscosity were improved through the addition of molasses and pasteurized at 80°C for 30 min prior to bottling.

Sweet potato flour (white, orange and purple fleshed varieties) was used to develop an instant gulab jamun mix in India (Padmaja *et al*. 2005). Gulab jamun is a popular sweet dessert of India, made traditionally from refined wheat flour and milk powder or 'khoa' (concentrated milk). The possibility of replacing part of the milk powder and refined wheat flour (RWF) with sweet potato flour was investigated. It was found that 20% sweet potato flour addition to milk powder: RWF mix (31:29) gave an instant mix, which produced highly acceptable gulab jamuns. White fleshed sweet potato varieties, having a soft texture on cooking are suited for making the instant mix (Padmaja *et al*. 2005).

NOVEL FOOD PRODUCTS FROM SWEET POTATO

Sweet potato has assumed great significance in recent years as a health food due to the various bioactive principles in it. Despite being a carbohydrate rich food, sweet potato is reported to have a low glycaemic index (<55), suggesting its use as a food for diabetics (Bjorck *et al*. 2000). Sweet potatoes also possess antidiabetic activity and the components contributing to this effect have been isolated and studied from white skinned varieties (Kusano and Abe 2000; Ludvik *et al*. 2003). The possibility of developing pasta from sweet potato was investigated by Jyothi Krishnan *et al*. (2011a). It was found that high protein pasta could be made from sweet potato using protein sources like whey protein concentrate (WPC) or defatted soy flour. Use of orange fleshed sweet potato variety, Sree Kanaka resulted in a dark orange coloured pasta (**Fig. 1A**) which had low starch digestibility and high resistant starch content, besides high carotene content. Scanning electron microscopy indicated the tight network formation between starch and WPC, which prevented the access of alpha-amylase to starch (**Fig. 1B**).

Low glycaemic foods rich in dietary fibre have been recognised to have protective effects against certain types of cancer, colon diseases, cardiovascular problems etc. Pasta products were developed from sweet potato flour (SPF) using dietary fibre sources like oat bran (OB), wheat bran (WB) and rice bran (RB) as additives. It was found that the products had low *in vitro* starch digestibility (**Table 1**) coupled with high resistant starch content (Jyothi Krishnan *et al*. 2011b). Iwe *et al*. (2004) produced extruded snack foods from blends of sweet potato flour with defatted soy flour and reported that high screw speed coupled with low die diameter facilitated lysine retention but increased the browning index.

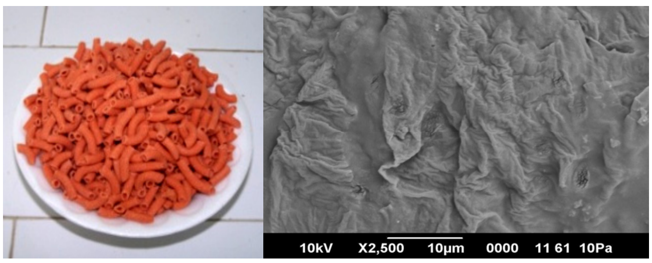

Fig. 1 (**A**) Pasta from orange fleshed sweet potato. (**B**) SEM pictures of 10% WPC-fortified sweet potato pasta (x2500).

Table 1 Rapidly digested, slowly digested and resistant starch fractions (expressed as % of total starch in the cooked and dried pasta) in the fiber enriched sweet potato pasta.

