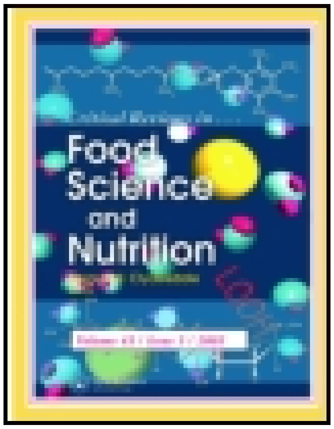

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Potential Impacts of Bio-processing of Sweet Potato: Review

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ABSTRACT

Sweet potato (*Ipomoea batatas* L.) is among the major food crops in the world and is cultivated in all tropical and subtropical regions particularly in Asia, Africa and the Pacific. Asia and Africa regions account for 95% of the world's production. Among the root and tuber crops grown in the world, sweet potato ranks second after cassava. In previous decades sweet potato represented food and feed security, now it offers income generation possibilities, through bioprocessing products. Bioprocessing of sweet potato offers novel opportunities to commercialize this crop by developing a number of functional foods and beverages such as sour starch, lacto-pickle, lacto-juice, soy sauce, acidophilus milk, sweet potato curd and yogurt, and alcoholic drinks through either solid state or submerged fermentation. Sweet potato tops, especially leaves are preserved as hay or silage. Sweet potato flour and bagassae are used as substrates for production of microbial protein, enzymes, organic acids, monosodium glutamate, chitosan, etc. Additionally, sweet potato is a promising candidate for production of bio-ethanol.This review deals with the

development of various products from sweet potato by application of bioprocessing technology. To the best of our knowledge, there is no review article on the potential impacts of the sweet potato bioprocessing.

Keywords

Sweet potato, nutritional aspects, bioprocessing technologies, food and feed bio-products, renewable biofuel

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is an important strategic and staple crop in many countries. According to FAOSTAT (2012), an estimated over 106 hundred millions metric tons of sweet potatoes valued at 5.07 billion dollars were produced globally. China is the dominant producer of sweet potatoes, cultivating roughly 80% of the world's crop, while Uganda and Nigeria produce roughly 3% of the global crop and rank 2nd and 3rd , respectively. In the United States, sweet potatoes are considered a specialty crop and the nation currently ranks 8th in terms of total global production and crop value (FAOSTAT, 2012).

Sweet potato has a long history as a life saver. The Japanese used it when typhoons demolished their rice fields. It kept millions from starvation in famine-plagued China in the early 1960's and came to the rescue in Uganda in the 1990's, when a virus ravaged cassava crops (CIP, 2010).

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, Netherlands and Japan being the major importing countries (FAOSTAT, 2011). The USA is the largest exporter of sweet potato accounting for 44% of world trade. The other exporters are China (10%), Netherlands (6.5%), Egypt (6%), Syrian (4%) and Canada/Indonesia (3%) (FAOSTAT, 2011). Most of the production 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 (Oke and Workneh, 2013).

NUTRITIONAL EFFICANCY OF SWEET POTATO: FACTS AND FIGURES

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

According to Lareo et al. (2013) and USDA (2014), besides carbohydrates, they are also rich in dietary fiber and have high water content and also provide 359 kj energy with low total lipids content, which is only about 0.05 g/ 100 g. In addition, sweet potatoes also are high in minerals such as potassium, calcium, magnesium, sodium, phosphorus, and iron (USDA, 2014). 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 fiber. Similarly, supplemental types of sweet potato must have many of the same characters as staple types in terms of nutritional components. However, as they will not be major food component, the level of components may be more flexible and good (Oke and Workneh, 2013).

Orange–fleshed sweet potato is an important source of β-carotene, the precursor to vitamin A. Just 125 g of a fresh sweet potato roots from most orange-fleshed varieties contain enough β-carotene to provide the daily pro-vitamin A needs of a preschooler. Vitamin A deficiency is rampant in Sub-Saharan Africa, affecting 43 million children under age 5, and contributing to high rates of blindness, disease, and premature death in children and pregnant women.

Sweetpotato is also a valuable source of vitamins B, C, and E and it contains moderate levels of iron and zinc. Nutritionists in the USA are exploring the potential cancer preventing properties of purple-fleshed sweetpotato. The anthocyanin that account for the purple pigmentation in this variety (also found in fruit and vegetables such as blueberries and red cabbage) are powerful antioxidants and have good bioavailability, meaning they are easily absorbed from the digestive tract into the bloodstream (CIP, 2010; Lu et al., 2010). Many researchers reported PSP anthocyanin could scavenge free radicals (Saigusa et al., 2005), attenuate liver dysfunction (Han et al., 2007), enhance memory function (Wu et al. 2008), decrease blood sugar (Ray and Tomlins, 2010) and lower insulin resistance (Kusano and Abe, 2000) and inhibit cancer cell growth (Wang et al., 2006). Ray et al. (2012) have developed a red wine by fermenting the starchy PSP roots with Saccharomyces cerevisiae and the wine has identical characteristics as that of commercial red (grape) wine.

