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Review

A review on sweet potato postharvest processing and preservation technology

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Sweet potato (SP) is an important root crop grown all over the world and consumed as a vegetable, boiled, baked or often fermented into food and beverages. It could be a very good vehicle for addressing some health related problems and also serve as food security. The research into sweet potato processing has established the fact that there is a lot more in sweet potatoes than its starch. The review has established that the nutritional quality content in sweet potatoes can be enhanced by developing new varieties from available germplasm. Natural colourant and antioxidant present in purple- and red-flesh potatoes can be used for developing functional foods. Available evidence for Africa suggested that postharvest processing and subsequent storage of sweet potatoes need further research to explore the ways by which the new cultivars could be used for industrial and export purposes. Based on the report of the review, study of the combined effects of blanching and/or freezing pre-treatments with higher drying temperatures, determination of moisture diffusivity and activation energy during different drying conditions are recommended for future research.

Key words: Sweetpotato, processing, preservation, storage, postharvest.

INTRODUCTION

Sweet potato roots are bulky and perishable unless cured. This limits the distance over which sweet potato can be transported economically. It was established that in cases where countries are capable of generating surplus, it tends to be relatively localized but dispersed and this leads to a lack of market integration and limits market size (Katan and De Roos, 2004; FAO, 2011). Moreover, production is highly seasonal in most countries leading to marked variation in the quantity and quality of roots in markets and associated price swings. Most especially, in Africa, there is commercial processing into chips or flour, which could be stored for year round consumption for use such as in bread and cakes, or processing into fermented and dried products like fufu. Sweet potato consumption has been adjudged to decline as incomes rise - a change often linked with urbanization, partly because it is perceived as a “poor man’s food” but mostly because of the lack of post-harvest processing or storage (FAOSTAT, 2008; Centro Internacional de la Papa, 2009). The latter can lengthen the period for which sweet potato can be marketed but may also be relevant for subsistence oriented households to increase the period over which sweet potato can be consumed, particularly where there is a marked dry season. A sensible approach to achieve the goal of sweet potato product development would be to increase the nutritional content of this highly consumed crop. The aim of this review is to re-examine the information on the processing

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of sweet potatoes.

GLOBAL SITUATION OF SWEET POTATO

United Nation's Food and Agriculture Organization (FAO) (1990, 2011) reported that sweet potato (*Ipomea batatas* (L.) Lam.) is a very important crop in the developing world and a traditional, but less important crop in some parts of the developed world. According to FAO (2011), sweet potato is one of the seven crops in the world produce over 105 hundred million metric tonnes of edible food products in the world annually. Only potato and cassava, among the root and tuber crops, produce more. China alone produced 80 to 85% of the total sweet potato production in the world while the remaining countries in Asia have the next highest production and then, followed by Africa and Latin America (Centro Internacional de la Papa, 2009).

In another report, sweet potato is among the world's most important and under-exploited food crops (Scott and Maldonado, 1999; Grant, 2003). With more than 133 million metric tonnes in annual production, sweet potato currently ranks as the fifth most important food crop on a fresh-weight basis in developing countries after rice, wheat, maize, and cassava (Scott and Maldonado, 1999; Grant, 2003). Despite the fact that sweet potato commonly categorized as a subsistence, "food security" or "famine relief" crop, its uses have diversified considerably in developing countries over the last four decades (Grant, 2003). The major producing countries are China, Russian Federation, Indian, Ukraine and the USA with the annual world production of potatoes in 2009 of about 329,581 million tones (FAO, 2011).

Wheat which is suitable for bread-making cannot be grown satisfactorily in many countries, therefore, the FAO statistics has demonstrated that the importance of sweet potato in the area where wheat production is often disadvantaged due to climatic restraints, and utilization of indigenous crops could lead to reduction in importation of wheat or wheaten flour (Katan and De Roos, 2004). Sweet potato is a very efficient food crop and produces more dry matter, protein and minerals per unit area in comparison to cereals (Woolfe, 1992). Research have reported that sweet potatoes being the staple food in the developed countries account for 130 kcal of energy per person per day against 41 kcal in the developing countries where it is still considered as vegetable. Apart from being a rich source of starch, sweet potatoes contain good quantity of secondary metabolites and small molecules which play an important role in a number of processes (Friedman, 1997). Many of the compounds present in sweet potato are important because of their beneficial effects on health, therefore, are highly desirable in the human diet and functions as a functional food (Katan and De Roos, 2004).

The global situation of sweet potato as a commodity is that it is widely grown throughout the world. However, only about one percent of production enters world trade with Canada, the United Kingdom, France and the Netherlands being the major importing countries (Katan and De Roos, 2004). The USA is the largest exporter of sweet potato accounting for 35% of world trade. The other exporters are China (12%), Israel (9%), France (7%), Indonesia (6%) and Netherlands/France (5%). The last two are also involved in re-exporting. Most of the product is used for table consumption with a small percentage going into industrial uses and animal feed. Sweet potatoes are grown throughout the world and are consumed in large quantities. One of the global health goals is to increase the availability of nutrients to a large population of the world. A reasonable and sensible approach to achieve this goal would be to increase the nutritional content of highly consumed crops (Katan and De Roos, 2004).

Sweet potato can, and does, play a multitude of varied roles in the human diets being either supplemental or a luxury food besides being a staple crop for some parts of the world (Papua New Guinea, some parts of Philippines, Tonga and Solomon Islands) (Sosinski et al., 2001). In Asia countries, sweet potato uses range from supplementary food of little status (Thailand) to a very important supplementary food (Ryukyu Islands, Japan) to rice and/or other root and tuber crops (Wanda, 1987). Sosinski et al. (2001) reported that in the United States and other developed countries, the role of sweet potato is strictly as a luxury food and in other parts of the world such as in Japan, where it plays its role as novel plant products and/or nutriceuticals.