Treatments [a]	Rapidly digested starch (RDS)		Slowly digested starch (SDS)		Resistant starch (RS)	
	V1	V2	V1	V2	V1	V2
Control (70% SP)	69.67 ± 1.45	69.23 ± 0.50	15.64 ± 2.67	13.55 ± 0.50	14.69 ± 2.67	17.22 ± 0.00
T1 (60% SPF + 10% OB)	49.03 ± 1.01	42.88 ± 0.50	8.45 ± 2.16	11.92 ± 0.64	42.52 ± 2.16	45.20 ± 0.14
T2 (50% SPF + 20% OB)	47.92 ± 3.32	44.64 ± 1.27	7.74 ± 0.64	6.89 ± 1.27	44.34 ± 2.11	48.47 ± 0.00
T3 (60% SPF + 10% WB)	53.84 ± 0.53	37.33 ± 0.40	2.61 ± 0.53	13.62 ± 3.15	43.55 ± 0.00	49.05 ± 3.15
T4 (50% SPF + 20% WB)	45.50 ± 0.49	41.05 ± 0.00	5.43 ± 0.03	4.30 ± 0.00	49.07 ± 0.45	54.65 ± 0.00
T5 (60% SPF + 10% RB)	45.46 ± 3.08	50.11 ± 0.94	16.64 ± 2.60	11.08 ± 0.54	37.90 ± 4.14	38.81 ± 1.48
T6 (50% SPF + 20% RB)	50.12 ± 0.27	47.08 ± 0.88	8.58 ± 0.44	10.08 ± 3.66	41.30 ± 0.44	42.84 ± 4.54

[a] All the formulations had 27% refined wheat flour (RWF) and 3% gelatinized cassava starch; V1-Sree Arun, V2- Sree Kanaka Each value is Mean ± SD from 3 replicates
Source: Jyothi. G. Krishnan, PhD thesis (unpublished data)

INTERMEDIARY FOOD PRODUCTS

Sweet potato roots can be termed as a '3-in-1' product, as it integrates the qualities of cereals (high starch), fruits (high content of vitamins, pectins, etc.) and vegetables (high content of vitamins, minerals, etc.). The beneficial effects of these ingredients have been appropriately put to use by converting the roots into a number of intermediary food products like jam, jelly, soft drinks, pickles, sauce, candies, etc. However, these are produced to a commercial level only in a few countries like Philippines and Bangladesh.

Sweet potato is processed into jams, in the Philippines, making use of the available water soluble pectin in the roots. The process consists of cooking a mixture of 20.7% sweet potato, 45% sugar, 34% water and 0.3% citric acid until a solids content of 68° Brix was reached. Sensory evaluation of fruit flavoured sweet potato jam scored high for taste, but gelling consistency was slightly softer than fruit jam due to the high content of starch in the roots. Sweet potato jam is also prepared on a small scale in parts of China (Sheng and Wang 1987). The high carotene content of orange fleshed variety 'Kamala Sundari' of sweet potato is utilized to develop naturally coloured jam in Bangladesh (Shah Chaudhury 1992). Jam is prepared from sweet potato pulp (1.0 kg), sugar (0.90 kg), citric acid 1% and pectin (0.5%) or alternatively using sugar cane or date molasses instead of sugar. The shelf life of the jam was found to be more than one year. Sweet potato pulp is mixed with fruit pulp like mango, banana or apple for making jams in India, which will also help to mask the typical sweet potato flavour (Padmaja and Premkumar 2002). However, the consistency was slightly softer due to the high starch in the roots, permitting the incorporation of only up to 60% levels.

Sweet potato is processed into candies in parts of Japan and China (Woolfe 1992). The pale cream or purple fleshed cultivars are used for this purpose. The sweet potato mash is mixed with barley malt for 1.5 h at 55°C to enable the hydrolysis of starch to maltose and dextrin. The expressed juice is then concentrated under fire and pulled by hand/machine to introduce air and harden it. The sheeted candy is cut into fixed shapes. Sweet potato candy was prepared in Malaysia using coconut milk, skimmed milk, refined sugar and glucose syrup (Samsiah *et al*. 2005). The best formation based on sensory scores was found to have 10% steamed sweet potato mash, cooked at 120°C. In China, sweet potato pieces are candied in sugar syrup, containing flavouring and then dried in an oven for 8 h (Wiersema *et al*. 1989). Jelly is prepared from orange fleshed sweet potato (variety: Kamala Sundari) by extracting the juice and mixing with sugar (50:50), citric acid (1.5%), pectin (2%) and flavourings. Jelly has a lighter consistency than the sweet potato jam (Shah Chaudhury 1992).