GROWING DEMAND FOR BIOPROCESSING TECHNOLOGY OF SWEET POTATO

Sweet potato fulfills 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 2). 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 (Oke and Workneh, 2013). 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).

Sweet potatoes are mostly consumed as fresh vegetables or they are processed into starch and fermented products that include mono-sodium glutamate (MSG), citric acid, soy sauce, vinegars, 'sochu' (an alcoholic [20-40%, v/v] drink made in Japan and Korea) and bio-ethanol. Besides sweet potato roots, the vines and wastes are fermented into feed for poultry and ruminants in many Asian countries; for example China, Indonesia and Vietnam. However, the overall demand of sweet potato as a crop has been gradually declining over the last few years, as well as the areas under its production (Ray and Ravi, 2005) with exception of Papua New Guinea (Ramakrishna, 2006) and some African countries (Low and Jaarsveld, 2006). In order to sustain sweet potato in the cropping system and make it a cash rich crop, efforts are to be made to increase its industrial applications. Extraction of starch and production of starch-based commodities such as noodles, vermicelli, etc.are one such direction (Bovell-Benjamin, 2007). In recent years, several sweet potato varieties have been released that are rich in poly-phenols and anti-oxidant pigments (β- carotene, lutein and anthocyanin) (Yoshimoto, 2010). These varieties have the advantage in that they can be processed for the production of functional foods, food additives and beverages (Ray and Sivakumar, 2009). Bioprocessing (fermentation) is a novel way to develop such functional foods, food additives and protein-rich feeds from sweet potato. Also, production of bio-ethanol from sweet potato is another promising opportunity in the current global crisis for gasoline (Ray and Ward, 2006).

BIO-PROCESSING OF SWEET POTATO INTO VALUE- ADDED PRODUCTS

Bio-processing

Bioprocessing or bioprocess engineering is broadly defined as biologically based (enzymes or microorganisms) techniques or technology to convert biological materials into other forms needed by mankind (Ray et al., 2006). It includes production of food, feed and industrial chemicals, i.e. bio-ethanol, acetone-butanol, enzymes, organic acids, etc., through fermentation and design and operation of fermentation systems, development of food and feed processing systems and many more (Ray et al., 2008).

Fermentation as Bio-processing offers Novel Opportunities to Commercialize Sweet Potato

Fermentation has advantages because it improves palatability, textural quality and upgrades nutritive value by enrichment with vitamins, minerals, essential amino acids, etc. (Ray and Ward, 2006). Unlike cassava, fewer fermented products are available from sweet potato. All fermented products arise through the use of naturally occurring microbial activities, generally believed to be a form of 'spoilage'. These primitive processes were eventually replaced with use of starter cultures. Humans have been fermenting foods from root crops for over 1000 years (Ray and Sivakumar, 2009), but it is only in the past 50-60 years that a real scientific understanding of these processes has been gained. Table 3 cited the global vision of the fermented (Bio)-products from sweet potato.

Sour Starch

Starch is the prime component of interest for food and industrial uses of sweet potatoes. Starch content in sweet potato is 55% on dry weight basis (Lareo et al., 2013). Although, over 10% of the annual production of 74 million tons of sweet potato in China (FAOSTAT, 2012) is processed into starch, sweet potato starch production in China has faced problems of slow sedimentation and poor separation of starch from some impurities, which produce off-colors in the final product. The microbiological composition of sweet potato dough and wet starch was examined. LAB was the principal group of microorganisms (Miguel et al., 2014). A mixed population of *Leuconostoc dextranicum* and *Lc. mesenteroides* dominated the dough. The wet starch had a more varied population of homo and hetero-fermentative lactobacilli, which included *Lactobacillus. brevis*, *Lb. casei*, *Lb. acidophilus* and *Lb. buchneri* (Timmins et al., 1991).

Sweet and Sour Flour

The possibility of utilizing wheat- sweet potato composite flours in breads and other baked goods have been investigated (van Hal, 2000). Sweet potato flour can act as an important source of β-carotene. The most important quality characteristics of sweet potato flour are moisture content, protein, β-carotene content, microbiological quality, color, taste and odor. Sweet potato bread has been commercialized on a limited scale in Peru and Japan.