NUTRITIONAL COMPOSITION OF SWEET POTATO

The nutritional composition of sweet potato which are important in meeting human nutritional needs including carbohydrates, fibres, carotenes, thiamine, riboflavin, niacin, potassium, zinc, calcium, iron, vitamins A and C and high quality protein (Tables 1 and 2). Sweet potato particularly provides energy in the human diet in the form of carbohydrates.

According to USDA (2009), besides carbohydrates, they are also rich in dietary fiber and have high water content and also provide 359 kJ energy with low total lipid content, which is only about 0.05 g per 100 g. In addition, sweet potatoes also are high in minerals such as potassium, calcium, magnesium, sodium, phosphorus, and iron (USDA, 2009). Because of the various roles that sweet potatoes play around the world, the concept of nutritional quality and its contribution must transform to meet specific roles in human diet. For instance, staple type diets could require high vitamin C, iron, potassium, protein and as well as high fibre. Similarly, supplemental types of sweet potato must have many of the same characters as staple types in terms of nutritional

Table 1. Sweet potato chemical composition (per Serving of one medium 5 inch long sweet potato; 130 g).

Nutrient	Unit	Composition
Calories	kJ/s	130
Calories from fat	g	0.39
Protein	g	2.15
Carbohydrate	g	31.56
Dietary Fiber	g	3.9
Sodium	mg	16.9
Potassium	mg	265.2
Calcium	mg	28.6
Folate	mcg	18.2
Vitamin C	mg	3.1 (excellent source)
Vitamin A	IU	18443 (excellent source)

Source: USDA, 2009.

Table 2. Nutritional value of raw sweet potato per 100 g.

Nutrient	Unit	Value per 100 g
Water	g	77.28
Energy	kJ	359.00
Protein	g	1.57
Total lipid (fat)	g	0.05
Ash	g	0.99
Carbohydrate	g	20.12
Fiber, total dietary	g	3.00
Calcium, Ca	g	30.00
Iron, Fe	mg	0.61
Magnesium, Mg	mg	25.00
Phosphorus, P	mg	47.00
Potassium, K	mg	337.00
Sodium, Na	mg	55.00
Vitamin C	mg	2.40
Pantothenic acid	mg	0.80
Vitamin B-6	mg	0.21
Vitamin A	IU	14187

Source: USDA (2009).

components. However, as they will not be major food component, the level of components may be more flexible and good.

PROCESSING TECHNIQUES OF SWEET POTATO

It was reported by Fellows (2000) that food processing entails combined procedures to achieve intended changes to the raw material and the processing technologies in the food industry. The processing is subdivided into two main groups, viz:

(i) Processing of foods with non-thermal methods (Lebovka et al., 2004, 2007) such as high pressure processing, pulsed electric field (PEF), electronic beams, and

(ii) Processing of foods with the application of heat (Yadav et al., 2006; Leeratanarak et al., 2006; Ahmed et al., 2010; Fernando et al., 2011; Singh and Pandey, 2012) such as blanching, pasteurization, sterilization, evaporation or concentration, drying or dehydration, microwave and infra-red heating.

PROCESSING OF FOODS WITH THERMAL METHODS AND HEAT

Heat treatment is one of the important methods used in food processing to extend the shelf life of foods either by destroying the enzymatic and microbial activity or by removing water to inhibit deterioration that results from higher water activity. Fellows (2000) enumerated the advantages of heat processing as:

(i) Simple control of processing conditions;
(ii) Production of shelf-stable products that need no refrigeration;
(iii) The destruction of anti-nutritional factors (e.g. trypsin inhibitor in some legumes); and
(iv) The enhancement of availability of nutrients for human consumption (e.g. improves digestibility of proteins and gelatinization of starches).

Processing by application of heat that can be used in product development from sweet potato can be carried out using four methods including:

(a) Heat processing with the use of hot air e.g. dehydration, baking, roasting (Ahmed et al., 2010; Doymaz, 2012).
(b) Heat processing with the use of water or steam e.g. blanching, pasteurization (Fernando et al., 2011).
(c) Heat processing with the use of hot oils e.g. frying (Troncoso et al., 2009).
(d) Heat processing using radiated and direct energy e.g. ohmic heating, di-electric heating, infrared heating (Zhong and Lima, 2003; Brinley et al., 2008; Wang et al., 2010).

PROCESSING OF SWEET POTATO INTO PRODUCTS

The traditional methods of processing sweet potato in most countries have been limited to washing, peeling and boiling. However, in some communities, the roots are washed, peeled, cut into small pieces and then lemon or tamarind juice sparingly added. The pieces are, then, dried in the sun and milled together with sorghum into flour that can be used in making porridge. Some farmers make chips, sun dry, store and later reconstitute by adding water then cook by boiling. Others dry the grated product, mill and then add to other flours to make composite flours. FAO (2011) developed improved processing methods to help overcome some of the problems associated with traditional method, in order to produce sweet potato flour (Figure 1) with improved odour, colour and nutritional qualities.

In cases where rare on-farm processing of sweet potato is done in sub-Saharan Africa, products made include flour which is mixed with sorghum to make porridge and mild alcoholic beverages from peeled, chopped, fermented and pounded sweet potato. This processing is only done when the crop has been harvested and there are no other immediate uses for the produce. In many other areas of the district, flour production was popular in the 60's but was abandoned in favour of maize flour.

The development of processed products from sweet potato presents one of the most important keys to the expanded utilization of the crop. Just like white potatoes, sweet potatoes are multipurpose vegetables. The development in sweet potato research and development (R&D), has transformed the crop from a simple staple food to an important commercial crop with multiple uses such as a snack, ingredient in various foods and complementary vegetable. Lopez et al. (2000) reported that sweet potato flakes (called sweet potato buds) with an increased β-carotene content were produced in Guatemala to conquest vitamin A deficiency in children. Fresh-market sweet potatoes can be baked, microwaved, broiled, grilled, and baked. In some countries alcohol is distilled from sweet potatoes. They can also be used in plate garnishes, casseroles, sautéed vegetables, pasta sauces, dipping vegetables green salads, (fresh- cut sticks), soups, stir-fry, and stews (Dawkins and Lu, 1991). They can be processed as follows:

(i) Dried/dehydrated: flour, flakes, chips,
(ii) Frozen: dices, slices, patties, French fries, and
(iii) Canned: candied, baby foods, mashed, cut/sliced, pie fillings.