Sweet potato (variety: Kamala Sundari) has been pickled in Bangladesh using the traditional ingredients. The sweet potato pieces were slightly fried, to enhance the taste (Shah Chaudhury 1992). In India, the pale cream varieties of sweet potatoes were found to give the most acceptable pickles. The diced cubes are first treated with 1.0% acetic acid solution for 1 h to prevent browning and impart acid taste to the slices. The cubes are then made into pickles using the standard ingredients. The shelf life of tightly bottled pickles was found to be more than six months (Padmaja and Premkumar 2002).

The soft texture of the sweet potato pulp is suited for making soft drinks, by mixing with thick or thin fruit pulps/juices. The cooked/mashed and sieved pulp is mixed with ripe mango pulp or orange/lemon/pineapple juice and made into soft drinks. Appropriate flavouring has been found to enhance the acceptability (Padmaja *et al*. 2005).

SWEET POTATO LEAVES AS HUMAN FOOD

Sweet potato leaves, though a rich source of vitamins, minerals and protein has been much less used as a human food. Sweet potato green tips are used as a vegetable in parts of the world (Villareal *et al*. 1979).The nutritive value of sweet potato leaves has been attributed to the high content of antioxidants especially phenolic compounds in them (Islam *et al*. 2002; Yoshimoto *et al*. 2005). The various phenolic fractions have been characterised from sweet potato leaves and the caffeoylquinic acid derivatives have been associated with the anti mutagenic effect of the leaves (Yoshimoto *et al*. 2005). Ishiguro and Yoshimoto (2005) also reported the high content of lutein (α-xanthophylls) in sweet potato leaves, which has got eye protectant effect. Lutein, present to the extent of 29.5 mg 100 g^{-1} fresh weight was more than the levels present in around 120 fruits and vegetables.

The cooking of young shoots of sweet potato has been reported to decrease its total protein from 3.7% to 2.5% (fresh weight basis (fwb) during a period of 4 min (Onate *et al*. 1970). Similar decreases have been reported in the case of American and Asian sweet potato varieties also (Leung *et al*. 1972; Haytowitz and Matthews 1984). Leaching losses of ascorbic acid, carotene and minerals have also been reporting during cooking in water for 4 min. Maeda and Salunkhe (1981) found that the fresh leaves of sweet potato contained around 49.6 mg 100 g^{-1} (fwb) of carotene and 1374 mg 100 g^{-1} vitamin C (fwb) and drying the leaves in open sunlight led to 96% loss in carotene and 98% loss in vitamin C. Blanching sweet potato leaves in boiling water for 50 second followed by drying in an enclosed solar drier retained 34% of carotene.

FUTURE PERSPECTIVES

Although sweet potato is known to be a low glycaemic food, there is not adequate research on this aspect and only a few products have been developed with this perspective. Nevertheless, considering the rise in diabetic and obese population round the globe and especially in the Asian countries, there is an imminent need to develop low calorie and low glycaemic foods like pasta and noodles from sweet potato. Browning related problems in sweet potato also needs further research as it adversely affects product development and the consumer appeal of the products. There is a lack of utilization of sweet potato for starch extraction in many countries other than China and one of the reasons cited is the presence of latex which clogs the raspers and the poor extractability of starch from sweet potatoes. This needs further research to enhance starch extraction through enzymic methods, which facilitate the release of trapped starch. Healtth benefits of orange and purple fleshed sweet potato and its leaves have not received proper attention from the researchers and consumers, which also needs further efforts.

REFERENCES

Baba T, Yamamura E (1981) Development of snack foods produced from sweet potatoes. II. Optimization of processing conditions in blanching and freezing for sweet potato chips. *Journal of the Japanese Society for Food Science and Technology* **28 (7)**, 355-359 (in Japanese)

Baba T, Kouno T, Yamamura E (1981) Development of snack foods produced from sweet potatoes. I. Factors affecting hardness and discoloration of sweet potato chips. *Journal of the Japanese Society for Food Science and Technology* **28 (6)**, 318-332

Bertoniere NR, McLemore TA, Hasling VC (1966) The effect of environmental variables on the processing of sweet potatoes into flakes and on some properties of their isolated starches. *Journal of Food Science* **31**, 574-582

Bouwkamp JC (1985) *Sweet Potato Products: A Natural Resource for the Tropics*, CRC Press, City, 271 pp