A commercial bakery in Peru uses the very simple method of mechanically grating peeled raw sweet potato roots and adding them to the dough, at 30% substitution for the wheat flour (Woolfe, 1992). This appears to be a cheap and practical solution for use in areas where fuel to dry sweet potato into flour is expensive or scarce and where it sun-drying is climatically difficult to achieve (van Hal, 2000). However, before applying this method, it should be ascertained that the baking process destroys trypsin inhibitors (Rekha and Padmaja, 2002), which may be present in the raw sweet potato (Sasikiran et al., 2002).

Gari

Gari is a wet fermented product from cassava (*Manihot esculenta* Crantz.) common in African countries. Gari made from sweet potato has been investigated as a fermented food. In Ghana, Oduro et al. (2000) produced sweet potato gari. The method (a type of solid state fermentation) was quite similar to that of cassava gari production (Osho and Dashiell, 2002; El Sheikha and Montet, 2014). The product had moisture content (3.83%), protein (0.60%), crude fibers (3.5%), ash (1.42%), pH (3.97), titratable acidity (0.50%) and swelling capacity (3.05), which were within the recommended levels.

Lacto-Pickles

Lactic acid bacteria (LAB) influence the flavor of fermented vegetables and fruits in a variety of ways. In many cases, the most obvious change in LAB fermentation is the production of acid and lowering of pH those result in an increase in sourness (Panda and Ray, 2007; Ray and Panda, 2007). Experimental work on pickling of β-carotene and anthocyanin-rich sweet potato by LAB fermentation (sauerkraut process) using 8-10% (w/v) brine had been conductedat Regional Centre of CTCRI, Bhubaneswar, India (Panda et al., 2007, 2009b). It not only produced lactic acid, which imparted taste and flavor to lacto-pickles, but also preserved ascorbic acid, phenols, and colored pigments (β-carotene and anthocyanin, 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. The flow chart for lacto-pickle production is given in Fig. 1. In a subsequent study, the pickles prepared from β- carotene- and anthocyanin- rich sweet potato were evaluated for their sensory attributes i.e. appearance, color, texture, aroma and sourness, by 100 rural consumers. The consumers liked SP pickle made in 8% salt solution. Logistic regression modeling of the sensory and consumer attributes revealed that the sourness (Wald statistic = 11.328, p=0.001) and aroma (Wald statistic = 8.374, p=0.004) of the SP pickle determined the consumer acceptability. Analysis also showed that the highly educated consumers were most likely to accept this SP pickle (Wald statistic = 5.038, p=0.025) (Sivakumar et al., 2010). Pickled sweet potato petioles have been commercialized in Japan. The petioles are preserved in soy sauce with the addition of little sugar, sesame seeds and chilies and vacuum sealed in plastic bags (Woolfe, 1992).

Lacto-Juices

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 Ray, 2008; Panda et al., 2009a). 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, flavor 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)]. The flow chart for lacto-juice preparation is given in Fig. 2.

Acidophilus Milk

Acidophilus milk is a probiotic drink, which is a product of milk fermentation by the bacteria, *Lactobacillus acidophilus*. The fermented milk has been reported to have therapeutic value for suppressing toxin-producing organisms in the intestine of humans especially in infants (Perez and Tan, 2006). It is known to have beneficial effects on the maintenance of normal intestinal microflora by producing inhibitors, stimulating the host immune system and reduction of serum cholesterol levels. It also helps in nutritional enhancement by reducing the levels of toxic substances.

Acidophilus milk enriched with purees from anthocyanin rich sweet potato varieties ("*kinampay*" and RC 2000) was developed in the Philippines. Addition of sweet potato puree to the acidophilus milk improved the sensory qualities and nutritional values (Perez and Tan, 2006). The flow sheet for production of acidophilus milk enriched with sweet potato puree is given in Fig. 3.

Sweet Potato Curd and Yogurt

Curd and yogurt, products of lactic acid fermentation of milk, are reported to possess several nutritional and dietary advantages over milk (Berger et al., 1979; Younus et al., 2002). For better enrichment of curd and yogurt with dietary fibres, starch, minerals and vitamins, vegetables like French bean, lemon, soybean or sweet potato are commonly co-fermented with milk (Holzapfel and Schillinger, 1992). While yogurt is very popular in American and European countries, consumption of curd is very common among Asian people, especially in Indian Sub-continent

(Sarkar et al., 1996; Younus et al., 2002). In curd much of the lactose in milk is converted to digestible lactic acid by LAB i.e. *Lactobacillus bulgaricus*, *Streptococcus lactis*, *St. clemoris*, *St. thermophilus*, etc. (Masud et al., 1991; Heller, 2001).