Sweet potatoes are also used as an ingredient in cakes, ice creams, icing, pie fillings, cookies, custards and various other bread products. As drying technology progressed, sweet potatoes began to be pureed and then dried to produce flakes, which can be easily reconstituted for direct use in various products like mashed sweet potato, pies and other products (Dawkins and Lu, 1991).

Dried sweet-sour sweet potato

Dried sweet-sour sweet potato was originally named Delicious-SP and it is a product that has the sweet and sour taste of dried fruits (Truong et al., 1998). The most acceptable product was made with boiled sweet potato slices 0.3 mm thick which were soaked in 60° Brix syrup containing 0.8 - 1.0% citric acid and dried at 65°C. Truong (1992) established that the Delicious-SP prepared from sweet potato variety VSP-1, which is a “moist” type sweet potato with low dry matter and starch content, obtained the highest sensory scores due to its attractive orange colour and soft texture. Dried sweet-sour sweet potato contains 13,033 I.U. of vitamin A per 100 g which is higher than both dried mango and dried apricot.

Sweet potato Catsup (Ketchup)

Sweet potato catsup consists of 32.3% (w/v) sweet potato, 42% water, 12.9% vinegar, 11.3% sugar, 1.0%

Figure 1. Sweet potato flour production.
Source: Okigbo (1989) and FAO (2011).

salt, 0.3% spices, and food colouring (references). The roots are washed, trimmed, chopped into chunks, and boiled. The boiled chunks are blended with water and other ingredients and boiled to the desired consistency before bottling. Various sweet potato cultivars having cooked flesh colours which range from yellow to orange and a “moist” texture can be used for catsup making. Sweet potato catsup had viscosity, pH, total soluble solids, and intermediate vitamin A content comparable to values found in banana catsup. In consumer acceptability tests, sweet potato catsup was ranked statistically equal to the leading brand of tomato and banana catsup in terms of colour, consistency, flavor, and general acceptability (Truong et al., 1990). Sweet potato catsup stored for four months at ambient temperature was given comparable sensory scores to that of freshly prepared samples.

Sweet potato jam

The sweet potato jam formula contains 20.7% (w/v) sweet potato, 45% sugar, 34% water, and 0% citric acid and this has proved most acceptable by the trained taste panel compared with other ratio. The initial steps in preparing sweet potato roots are similar to those for sweet potato catsup. The cooked chunks are blended with water, sugar, citric acid, and optionally with flavourings. The slurring is then cooked until total soluble solids of 68° Brix was obtained (Truong et al., 1986). Due to the high starch content of sweet potato roots as compared to fruits, the proportions of sweet potato and sugar are different from the standard formula of 45% fruit and 55% sugar in fruit jams (Gross, 1979).

Sweet potato beverage

The processing steps for sweet potato beverage involve washing, peeling, trimming to remove damaged parts, steaming, extracting, and formulating with 12% (w/v) sugar, 20% (w/v) citric acid, and 232 mg/L ascorbic acid as vitamin C fortification (Truong and Fermentira, 1990). The formulated beverage is bottled in 150 ml glass containers and pasteurized at temperature of 90 to 95°C. Various sweet potato varieties were evaluated for their suitability in processing into the beverage. In general, the orange coloured beverage is preferred to other coloured products. Addition of the juice or pulp of different fruits, e.g., guava, pineapple, or Philippine lemon, at concentrations of 0.6 to 2.4% (w/v) significantly improved aroma scores. Similar to jam, incorporation of artificial orange flavouring also enhanced the aroma of sweet potato beverage. More than 85% of consumer respondents rated “like” for the sweet potato beverage, and 96% liked guava-flavoured sweet potato beverage (Truong and Fermentira, 1990).

Sweet potato leather

Steamed sweet potato chunks are blended with water, sugar, salt, citric acid, and optionally with artificial fruit flavours in processing sweet potato leather. The slurry is then thinly spread on plastic sheets and dried in a mechanical drier until the desired moisture content and texture of the product are obtained. A loading density of 4 kg slurry per m^2 produced the sweet potato leather which was rated with high sensory scores for thickness, texture, and general acceptability. The product also obtained scores of over 7.0 for colour, sweetness, and sourness on the 9-point hedonic scale. Addition of pectin at 0.05 to 0.15% w/w did not improve the texture of the product. Apparently the pectin content of sweet potato is sufficient to produce a leathery textured product (Truong et al., 1998).

OPPORTUNITIES FOR EXPANDING SWEET POTATO PROCESSING

Opportunities for expanding the use of sweet potato lie in three categories: (1) fresh and processed for human consumption, (2) fresh and dried for animal feed, and (3) starches and flours for food and non-food uses.

Table 3. Food crops and their vitamin-calorie contribution per capita/day.

Food crops	Calorie cost ($)	A (Si)	Vitamin		Minerals		
			B1 (mg)	C (mg)	Fe (mg)	Ca (mg)	Fe (mg)
Rice	2.75	0	0.69	0	20.82	486	2.78
Maize	1.38	1795	1.34	0	35.20	901	8.45
Cassava	0.94	3065	236	0.48	262.68	318	5.57
Sweet potato	1.34	78232	224	0.91	304.80	498	7.11

Source: Scott et al. (2000).

Human consumption

Sweet potato fulfils a number of basic roles in the global food system, all of which have fundamental implications for meeting food requirements, reducing poverty, and increasing food security. Sweet potato is a cheap calorie producer and is rich in vitamin A and C and minerals (Table 3). The production growth of sweet potato must be higher than the population growth for food security. World sweet potato production growth is projected at 1.45% and roots in fresh form generally have little competitive overlap on either the supply or demand side. The processed products made from sweet potato not only compete with cereals, but also with each other's processed products in terms of market and raw material. Declining availability of rice, population growth, modest absolute income levels for large segments of consumers, and declining farm size will contribute to a growing use of fresh roots, and in certain areas, of leaves for human consumption. It was established that consumers prefer processed products of roots such as noodles to fresh roots (Scott et al., 2000).