Bradbury JH, Beatty RE, Bradshaw K, Hammer B, Holloway WD, Jealous W, Lau J, Nguyen T, Singh U (1985) Chemistry and nutritive value of tropical root crops in the South Pacific. *Proceedings of the Nutrition Society of Australia* **10**, 185-188

Chang KJ, Lee S R (1974) Development of composite flours and their products utilizing domestic raw materials. IV. Textural characteristics of noodles made of composite flours based on barley and sweet potato. Korean *Journal of Food Science and Technology* **6 (2)**, 65-69 (in Korean)

Chaudhury SJC (1992) Processing of sweet potato. *Bangladesh Agricultural Research Institute Bulletin*, 40 pp

Chellammal S, Prema L (1996) Feasibility of developing extruded food products based on cassava and sweet potato. In: Kurup GT, Palaniswami MS, Potty VP, Padmaja G, Kabeerathumma S, Pillai SV (Eds) *Tropical Tuber Crops: Problems, Prospect and Future Strategies*, Oxford & IBH Publishing Co Pvt. Ltd, New Delhi, India, pp 508-512

Chen Z (2003) Physicochemical properties of sweet potato starches and their application in noodle products. PhD thesis, Wageningen University, the Netherlands, 145 pp

Collins JL, Pangloli P (1997) Chemical, physical and sensory attributes of noodles with added sweet potato and soy flour. *Journal of Food Science* **62 (3)**, 622-625

Collins JL, Aziz A (1982) Sweet potato as an ingredient in yeast- raised doughnuts. *Journal of Food Science* **47 (4)**, 1133-1139

Data E, Operario JJA (1992) Processing and storage characteristics of sweet potato chips. In: In: Hill WA, Bonsi CK, Loretan PA (Eds) *Sweet Potato Technology for the 21st Century*, Tuskegee University, Alabama, USA, pp 407-414

Datta ES, Diamante JC, Forio EE (1986) Soy sauce production utilizing root crop flour as substitute for wheat flour (100% substitution). *Annals of Tropical Research* **8 (1)**, 42-50

Deobald HJ, McLemore TA (1964) The effect of temperature, antioxidant and oxygen on the stability of pre-cooked dehydrated sweet potato flakes. *Food Technology (Chicago)* **18**, 145-148

Fasina OO, Farkas BE, Fleming HP (2003) Thermal and dielectric properties of sweet potato puree. *International Journal of Food Properties* **6 (3)**, 461-472

Golder PC, Hossain MA, Altaluri S, Ilangantileke S (2005) Home scale processing of sweet potato. In: 2nd *International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June, 2005, pp 165-166

Grabowski JA, Troung VD, Daubert CR (2006) Spray-drying of amylase hydrolysed sweet potato puree and physicochemical properties of powder. *Journal of Food Science* **71 (5)**, 209-217

Grabowski JA, Troung VD, Daubert CR (2007) Nutritional and rheological characterization of spray-dried sweet potato powder. *LWT Food Science and Technology* **41**, 206-216

Haytowitz DB, Mathews RH (1984) Composition of foods: Vegetables and vegetable products. Human Nutrition Information Series, USDA Agriculture Handbook No. 8-11, pp 428-439

Hong EH (1982) The storage, marketing and utilization of sweet potatoes in Korea. In: Villareal RL, Griggs TD (Eds) *Sweet Potato: Proceedings of First International Symposium*, AVRDC, Tainan, Taiwan, pp 405-411

Hoover MW (1966) An enzyme process for producing sweet potato flakes from starchy and uncured roots. *Food Technology (Chicago)* **20**, 84-87

Hoover MW (1967) An enzyme activation process for producing sweet potato flakes. *Food Technology (Chicago)* **21**, 322-325

Hoover MW, Miller NC (1973) Process for producing sweet potato chips. *Food Technology (Chicago)* **27 (5)**, 74, 76, 80

Ice JR, Hamann DD, Purcell AE (1980) Effects of pH, enzymes and storage time on the rheology of sweet potato puree. *Journal of Food Science* **45**, 1614-1618