The starter culture for yogurt is *Lb. bulgaricus* and *Streptococcus thermophilus*. Partial pre-digestion of protein in curd and yogurt may have beneficial effects for individuals with poor digestive capacity (Collins et al., 1991a, b). A yogurt like product, having a titratable acidity of 0.85%, was prepared from sweet potato puree, milk, sucrose and freeze-dried yogurt inoculums (Collins et al., 1991a). On average, the product contained 19% protein, 3.8% ash, 2.5% dietary fibers, 80% moisture and 8.0-1.9% fat (Collins et al., 1991b). A trained panel gave a mean score of 7.7 (scale 1-10) for flavor, 3.9 (scale 1-5) for body/ texture and 3.8 for appearance and color (scale 1-5).

Similarly, sweet potato curd was prepared by fermenting boiled β-carotene-rich sweet potato puree and cow milk with curd (starter) culture (*Lactobacillus bulgaricus*, *Streptococcus lactis*, *St. diaceticlactis*, etc.) (Mohapatra et al., 2007). There were not much variation in pH (3.6-3.9), titratable acidity (10-11.8 g/ kg) and lactic acid (7.9-5.3 g/ kg) contents in curd consisting different concentration of sweet potato puree. However, curd with 12-16% sweet potato puree was most preferred by the consumers. The addition of sweet potato puree (12-16%) made the curd quite firm and imparted flavor, body/texture, minerals, nutrients, anti-diabetic substances, β-carotene pigments (antioxidant), dietary fibers and starch (carbohydrate source). The lactic acid bacterial counts in the curd after 18h of fermentation having 8 and 16% sweet potato were 7×10^7 and 14×10^7 (CFU/ mL), respectively. Ina subsequent study, 100 consumers evaluated sweet potato curd in terms of five major sensory attributes, i.e. sweetness, color, texture, aroma and general appearance on a 9-point hedonic scale. The responses were modeled through binary logistic regression to understand the sensory attributes, which govern the decision process. Color and texture were found to influence consumer acceptability. The β-carotene supplied by sweet potato enriched yellow color of the curd, and starch and dietary fiber enhanced the thickness of curd (Sivakumar et al., 2008). Similarly, sweet potato curd was prepared using anthocyanin pigments rich sweet potato roots (Panda et al., 2006). The flow chart for preparing sweet potato curd is given in Fig. 4.

Soy Sauce

Soy sauce, a popular condiment used every day with Asian dishes is traditionally prepared from a mixture of soybeans and wheat, fermented by moulds, especially *Aspergillus oryzae* or *A. sojae*, to give a dark brown salty liquid used as a flavoring agent. The potential replacement of wheat flour with suitable substitutes in soy sauce manufacture, as in the case of bread, could mean a considerable utilization of available resources such as sweet potato flour (Data et al., 1986). The flow chart for production of soy sauce using sweet potato flour is given in Fig. 5.

The starter culture was prepared by inoculating pressure-cooked rice with *A. oryzae* or *A. sojae* at room temperature for 4-6 days. During the subsequent koji preparation the healthiest growth of mold spores and finally the highest yield of sauce were given by sweet potato flour made from cooked rather than raw roots because cooking gelatinized the sweet potato starch thus rendering it more vulnerable for breakdown by microorganisms. Sensory evaluation revealed no significant difference between the soy sauce made with sweet potato flour and two commercial brand of soy sauce from Philippines in terms of color, aroma, consistency, flavor and overall acceptability.

Vinegar

Vinegar is a condiment made from sugar- or starch-containing materials by an alcoholic fermentation, followed by the microbial oxidation of alcohol to acetic acid. When starch-based material such as sweet potato is used as raw material, the starch requires initial hydrolysis to sugars before alcoholic fermentation by yeasts (*Saccharomyces cerevisiae*) can take place. The next step, oxidation of the alcohol to acetic acid is carried out by acetic acid bacteria (*Acetobacter* sp.). The completed vinegar must contain a minimum of 4 g acetic acid/100 mL (Ward, 1989).

Recently, new red vinegar has been developed in Japan *via* fermentation with the storage root of purple fleshed sweet potato cv. *Ayamurasaki*. The red vinegar had a higher antioxidant activity than white or black vinegars. The red vinegars contained some new components possibly derived from the original purple sweet potato. A major component was isolated using preparative HPLC (High Performance Liquid Chromatography) and the chemical structure was determined to be 6-O-(E) –caffeoyl- (2-O-ß-d- glucopyranosyl) - *α*-d-gkucopyranose (caffeoylsophorose) by MS (mass spectroscopy) and NMR (nuclear magnetic resonance). Because the caffeoylsophorose showed a high antioxidant activity, it plays an important functional role in red vinegar as do anthocyanin and other components (Terahara et al., 2003).