Consumption of fresh roots tends to decline as per capita income rises and consumers will switch to more preferred foods. Therefore, future research must investigate the feasibility of improving quality and lowering unit cost, or channelling output into emerging specialist markets such as the starch market for upstream industries. Future economic trends will also help determine whether shifts in relative prices and exchange rates, and pace of technological innovation, will change the market for this type of product either into a more regional market, or a highly localized one.

Sweet potato starch and flour can be processed into many food and non-food products (Figure 2). It is possible to develop flour and starch as strategic products for upstream industries. Expanding sweet potato for industrial uses must be backed up by innovative postharvest technologies. Physicochemical properties of sweet potato significantly differ among varieties. Therefore, suitable varieties for each processed product are needed (Lin, 2000).

Idris and Hasim (2000) reported that sweet potato starch can provide modified starch that is a raw material for processed products like sauces and fermented foods from sweet potato. This implies that there is an opportunity for expanding the uses of sweet potato in industry. The physical properties of starch differ widely across varieties and these differences markedly affect the quality of starch noodle produced (Collado and Corke, 2000; Panda and Ray, 2007; 2008; Panda et al., 2007, 2009). Some of the fermented foods include lacto-pickle, lacto-juice, sweet potato curd and yoghurt, wine and beer.

Lacto-pickles

Lactic acid (LA) bacteria influence the flavour of fermented foods in a variety of ways. In many cases, the most obvious change in LA fermentation is the production of acid and lowering of pH those result in an increase in sourness (Panda and Ray, 2007). Experimental work on pickling of β-carotene and anthocyanin-rich sweet potato by LA fermentation (sauerkraut process) using 5.20% (w.v) brine solution has been carried out at Regional Centre of CTCRI, Bhubaneswar, India (Panda et al., 2007, 2009). It not only produced LA which imparted taste and flavour to lacto-pickles, but also preserved ascorbic acid, phenols, and coloured pigments (β-carotene and anthocyanin); all these are considered as anti-oxidants (Shivashankara et al., 2004).

Anthocyanin-rich sweet potato lacto-pickle had a pH (2.5 - 2.8), titratable acidity (TA) (1.5 - 1.7 g kg^{-1}), lactic acid (1.0 - 1.3 g kg^{-1}), starch (56 - 58 g kg^{-1}) and anthocyanin content (780 mg kg^{-1}) on fresh weight basis. Sensory evaluation rated the anthocyanin-rich sweet potato lacto-pickle acceptable based on texture, taste, aroma, flavour and aftertaste (Panda et al., 2009).

Lacto-juice

Lacto-juices processed by lactic acid fermentation bring about a change in the beverage assortment for their high nutritive value, vitamins and minerals which are beneficial to human health when consumed (Panda and Ray, 2008). Lacto-juice was prepared by fermentation of β-carotene and anthocyanin-rich sweet potato cultivars by inoculating LAB, *Lb. plantarum* MTCC 1407 (Panda and

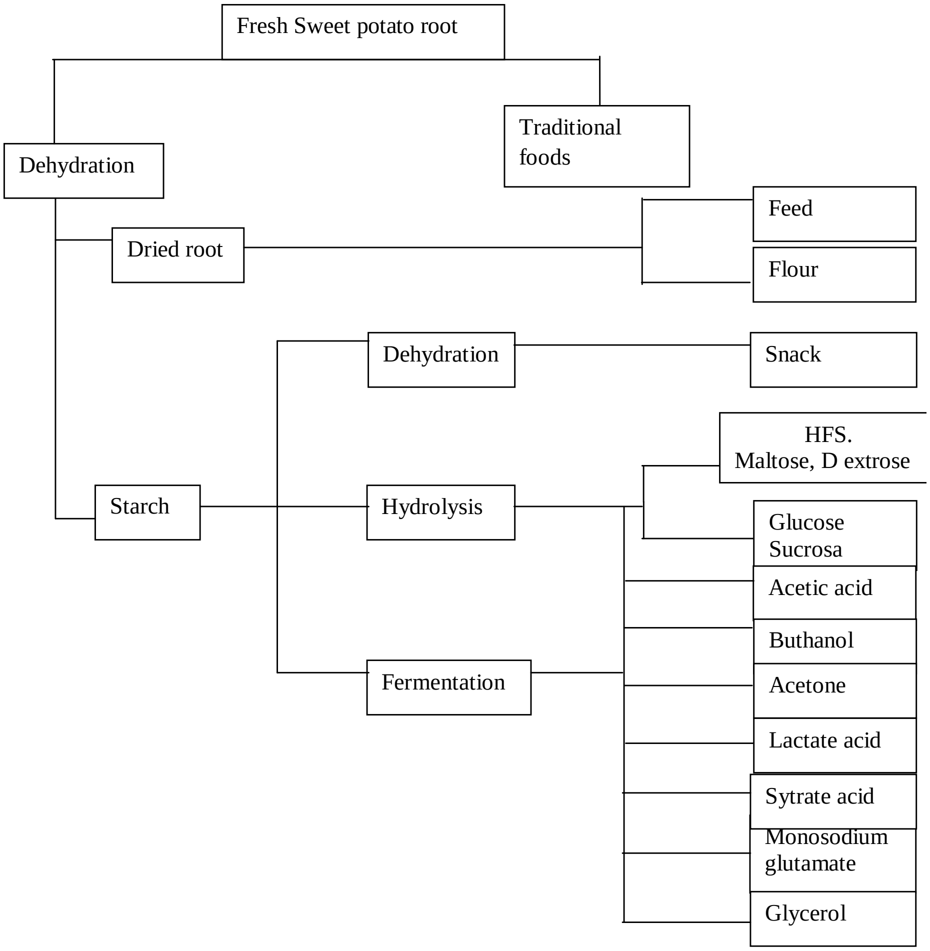

Figure 2. Flow chart on the use of sweet potato as starch and flour. Source: Lin (2000).