Ishiguro K, Yoshimoto M (2005) Content of eye- protective nutrient lutein in sweet potato leaves. In: 2nd *International Symposium on Sweet Potato and Cassava*, 14-17 June, 2005, Kuala Lumpur. Malaysia, pp 213-214

Islam MS, Yoshimoto M, Yahara S, Yamakawa O (2002) Identification and characterization of foliar polyphenolic composition in sweet potato (*Ipomoea batatas* L.) genotypes. *Journal of Agricultural and Food Chemistry* **50**, 3718-3722

Iwe MO, Zuilichem DJV, Ngoddy PO (2000) Color of single-screw extruded blends of soy-sweet potato flour - A response surface analysis. *Plant Foods for Human Nutrition* **55 (2)**, 159-168

Iwe MO, Zuilichem DJV, Stolp W, Ngoddy PO (2004) Effect of extrusion cooking of soy-sweet potato mixtures on available lysine content and browning index of extrudates. *Journal of Food Engineering* **62 (2)**, 143-150

Jyothi G Krishnan, Renjusha Menon, Padmaja G, Sajeev MS, Moorthy SN (2011) Nutritional and functional characteristics of protein-fortified pasta from sweet potato. *Food and Nutrition Sciences* **2**, 944-955

Jyothi G Krishnan, Renjusha Menon, Padmaja G, Sajeev MS, Moorthy SN (2012) Evaluation of nutritional and physico-mechanical characteristics of dietary fiber enriched sweet potato pasta. *European Food Research and Technology* **234**, 467-476

Kelly EG, Baum RR, Woodward CF (1958) Preparation of new and improved products from eastern (dry type) sweet potatoes: Chips, dice, julienne strips and frozen French fries. *Food Technol*ogy *(Chicago)* **12**, 510-514

Kudo T, Hidaka T (1984) Removal of bitter components from shochu produced from diseased sweet potatoes by carbon treatment. *Journal of the Society for Brewing Japan* **79 (12)**, 900- 901 (in Japanese)

Kudo T, Hamakawa S, Nakayama K, Hidaka T (1979) Production of shochu by vacuum distillation. *Journal of the Society for Brewing Japan* **74 (7)**, 484-486 (in Japanese)

Lee SY (2005) Extruded products from sweet potato-from breakfast food to snacks. In: 2nd *International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June, 2005, pp 219-220

Leung WTW, Butrum RR, Chang FH (1972) Food composition table for use in East Asia. Part I. In: *Proximate Composition, Mineral and Vitamin Contents of East Asian Foods*, U.S. Department of Health, Education and Welfare, Bethesda, M.D, FAO, Rome

Lopez A, Wood CB, Boyd EN (1976) Changes in some monocarbonyl classes during processing and storage of sweet potato flakes. *Journal of Food Science* **41**, 524-526

Maeda EE, Salunkhe DK (1981) Retention of ascorbic acid and total carotene in solar dried vegetables. *Journal of Food Science* **46**, 1288-1290

Martin FW (1987) Fried chips from staple type sweet potatoes. *Journal of the Agricultural University of Puerto Rico* **71 (4)**, 373-378

Martin FW (1986) Sugars in staple type sweet potatoes as affected by cooking and storage. *Journal of the Agricultural University of Puerto Rico* **70 (2)**, 121-126

Mason RL (1982) Sweet potato canning investigations. *Food Technology Australia* **34 (12)**, 574-576

Montemayor NR, Notario JN (1982) Development of food products using soybean and root crop flours. *CMU Journal of Agriculture and Food Nutrition* **4 (3)**, 274-288

Ogawa K, Toyama H, Toyama N (1982) Utilization of enzyme preparations in shochu making. *Bulletin of Faculty of Agriculture, University of Miyazaki* **29 (1)**, 203-211 (in Japanese)

Ohtai T, Ikutai R, Nakashima M, Morimitsu Y, Samutai T, Saikii T (1990) Characteristic flavor of Kamho-shochu (sweet potato spirit). *Agricultural and Biological Chemistry* **54 (6)**, 1353-1357

Onate LU, Arago LL, Garcia PC, Abdon IC (1970) Nutrient composition of some raw and cooked Philippine vegetables. *Philippine Journal of Nutrition* **23 (3)**, 33-44