Alcoholic Beverages

Shochu

Shochu is an alcoholic beverage of Japan, most commonly distilled from barley, sweet potato or rice. Typically it is 25% alcohol by volume, making it weaker than whisky, but stronger than wine and sake (Yamakawa, 2000). The production of koji, a heavy inoculum of *Aspergillus kawachii* or *A. niger*on steamed rice provides a source of enzymes which hydrolyze sweet potato

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starch to sugar. *A. niger* also produces citric acid (Bindumole et al., 2000) in the first moromi (seed mash), which leaves the pH to 3.2-3.4 and thus inhibits the growth of undesirable microorganisms. Fresh and unpeeled sweet potato is trimmed, washed, steamed and crushed and added (4:1) to the moromi. During fermentation of this main mash, simultaneous starch conversion to sugar by the koji enzymes and fermentation of sugar to alcohol by the yeast *S. cerevisiae* takes place. The final alcohol concentration of the mash is 13-15%. The mash is then pumped to the still and the alcohol is distilled off. Different batches of shochu may be blended to give a uniform product and the alcohol content is adjusted to 20-40% (v/v) before bottling (Woolfe, 1992).

Wine and Beer

Wine and beer are the other products which can be processed sweet potato (Yamakawa, 1997). Yellow, red and black colored beverages (sparkling liquor) are sold in the Kyushu Province in Japan (Yamakawa, 1997, 2000). Purple sweet potato is a special type of sweet potato having high anthocyanin pigment in the root. Thestarch contents of the roots (root ⁄ water homogenized in 1:1 ratio) were enzymatically saccharified [using commercial thermo stable enzymes [Termamyl (0.2%) and DextrozymeGA (1%)] to fermentable sugars,and the filtrate was ameliorated with cane sugar to achieve 20° Brix, for subsequent fermentation into a red wine using 2% yeast (*Saccharomyces cerevisiae*) as starter culture. The wine had the following proximate compositions: total soluble sugar (TSS), 2.25° Brix; starch, 0.15 g per 100 mL; total sugar, 1.35 g per100 mL; TA, 1.34 g tartaric acid per 100 mL; phenol, 0.36 g (caffeic acid equivalent) per 100 mL; anthocyanin, 55.09 mg per 100 mL; tannin, 0.64 mg per 100 mL; lactic acid, 1.14 mg per 100 mL; ethanol, 9.33% (v ⁄ v); and pH, 3.61. 2, 2-Diphenyl-1-picrylhydrazyl

(DPPH) scavenging activity of the wine was 58.95% at a dose of 250 $\mu g.mL^{-1}$. The red wine produced contains essential antioxidants and acceptable sensory qualities (Ray et al., 2012). The flow chart for wine preparation is given in Fig. 6. In a more recent study, A herbal purple sweetpotatowine was prepared from purple fleshed sweet potato and 18 medicinal plant parts (fruits of ink nut, Indian gooseberry, garlic cinnamon, leaves of holy basil, night jasmine, Malabar nut, roots of belladonna, asparagus, rhizome of ginger, etc.) by fermenting with wine yeast, *Saccharomyces cerevisiae*. The medicinal wine was rich in anti-oxidants and had therapeutic values (Panda et al., 2013).

Beer is the world's most widely consumed and probably the oldest alcoholic beverage. Beer is generally prepared by using malt of barley (Bamforth, 2004). Due to unavailability of barley in various regions it is either partially substituted by certain adjuncts such as rice or maize flakes or completely substituted by cereals like sorghum and wheat (Eßlinger, 2009). The incorporation of sweet potato along with barley sproutsin the preparation of a beer like beverage prepared from rice resulted in an increase of sweetness, flavor in the beverage as the enzymes of sweet potato are efficient and more stable to heat than that of barley (Suh et al., 2003). Miki, the traditional Japanese alcoholic beverage was re-produced by using cooked rice and mashed raw sweet potato roots as the saccharifying agent in different combinations (a mixture of 30 g of ground autoclaved rice with 6, 12, 30 and 60 g of raw sweet potato mash, respectively). The resulting miki like alcoholic beverage contained 5-6% ethanol (v/v); it had a pleasant aroma but a sour taste and faint bitterness. Oligosaccharides including maltotriose and maltopentaose were detected in miki made with higher concentration of sweet potato mash (Teramoto et al., 1998). Similarly, sorghum malt was replaced by sweet potato flour 20% (w/v) in preparation of sorghum beer. The advantages of using sweet potato flour were as follows: the free alpha amino nitrogen of wort prepared by the combination of sorghum and sweet potato was lower as compared to whole sorghum wort; as a result, the beer produced from sweet potato as adjunct gave more clarity. Incubation of sweet potato enzymatic extract with isolated sorghum endosperm cell walls and viscosity tests demonstrated the presence of (1→3, 1→4) β-glucanase (limiting in sorghum) in sweet potato (Etim and EtokAkpan, 1992).