Ray, 2008; Panda et al., 2009). β-carotene-rich sweet potato roots (non-boiled/fully-boiled) were fermented with *Lb. plantarum* at 28 ± 2°C for 48 h to make lacto-juice.

During fermentation both analytical [pH, TA, LA, starch, total sugar, reducing sugar (g kg^{-1} roots), total phenol and β-carotene (mg kg^{-1} roots)] and sensory (texture, taste, aroma, flavour and aftertaste) analyses of sweet potato lacto-juice were evaluated. The fermented juice was subjected to panelist evaluation for acceptability. There were no significant variations in biochemical constituents (pH, 2.2 - 3.3; LA, 1.19 - 1.27 g kg^{-1} root; TA, 1.23 - 1.46 g kg^{-1} root, etc) of lacto-juices prepared from non-boiled and fully-boiled sweet potato roots except β-carotene concentration [130 ± 7.5 mg kg^{-1} (fully-boiled roots) and 165 ± 8.1 mg kg^{-1} (non-boiled roots) (Panda and Ray, 2008)].

Sweet potato curd and yoghurt

Yoghurt and curd are consumed by lactase-deficient individuals because much of the lactose in milk is converted to digestive LA by curd- or yoghurt-producing bacteria during fermentation. While the starter culture for curd is a mixture of undefined cocktail of LA producing micro-organisms, that is *Lb. bulgaricus, Streptococcus clemoris, St. thermophilus*, etc, the starter culture for yoghurt is the use of specific symbiotic or mixed culture of *Lb. bulgaricus* and *St. thermophilus*. In a recent study, a curd like product was prepared by co-fermenting boiled sweet potato pulp (8 to 16%) from β-carotene and anthocyanin-rich variety, sugar and curd inoculum (Panda et al., 2006; Mohapatra et al., 2007). Curd with 12 to 16% sweet potato pulp was most preferred by consumers' panelists (Ray et al., 2005). As this product is highly enriched with LAB, it has all the qualities to be addressed as 'probiotic' food.

Wine and beer from sweet potato

Yellow, red and black coloured beverages like beer (sparkling liquor) and wine are being sold in the Kyushu Province in Japan prepared from anthocyanin-rich sweet

Table 4. Total starch, α-amylase activity and trypsin inhibitor activity in fresh sweet potato roots at harvest.

Genotype	Dry matter (%, dry basis)	Total starch (%, dry basis)	α-amylase activity (Ceralpha unit/g, dry basis)	Trypsin inhibitor activity (U/mg, dry basis)
Hi-dry	33.5±0.9	73.6±0.5	0.41±0.01	16.5±1.84
Yan1	29.3±1.6	55.3±0.1	0.81±0.01	18.6±2.56
Chao1	22.6±0.6	46.8±2.0	1.73±0.06	3.90±0.18
Yubeibai	27.9±0.1	52.6±1.1	1.25±0.18	4.99±0.17
Guang7	26.9±1.2	57.6±3.4	1.14±0.04	8.74±0.89
Guang16	24.3±0.4	49.6±1.1	1.44±0.04	21.8±1.74
Mean	27.4	55.9	1.13	12.41
LSD (0.05)	2.59	4.8	0.20	3.50

Values are means of two replicates. Source: Zhang et al. (2002).

potato (Yamakawa, 2000).

Sweet potato as animal feed

BPS (2000) established that until 2000, the volume of fresh roots processed as feed in Indonesia was relatively low and the use of unmarketable fresh roots (very small size, damaged by pests/diseases) was most common in production areas. Moreover, sweet potato foliage as feed for livestock has been gaining importance. Cattle fed with it produce much manure which can be recycled as fertilizer in crop production. In a rice-sweet potato cropping system where rice is fertilized with cattle manure, root yield increases significantly (Wargiono et al., 2000). Good sweet potato growth means robust foliage for feed that, in turn, increases cattle manure to fertilize rice after growing sweet potato. Therefore, it is necessary to develop integrated crop management in production areas.

PREVIOUS WORK ON THE PROCESSING OF SWEET POTATO

Biochemical changes during storage of sweet potato roots

Changes during storage were investigated in carbohydrate level, digestibility, α -amylase, trypsin inhibitor activity and pasting properties of roots of six genotypes of sweet potato (*Ipomoea batatas* (L.) Lam) differing in dry matter content by Zhang et al. (2002). They reported that most genotypes showed a slight decrease in starch content during 0 to 180 days of storage, but in the genotype Hi-dry, it decreased substantially. Alpha-amylase activity increased during the first 2 months of storage, followed by a decrease with continued storage to a level similar to that at harvest. The decline in starch content was correlated with α -amylase activity in the first 60 days storage (r=0.80, P=0.06). Trypsin inhibitor activity (TIA) in the fresh roots varied among genotypes from 3.90 to 21.83 U/mg (Table 4) and storage had little influence on TIA level. There was considerable genotypic variation in digestibility, with up to 27% reduction in digestibility after 120 days in storage. Glucose and sucrose concentration increased early in storage and then remained fairly constant. Storage reduced flour pasting viscosities, with up to nearly a 30% decline in peak viscosity.

Frying of sweet potato at different processing conditions

The research of Troncoso et al. (2009) studied the effect of different processing conditions on physical and sensory properties of sweet potato chips. Potato slices of Desire´e and Panda varieties (diameter: 30 mm; thickness: 3 mm) were pre-treated in the following ways: (i) control or unblanched slices without predrying; (ii) blanched slices in hot water at 85°C for 3.5 min and air-dried at 60°C until a final moisture content of 0.6 kg water/kg dry solid; (iii) control slices soaked in a 3.5 kg/m^3 sodium metabisulphite solution at 20°C for 3 min and pH adjusted to 3. Pre-treated slices were fried at 120 and 140°C under vacuum conditions (5.37 kPa, absolute pressure) and under atmospheric pressure until they reached final moisture content of w1.8 kg water/100 kg (wet basis). An experimental design was used to analyze the effect of pre-treatment, sweet potato variety, type of frying and frying temperature over the following responses: oil content, instrumental color and texture and sensory evaluation. Vacuum frying increased significantly ($p < 0.05$) oil content and decreased instrumental color and textural parameters. Sensory attributes, flavor quality and overall quality, were significantly improved using vacuum frying.