Padmaja G, Premkumar T (2002) *Tuber Crops Recipes*, Technical Bulletin Series 36, CTCRI, Kerala, India, 26 pp

Padmaja G, Moorhty S N, Nanda S K, Sajeev MS (2005) Innovative approaches in the value addition of sweet potato and cassava for mini-agri-business in developing countries. In: 2nd *International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June 2005, pp 15-16

Panda S, Ray RC (2007) Lactic acid fermentation of β-carotene rich sweet potato (*Ipomoea batatas* L.) into lacto-juice. *Plant Foods for Human Nutrition* **62 (2)**, 65-70

Picha DF (1986) Influence of storage duration and temperature on sweet potato sugar content and chip color. *Journal of Food Science* **51 (1)**, 239-240

Purcell AE, Walter WM Jr. (1968) Autoxidation of carotenes in dehydrated sweet potato flakes using ^{14}C-B-carotene. *Journal of Agricultural and Food Chemistry* **16**, 650-653

Purcell AE, Walter WM Jr. (1988) Comparison of carbohydrate components in sweet potatoes baked by convection heating and microwave heating. *Journal of Agriculture and Food Chemistry* **36 (2)**, 360-362

Rao VNM, Hamann DD, Humphries EG (1974) Mechanical testing as a measure of kinesthetic quality of raw baked sweet potatoes. *Transactions of the American Society of Agricultural Engineering* **17**, 1187-1190

Ray RC, Naskar SK, Sivakumar PS (2005) *Sweet Potato Curd*, CTCRI Technical Bull. Series No. 39, 24 pp

Reddy NN, Sistrunk WA (1980) Effect of cultivar, size, storage and cooking method on carbohydrates and some nutrients of sweet potatoes. *Journal of*

Food Science **45 (3)**, 682-684

Reungmaneepaitoon S, Poolperm N, Jariyavattanavijit C, Teangpook C (2005) Production of sweet potato frozen French- fry- type products from sweet potato grown in Thailand. In: *2nd International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June 2005, pp 185-186

Salma O, Zaidah I (2005) Sweetpotato for the production of nutritious food products. In: *2nd International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June, 2005, pp 181-182

Samsiah MS, Latifah MS, Ong CY (2005) Sweet potato candy. In: *2nd International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14- 17 June, 2005, pp 223-224

Schwartz SJ, Walter WM, Carroll DE, Giesbrecht FG (1987) Chemical, physical and sensory properties of a sweet potato French-fry type product during frozen storage. *Journal of Food Science* **52 (3)**, 617-619, 633

Scott LE (1952) Sweet potato discoloration in relation to HP steam peeling. *Food Packer* **33 (3)**, 38-39

Scott LE, Kattan AA (1957) Varietal differences in the catechol oxidase content of the sweet potato root. *Proceedings of the American Society for Horticultural Science* **69**, 436-442

Seralathan MA, Thirumaran AS (1990) Utilization of sweet potato (*Ipomoea batatas*) flour in South Indian dishes. In: Howeler RH (Ed) *Tropical Root and Tuber Crops: Changing Role in a Modern World*, Proceedings Eighth Symposium of the International Society for Tropical Root Crops. October 30-November 5, 1988, Bangkok, Thailand, p 600 (Abstract)

Shah Chaudhury JC (1992) *Processing of Sweet Potato*, Bangladesh Agricultural Research Institute Bulletin, 40 pp

Sheng J, Wang S (1987) The status of sweet potato in China from 1949-to the present. Cited in: Woolfe JA (Ed) *Sweet Potato: An Untapped Food Resource*, Cambridge University Press, 1992, 643 pp

Smith DA, McCaskey TA, Harris H, Rymal KS (1982) Improved aseptically filled sweet potato purees. *Journal of Food Science* **47**, 1130-1132, 1147

Spadaro JJ, Patton EL (1961) Pre-cooked dehydrated sweet potato flakes. *Food Engineering* **33**, 46-49

Szyperski RJ, Hamann DD, Walter WM (1986) Controlled alpha-amylase process for improved sweet potato puree. *Journal of Food Science* **51 (2)**, 360-363, 377