Protein Enriched Animal Feed

Silage

Sweet potato tops, especially leaves, are very rich in nutrients such as proteins, vitamins and minerals (Otieno et al., 2006). They also contain polyphenols, in particular, chlorogenic and iso-chlorogenic acids, which are anti-oxidants (Yoshimoto, 2010). The production of silage from sweet potato vines and roots has been studied in China (Zhang, 1995), Japan and the Philippines (Mariscal et al., 1997) and more recently in Vietnam and Kenya (Peters, 2010). Silage of excellent fermentative quality was obtained from sweet potato foliage when no additives such as urea or sweet potato roots were used (CIP, 2000). The addition of sweet potato roots had no noticeable effect on dry matter losses or lactic acid production, but increased acetic and butyric acid concentrations. The vine silage without additives, on the other hand, had acceptable characteristics with an average pH of 3.9, a low concentration of butyric acid and a low (11%) loss of dry matter by putrefaction (Tinh et al., 2000).

Two experiments were conducted with hybrid tilapia (*Oreochromis niloticus X O. Mossambicus*) to evaluate a meal made by extrusionco-processing culled sweet potatoes and poultry mortality silage (ESPFP). In both experiments, dried, culled sweet potatoes and fermented whole turkey carcasses (60:40 ratio, w/w wet basis) were co-extruded, dried, and hammer-milled to make the ESPFP test ingredient. The resulting ESPFP meal was included at 0%, 11%, 22%, and 33% by weight in iso-caloric, iso-nitrogenous pelleted diets. In 87 day growth trial, no significant differences were found in the growthparameters or carcass (market) yields among the treatment groups. Extrusion co-processing of culled sweet potatoes and poultry mortality silage produces an acceptable feed ingredient for hybrid tilapia that can be included at up to 33% of the diet without adversely affecting growth, market yield, sensory indices, or water quality as compared to a standard tilapia diet (Middleton et al., 2001).

Single Cell Protein (SCP)

Sweet potato wastes (bagassae) are a good candidate for SCP because of its abundant supply in several countries like China, Taiwan, Japan and Sub-Saharan Africa at reasonable cost. The bagassae contains 2.32% protein and 65.4% total carbohydrates and is itself not a good source of protein for animal feeding (Ray et al., 2006).

Sweet potato-root meal was fermented with three fungal species, *Aspergillus niger*, *Aspergillus oryzae* and *Pleurotus ostreatus* using solid-state fermentation. The changes in total lipid, fatty acids and total protein composition were determined at specificintervals during the study. The total lipid of sweet potato fermented with *A. niger* and *A. oryzae* increased from 1.93% to 3.17% and 1.93% to 8.71%, respectively, while it decreased on *P. ostreatus* from 1.93% to 0.54%. Protein contents of fermented sweet potato increased significantly abovethe unfermented samples, and protein enrichment was highest with *A. niger*, followed by *A. oryzae*, and lowest on *P. ostreatus* (Abu et al., 2000). Sweet potato bagassae was treated with *Endomycopsis fibuligera*, *Candida utilis* and *Trichoderma koningii via* solid state fermentation. Yeast strains did not produce any fungal toxin (Tian, 2006); therefore, the protein enrichment of sweet potato bagassae with yeast strains for animal feeds appears to have commercial potential. Microbial cells (*Geotrichum* sp.) are applied for dehydration of the distilled waste of sweet potato shochu (Yoshi et al., 2001) and the dried product can be used as SCP. The yeast- enriched SCP from sweet potato is as good as those obtained using potato wastes (Gelinas and Barrette, 2007).

Food and Feed Additives

Microbial Enzymes

Root crops as a whole, starch, flour or residues in particular could be used as cheap fermentation substrates for the production of microbial enzymes (Ray et al., 2006). Sweet potato bagassae (moisture content, 50-58%; pH 3.5- 4.33) was used as substrate for protease production by amylolytic fungi in solid-state fermentation. Several strains of *Aspergillus*, *Rhizopus*, *Actinomucor* and *Mucor* were tested. *Aspergillus* and *Rhizopus* sp. showed higher proteinase activity than *Mucor* sp. (Yang and Huang, 1994). In another study, protease was produced using sweet potato supplemented with rice bran and minerals as substrate in solid-state fermentation. Partially purified protease with DEAE (Diethyl amino ethyl) cellulose-Sephacel column chromatography was thermally stable and was able to retain 80-100% of activity in pH 4.0- 5.5 at 50°C for 40 min (Yang and Chiu, 1986).