The higher frying temperature (140°C) increased DE, maximum breaking force, hardness and crispness and decreased L* and b* values. On the other hand, Panda sweet potato variety improved the color of the product. A great improvement on color parameters was obtained using sulphited potato slices instead of the other pre-treatments. Although, the better flavor was obtained for control sweet potato chips, no significant differences were found for overall quality between control and sulphited sweet potato chips. Significant correlations ($p < 0.01$) between sensory and instrumental responses were found.

Chemical and phytochemicals in sweet potato

Das et al. (2010) studied the chemical modification of sweet potato (*Ipomoea batatas*) by acetylation using vinyl acetate ranging from 4 to 10% and dual modification using propylene oxide at specific level of 7% followed by adipic acid anhydride at levels ranging from 0.05 to 0.12%. Degree of substitution ranges between 0.020 to 0.034% and 0.018 to 0.058% for dual-modified and acetylated starch samples, respectively. There was significant increase in water binding and oil-binding capacities, solubility, paste clarity, gel strength due to modification; however, rupture strength, gel elasticity and adhesiveness decrease in both modified starches. Analysis of SEM revealed that the modification altered starch morphology. Acetylation brought about slight aggregation or cluster formation of granules with deep groove in the central core region whereas in dual-modified starches there were present a number of aggregates of starch granules with development of few blister like appearances along with protuberances on their surfaces.

It was observed that morphology of sweet potato starch granule gets altered due to chemical modification and in food application; all these modified starches can be used for development of different products depending on the quality requirement of the product, which could be evaluated with specific applications on them.

Anti-oxidative activities by three methods in the sweet potato plant and in home processed roots were carried out by Jung et al. (2011). Total phenolic content was highest in the leaves. Eight root varieties were partitioned and analyzed for phenolics. The stem end of the root had significantly more phenolics. In all samples the predominant chlorogenic acids were 5-caffeoylquinic acid (5-CQA) and 3,5-diCQA. 3,4-diCQA was present in significant amounts in the leaves and the flower, and 4,5-diCQA in the leaves. Six home-processing/cooking techniques reduced phenolic content from 7% (baking) to -40% (deep frying/boiling). High correlations were observed between phenolic compounds determined by high-performance liquid chromatography (HPLC) and Folin-Ciocalteu, radical scavenging activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH), and oxidative activity by ferric thiocyanate (FTC) and thiobarbituric acid (TBA) methods. The results show that there is a large variation in phenolics among sweet potato varieties and different parts of the plant and that high-phenolic sweet potato leaves, widely consumed in Asian countries as a vegetable, should be considered for diets of other countries.

These observations on anti-oxidative effects of sweet potatoes complement and extend previous cited findings on the relationships between content of phenolic compounds and anti-oxidative activities in other sweet potato genotypes. Their findings emphasize the substantial variation found among sweet potatoes and suggest that consumers have a choice in selecting sweet potato varieties with a high content of phenolic compounds and high anti-oxidative effects. The studies also showed that sweet potato leaves contain considerably more phenolic compounds that the roots, indicating that perhaps leaves, widely consumed as vegetables in Asian countries, may merit inclusion in diets of Western countries.

In conclusion, the methods they used to obtain the cited data on the content and distribution of caffeoylquinic acids and of total phenolic content in sweet potato plant stems, roots, leaves, and flowers and in home processed roots should facilitate future studies designed to assess the role of sweet potato phenolic compounds in host-plant resistance, food microbiology, food chemistry, plant breeding, medicine and nutrition. The results may also help consumers select sweet potatoes with high levels of health promoting compounds to select cooking conditions that minimize losses and also for human use.

Ezekiel et al. (2013) reviewed the beneficial phytochemicals in sweet potato and reported that in addition to supplying energy, sweet potatoes contain a number of health promoting phytonutrients such as carotenoids, folates, flavonoids, anthocyanins, kukoamines, and phenolics. They established that phytochemicals content in sweet potatoes can be enhanced by developing new varieties from available germplasm high in these compounds. Antioxidant and natural colourant present in red-flesh- and purple sweet potatoes can be used for developing functional foods. Taking into consideration the large quantities in which sweet potatoes are consumed throughout the world, sweet potatoes could be a very good vehicle for addressing some health related problems. Available evidence suggests that postharvest storage of sweet potatoes do not significantly affect the content of phytochemicals, but antioxidant levels are generally higher in sweet potatoes grown in high-yielding environments, and increased during storage.

Since the cost of production of sweet potatoes is relatively low as compared to other horticultural crops, pigmented sweet potatoes may also serve as a potential source of natural anthocyanins for use in food industry. Furthermore, sweet potato is a high yielding crop in which cultural and storage practices are well established in its usage. However, for the economy of the whole process of pigment extraction, sweet potatoes with high

Table 5. Yields of sweet potatoes per unit area (t/ha).

Variety	d 100	d 130	d 160	Average
NS 88	21.75	26.25	27.38	25.13
XS 18	12.75	18.00	20.18	16.98
YZ 263	22.88	22.50	28.88	24.75
NS 009	20.63	15.75	22.88	19.76
NS 007	21.00	28.50	28.97	26.16
200730	27.38	31.50	34.01	30.96
SS 19	25.13	37.50	38.63	33.75
WS 34	19.50	29.25	31.13	26.63
2-I2-8	20.25	30.00	35.25	28.50
XS 22	18.00	26.25	34.13	26.13

Source: Jin et al. (2012).

Table 6. Feedstock consumptions (t) of the sweet potatoes to produce 1 t of anhydrous.