Tan JD, Forio EE, Estoy LS (2005) Production and market potential of sweet potato flakes. In: *2nd International Symposium on Sweet Potato and Cassava*, Malaysia, 14-17 June, 2005, pp 215-216

Taubenhaus JJ (1923) *The Culture and Diseases of the Sweet Potato*, E. P. Dutton, New York, 179 pp

Thirumaran AS, Ravindran DM (1992) Processing of sweet potato vermicelli in India. In: Hill WA, Bonsi CK, Loretan PA (Eds) *Sweet Potato Technology for the 21st Century*, Tuskegee University, Tuskegee, Al, pp 468-472

Truong VD (1987) New developments in processing sweet potato for food. In: *International Sweet Potato Symposium*, 20-26 May, 1987, Visca, Philippines

Truong VD (1990) Development of small scale technology for dehydrated sweet potato cubes for traditional food preparations In: Howeler RH (Ed) *Tropical Root and Tuber Crops: Changing Role in a Modern World*, Proceedings of the Eighth Symposium of the International Society for Tropical Root Crops, October 30 - November 5, 1988, Bangkok, Thailand, p 600 (Abstract)

Truong VD (1992) Sweet potato beverages: Product development and technology transfer. In: Hill WA, Bonsi CK, Loretan PA (Eds) *Sweet Potato Technology for the 21st Century*, Tuskegee University, Tuskegee, Al, pp 389-399

Truong VD, Fementira GB (1990) Formulation, consumer acceptability and nutrient content of non- alcoholic beverages from sweet potato. In: Howeler RH (Ed) *Tropical root and tuber crops: Changing role in a modern world*, Proceedings of the Eighth Symposium of the International Society for Tropical Root Crops, October 30-November 5, 1988, Bangkok, Thailand, pp 589-599

Utomo JS, Che Man YB, Rahman RA, Saad MS (2005) Physical and chemical characteristics of restructured sweet potato sticks made from three sweet potato cultivars. In: *2nd International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June 2005, pp 221-222

Walter WM Jr., Hoover MW (1986) Preparation, evaluation and analysis of a French-fry type product from sweet potatoes. *Journal of Food Science* **51 (4)**, 967-970

Walter WM Jr., Purcell AE (1980) Effect of substrate levels and polyphenol oxidase activity on darkening in sweet potato cultivars. *Journal of Agricultural and Food Chemistry* **28**, 941-944

Walter WM Jr., Schadel WE (1982) Effect of lye peeling conditions on sweet potato tissue. *Journal of Food Science* **47**, 813-817

Walter WM Jr., Schwartz SJ (1993) Controlled heat processing of Jewel sweet potatoes for puree production. *Journal of Food Quality* **16**, 71-80

Walter WM Jr., Purcell AE, Hoover MW, White AG (1978a) Preparation and storage of sweet potato flakes fortified with plant protein concentrates and isolates. *Journal of Food Science* **43**, 407-410, 419

Walter WM Jr., Purcell AE, McCollum GK (1979) Use of high pressure liquid chromatography for analysis of sweet potato phenolics. *Journal of Agricultural and Food Chemistry* **27 (5)**, 938-941

Wiersema SG, Hesen J, Song BF (1989) Report on a sweet potato post harvest advisory visit to the People's Republic of China, 12-27 January, International Potato Centre, Lima, Peru

Woodroof JG, Atkinson IS (1944) Preserving sweet potatoes by freezing. *Gallenkamp Agricultural Experimental Station Bulletin*, 232 pp

Woolfe JA (1992) *Sweet Potato: An Untapped Food Resource*, Cambridge University Press, 643 pp

Yaacob CM, Raya S (1983) A preliminary study on processing of sweet potato leather. *Pertanika* **6**, 17

Yoshimoto M, Kurata R, Okuno S, Ishiguro K, Yamakawa O, Tsubata M, Mori S, Takagaki (2005) Nutritional value of and product development from sweet potato leaves. In: *2nd International Symposium on Sweet Potato and Cassava*, Kuala Lumpur, Malaysia, 14-17 June, 2005, pp 183-184