Organic Acids

Lactic acid could be produced by *Lactobacillus* sp. from potato and sweet potato flour (Ray et al., 1991). In a recent study, the production of lactic acid was increased 2.5 fold over the conventional method by applying the response surface methodology (statistical design) and using the amylolytic lactic acid bacterium, *Lactobacillus plantarum* as the microbial culture and sweet potato flour as the carbohydrate source in submerged fermentation (Panda and Ray, 2008).

Sweet potato has been used a substrate for citric acid production using *Aspergillus niger* in solid-state fermentation (Bindumole et al., 2000). Leangon et al. (1999) studied the biochemical mechanism of citric acid accumulation during solid-state fermentation of sweet potato using a low citrate-producing mutant of *A. niger* Yang No. 2. It was found that over production of citric acid was related to an increased glucose flux through glycolysis. At low glucose fluxes, oxalic acid is accumulated. When the process was operated in a packed-bed reactor in submerged fermentation, the bed loading, airflow rate and substrate particle sizes were the important operational parameters. However, yield was extremely low, 0.82 g citrate/ kg sweet potato (Lu et al., 1995, 1997; Zheng and Shetty, 1999). Several countries, notably China, Japan and Vietnam, are now manufacturing citric acid from sweet potato starch or from its by-products (Jiang et al., 1993; Zhang, 1995; Lu et al., 2006). The process necessitates the initial breakdown of starch to sugars before these sugars are fermented by moulds, for example, *Aspergillus niger*, to citric acid. In Sichuan Province, China, the largest sweet potato growing area of the country, citric acid is the fourth most important product from sweet potato after starch, noodles and alcohol (Wiersema et al., 1989; Jiang et al., 1993). In the food industry, citric acid is added as a flavor enhancer or preservative in a wide ranges of products particularly soft drinks.

Monosodium Glutamate (MSG)

MSG is an important flavor enhancer of a wide range of savory foods. China is the largest producer and consumer of MSG in the world (Bovell-Benzamin, 2007). The starch has first to be degraded to sugars, which are then converted by microorganisms such as *Brevibacterium* *glutamicum* to glutamic acid. This is then converted to MSG salt (Jiang et al., 1993). China uses sweet potato starch as one of the raw materials for production of MSG. In Siachuan Province in China, it is the fifth most important product from sweet potato, almost equal in tonnage to citric acid.

Sugar Syrups

The conversion of starch into a range of syrups and other derivatives is becoming increasingly important in some countries where these products can be used to replace more expensive imported sugar extracted from cane or beet. These conversions employ are based on microbial enzymes and can utilize starch sources including sweet potato and cassava, which may be particularly appropriate as they are highly susceptible to saccharification by enzymes (Paolucci et al., 2000). Though, starch can be converted into sugars by the use of acids, the specific properties of which give rise to a variety of compounds useful in the dessert, bread, fermented milk products, brewing and other industries. Glucose syrup, for example, is produced from starches, including sweet potato starch (Ray and Ward, 2006) by bacterial amylase. Another sugar, maltose is produced from starch by the action of β-amylase (Fontana et al., 2001) is useful to the brewing industry.

Other Products

Baker's Yeast

To identify improved baker's yeast for industrial manufacture of bakery products, yeasts (*S. cerevisiae*) strains from dried sweet potatoes (*hoshi-imo*), a traditional preserved food in Japan were isolated and characterized (Nishida et al., 2004). The strain ONY1 had characteristics typical of commercial baker's yeast strain (T128).

Oxytetracycline

Sweet potato served as the substrate for production of oxytetracycline in solid-state fermentation (Yang and Yuan, 1990).

Chitosan

Large amounts of waste water containing high concentration of organic matter are produced during distillation of shochu. Fungal treatment of these distillery effluents for production of chitosan was investigated (Yokoi et al., 1998). *Absidia atrospora* and *Gongronella butleri* grew well in shochu distillery waste water and sweet potato shochu waste water. Chitosan production was highest from *G. butleri* strain**.** Nitar and Stevens (2002) have described an improved method for production of chitosan from mycelia of the fungus *G. butleri* USDB 0201 by solid-state fermentation of sweet potato. The chitosan was extracted with NaOH and acetic acid. The resulting extract was clarified using a heat stable commercial *α*- amylase. The yield (4-6 g/100 g mycelia) of chitosan increased with increasing duration of fungal growth up to 6th day.