Variety	d 100	d 130	d 160	Average
NS 88	10.04	7.93	7.82	8.60
XS 18	7.25	6.45	6.61	6.77
YZ 263	8.12	7.03	7.34	7.50
NS 009	6.87	6.30	6.38	6.52
NS 007	6.57	6.02	5.99	6.19
200730	13.18	13.25	13.86	13.43
SS 19	8.07	7.10	7.61	7.59
WS 34	7.46	7.35	6.98	7.26
2-I2-8	8.52	7.34	8.57	8.15
XS 22	7.86	7.17	7.99	7.67

Source: Jin et al. (2012).

concentrations of anthocyanins are desirable. In general, cooking leads to losses of nutrients in sweet potatoes, however, phytonutrients are either not affected or sometimes increased due to increase in extractability and bioavailability. There is a need for further research to explore the ways by which losses in phytochemicals can be reduced such as co-pigmentation, and their stability can be enhanced. Sweet potatoes contain enough phytochemicals to justify the claim of being health promoters, therefore, should form a substantial part of our daily diet. Different pigmented sweet potato based foods needs to be developed and evaluated especially with respect to the antioxidant capacity and other health benefits.

Biofuel production from sweet potato

The performance in the ethanol production of 10 varieties of sweet potato was evaluated by Jin et al. (2012), and the consumption in raw materials, land occupation and fermentation waste residue in producing 1 ton of anhydrous ethanol were investigated. The comparative results (Tables 5 to 7) between 10 varieties of sweet potato at 3 growth stages indicated that NS 007 and SS 19 were better feedstock for ethanol production, exhibiting the highest level of ethanol output per unit area (4.17 and 4.17 ton/ha, respectively), less fermentation waste residue (0.56 and 0.55 tons/ton ethanol, respectively), the least land occupation (0.24 and 0.24 ha/ton ethanol, respectively), less feedstock consumption (6.19 and 7.59 tons/ton ethanol, respectively), and a lower viscosity of the fermentation culture (591 and 612 mPa S, respectively). In most varieties, the ethanol output speed at day 130 was the highest and therefore, NS 007 and SS 19 could be used for ethanol production and harvested after the period (130 days) of growth from an economic point of view. In addition, the high content of fermentable sugars and low content of fiber in sweet potatoes are criteria for achieving low viscosity in ethanol fermentation cultures.

In this work, among the 10 strains tested, the sweet potato strains NS 007 and SS 19 had the least land occupation, less feedstock consumption, and the highest

Table 7. Land occupation (ha) of the sweet potatoes to produce 1 t of anhydrous ethanol.

Variety	d 100	d 130	d 160	Average
NS 88	0.46	0.30	0.29	0.35
XS 18	0.57	0.36	0.33	0.42
YZ 263	0.35	0.31	0.25	0.31
NS 009	0.33	0.4	0.28	0.34
NS 007	0.31	0.21	0.21	0.24
200730	0.48	0.42	0.41	0.44
SS 19	0.32	0.19	0.20	0.24
WS 34	0.38	0.25	0.22	0.29
2-I2-8	0.42	0.24	0.24	0.30
XS 22	0.44	0.27	0.23	0.31

Source: Jin et al. (2012).

level and speed of ethanol output per unit area as well as a lower viscosity of fermentation culture and reduced fermentation waste residue. Although they did not have the lowest viscosity of fermentation cultures or the least fermentation waste residue, these strains could be used for ethanol production and harvested after growing for 130 days or act as parent crops to obtain hybrids that have ideal characteristics for ethanol production.

Drying process of Sweet potato for Human consumption

Yadav et al. (2006) reported the changes occurring in the characteristics of sweet potato flour as a result of processing. The pasting characteristics decreased due to gelatinization of starch during processing. The degradation of starch by amylases during hot air drying further lowered the total amylose and water binding capacity/viscosity and increased the digestibility compared to those of drum dried and native flour. Solubility and swelling power of the flours increased as a result of processing which subsequently increased with increase in temperature. Scanning electron micrographs of starch granules showed tendency of clustering, especially in drum dried samples. X-ray diffraction patterns showed alteration from Ca-type to V-type with a marked reduction in crystallinity index as a result of processing. The ^{13}C NMR spectra of processed starches showed reduced peak intensities and line widths due to depolymerizing effects, and also pointing to their change in crystallinity.

Hatamipour et al. (2007) worked on drying characteristics of six varieties of sweet potatoes in different dryers. In this work, which was designed for drying of agro-food products, six varieties of sweet potatoes (Santana, Marfona, Santea, Koncord, Diamant, and Renjer) were chosen as drying material. A fluidized bed dryer, with and without air circulation, and a pilot-scale tray dryer were used for performing drying experiments. The experiments were performed with and without blanching. The changes in structure and colour of six varieties of potatoes were studied.

Temperature did not show significant effect on shrinkage, but blanching time and air circulation had significant effect on shrinkage as well as on the appearance of dried product. Less shrinkage occurred in Renjer and Diamant varieties at 80°C in comparison with other varieties. Santana (at 80°C), Santea (at 70°C) and Renjer (at 80°C) had better appearance and colour after free convection drying, whereas the appearance, colour and quality of Marfona variety was not acceptable at all. The quality and appearance of Marfona variety improved by using a tray dryer with air circulation. The quality and appearance of all varieties was very good in fluidized bed dryer. Blanching was effective in improving the colour of all dried varieties.

Ahmed et al. (2010) reported the effect of pretreatments with 1 w⁄v % sodium hydrogen sulphite ($NaHSO_3$) and 1 w⁄v % calcium chloride ($CaCl_2$) and drying temperatures (55, 60 and 65°C) on sweet potato flour. Flour treated with $CaCl_2$ had higher amounts of b-carotene and ascorbic acid (3.26–3.46 and 10.61–12.54 mg 100 g/L wet basis, respectively) than that treated with $NaHSO_3$ (3.05–3.43 and 9.47–11.47 mg 100 g/L wet basis, respectively). Water absorption index (wet basis) and total phenolic content were highest at 65°C when treated with $NaHSO_3$ (2.49 g g/L and 10.44 mg 100 g/L respectively) and $CaCl_2$ (2.85 g g/L and 9.52 mg 100 g/L respectively). Swelling capacity (wet basis) was highest at 55°C when treated with $NaHSO_3$ (2.85 g g/L) whereas when treated with $CaCl_2$ (2.96 g g/L) it was highest at 60°C. Freeze-dried samples treated with $CaCl_2$ had higher b-carotene and ascorbic acid while $NaHSO_3$-treated samples had higher lightness and total phenolic content. The results showed that good quality flour could be produced after soaking in $CaCl_2$ and dried at 65°C

The effect of pretreatments on drying characteristics of potato slices was investigated in a cabinet dryer by Doymaz (2012). The experiments were conducted on potato slices with thickness of 8 mm at 65°C with an air velocity of 2.0 m/s. Potato slices were pretreated with citric acid solution (1:25 w/w, 3 min, 20°C) or blanched hot water (3 min, 80°C) prior to drying while the untreated samples were dried as control. The shortest drying time was obtained with potatoes pretreated with citric acid solution. The drying data were fitted with ten mathematical models available in the literature. The results indicated that parabolic, logarithmic, modified Henderson and Pabis, two term, Midilli et al. and Verma et al. models were found better to describe the drying of potato slices. The values of effective moisture diffusivity were found to be range between 1.78×10^{-10} and 2.94×10^{-10} m^2/s and influenced by pretreatments.

Fernando et al. (2011) studied the convective drying rates of thermally blanched slices of potato (*Solamum tuberosum*): Parameters for the estimation of drying rates. They concluded that thermal blanching is a pre-drying treatment applied to some food products in order to inactivate enzymes for preservation of colour and flavours. This process leads to modified surface layers in the products. Drying of such products involve moisture transfer across such layers leading to build-up of moisture concentration gradients within the material being dried. In this study microscopic investigation of surface layers of blanched potato confirms that the presence of such surface layers. Rates of drying of thermally blanched slices of potato (*Solanum tuberosum*) of different thicknesses are obtained experimentally in a laboratory convective tray dryer at 85 and 95°C. A model (Fernando et al., 2008) for estimation of dehydration rates of materials with surface layers which describe three parameters ($l/\sqrt{D}$), *r* and *KpH* related to the drying material and the process is employed in order to evaluate the respective parameters based on the experimental data with the aid of a Matlab optimization program. Consistent values of the parameters were obtained for different thicknesses indicating applicability of the parameters in the model for characterization of species for drying of the blanched materials. Drying rates regenerated using the averaged parameters showed compatibility with experimental data with a correlation coefficient of 0.992. It can therefore be seen that drying rates of blanched slices of potato could be evaluated using three parameters $l/\sqrt{D}$, *r* and *KpH* making it possible to estimate the drying rates of blanched slices using the model equation assumed.

The effects of drying conditions on the drying behavior of sweet potato (*Ipomoea batatas* L.) were investigated in a cabinet dryer by Singh and Pandey (2012). The convective air drying was carried out under five air velocities of 1.5, 2.5, 3.5, 4.5 and 5.5 m/s, five air temperatures; 50, 60, 70, 80 and 90°C, and three sweet potato cubes of 5, 8 and 12 mm thickness. The data generated were analyzed to obtain diffusivity values from the period of falling drying rate. Results indicated that drying took place in the falling rate period. Moisture transfer from sweet potato cubes was described by applying the Fick's diffusion model, and effective moisture diffusion coefficients were calculated. The values of calculated effective diffusivity for drying at 50, 60, 70, 80 and 90°C of air temperature and 1.5–5.5 m/s of air flow rates ranged from 1.26×10^{-9} to 8.80×10^{-9} m^2/s. Effective diffusivity increased with increasing temperature. An Arrhenius relation with an activation energy value of 11.38 kJ/mol expressed effect of temperature on the diffusivity. Two mathematical models available in the literature were fitted to the experimental data. The page model gave better prediction than the first order kinetics of Henderson and Pabis model and satisfactorily described drying characteristics of sweet potato cubes.

Sweet potato slices were dried using both low-pressure superheated steam drying (LPSSD) and hot air drying in the study of Leeratanarak et al. (2006). The effects of blanching as well as the drying temperature on the drying kinetics as well as various quality attributes of potato slices viz. color, texture, and brown pigment accumulation were also investigated. It was found that LPSSD took shorter time to dry the product to the final desired moisture content than that required by hot air drying when the drying temperatures were higher than 80°C. Drying methods had no obvious effect on the product quality except the browning index. Longer blanching time and lower drying temperature resulted in better color retention and led to chips of lower browning index. It was also established that blanching reduced the hardness and shrinkage of the product; however, the use of different blanching periods did not significantly affect the product hardness. A blanching time of 5 min followed by LPSSD at 90°C at an absolute pressure of 7 kPa was proposed as the best condition for drying potato chips in this study. These conditions gave puffed product, less hard with moderate browning index, which corresponded to less nutrients and other heat damages. These conditions also provided potato chips that had small changes of colors from their natural values and required shortest drying time. However, the best condition proposed still led to chips of inferior quality compared with the commercially available potato chips, especially in terms of hardness. The study of the combined effects of blanching and/or freezing pre-treatments with higher drying temperature is recommended for future work.

CONCLUSION

The research in sweet potato processing has established the fact that there is a lot more in sweet potatoes than starch. The nutritional quality content in sweet potatoes can be enhanced by developing new varieties from available germplasm. Natural colourant and antioxidant present in purple- and red-flesh potatoes can be used for developing functional foods. Considering the large quantities in which sweet potatoes are consumed throughout the world, sweet potatoes could be a very good vehicle for addressing some health related problems and also serve as food security. Available evidence suggests that postharvest processing and subsequent storage of sweet potatoes need further research to explore the ways by which the new cultivars could be used for industrial and export purposes in countries producing sweet potato. Based on this review, future studies of the combined effects of blanching and/or freezing pre-treatments with higher drying temperature, determination of moisture diffusivity and activation energy during different drying conditions are recommended.

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