Alkali Metal Glucoheptonate

The alkali metal glucoheptanate is used as water conditioning chelant and the protein-containing pulp residue as animal food. Alkali metal glucoheptonate has been produced from sweet potato by reducing the size of sweet potatoes to particles to about 1/40 cm and slurring the sweet potato particles. Then, commercial *α*-amylase is added to the slurry. The slurry was boiled and filtered to separate liquid syrup and a protein-containing pulp residue. The liquid syrup was cooled down and gluco-amylase added before boiling again. Subsequently, alkali metal cyanide was added to the liquid syrup to produce the alkali metal glucoheptanate (www.freepatentsonline.com/5435845.html).

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Biofuel Production from Sweet Potato

There is a considerable interest in developing bio-renewable alternatives to substitute fossil fuels such as bioethanol as transportation fuel. Bioethanol contributes to diminish petroleum dependency, generates new development opportunities in the agricultural and agro-industrial sectors, more farm work and environmental benefits. Main feedstocks for bioethanol production are sugarcane (Brazil) and corn grain (USA) (Mussatto et al., 2010). Thus, there is a growing interest to find alternative bio-resources other than sugarcane/beet molassess and starchy crops such as cassava, sweet potato, and sweet sorghum for ethanol production (Swain et al., 2013).

Bio-ethanol

Sweet potato, apart from its value as a wholesome food, has been considered a promising substrate for alcohol fermentation since it has a higher starch yield per unit land cultivated than grains (Duvernay et al., 2013). Sweet potato is cheap, readily available in the local market and offers ease in product processing. It contains starch (550.5 g /kg), total sugars (750 g /kg) and protein (35 g/kg) on dry weight basis (Lareo et al., 2013).Industrial sweet potatoes are not intended for use as a food crop. They are bred to increase its starch content, significantly reducing its attractiveness as a food crop when compared to other conventional food cultivars (visual aspect, color, taste). Therefore, they offer potentially greater fermentable sugar yields from a sweet potato crop for industrial conversion processes and the opportunity to increase planted acreage (even on marginal lands) beyond what is in place for food. It has been reported that some industrial sweet potatoes breeding lines developed could produce ethanol yields of 4500-6500 L/ha compared to 2800-3800 L/ha for corn (Duvernay et al., 2013). Sweet potato has several agronomic characteristics that determine its wide adaptation to marginal lands such as

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drought resistant, high multiplication rate and low degeneration of the propagation material, short grow cycle, low illness incidence and plagues, cover rapidly the soil and therefore protect it from the erosive rains and controlling the weed problem (Cao et al., 2011; Duvernay et al., 2013).

Previous transformation of the raw material into chips or flour (powder) can be done in order to facilitate its transport and/or plant conservation. Sweet potato chips or flour is commonly utilized for ethanol production. The process followed is similar to that for cassava: adding water to the dried chips and boiling, adding enzymes to convert starch to sugar, fermenting the sugar to alcohol and distilling (Ray and Naskar, 2008). Various factors, i.e. acid or enzyme concentration, temperature, pH of the mash, fermentation period, cell immobilization, etc. were studied on ethanol fermentation from sweet potato in membrane reactors (Yu et al., 1996). One of the process developments made for enzymatic hydrolysis of various starch-containing crops and biomass is the introduction of simultaneous saccharification and fermentation process (Ward et al., 2006). This process employs thermotolerant yeast strains to reduce the number of reactors involved by eliminating the separate (saccharification) reactor. In a recent study, ethanol yield of 258 g/kg flour and 95 g/kg roots of sweet potato was obtained by applying simultaneous saccharification and fermentation technology employing thermotolerant (≤ 40°C) yeast (S.cerevisiae CTCRI 10) strain (Ray and Naskar, 2008). The process partially reduces the production cost as saccharification and fermentation process have been combined. However, the cost (US$) of ethanol production/litre is still higher (0.72) as compared to sugar cane (0.27) and cassava (0.55) (Mohanty et al., 2009). The holistic life cycle of sweet potato-based bioethanol conversion of sweet potato is presented in Fig. 7.

Fresh sweet potato contains high water content. The drying process of this material is an aspect to be studied to optimize its transport, storing and processing. The use of flour of sweet potato would allow working with higher sugar concentration during the fermentation than fresh sweet potato without the addition of water. In this case, it should be assessed the energy saving of manipulating lesser amount of material, the handling of high viscous material, the extra cost of drying and the effect of drying on the performance of the process (conversion of starch to fermentable sugars) (Moorthy, 2002). The conventional process for bioethanol production from starch-based materials includes the conversion of starch into fermentable sugars which generally takes place in two enzymatic steps: liquefaction using thermal-stable α-amylase and saccharification by addition of amyloglucosidase (AMG). Most studies of starch hydrolysis use enzymes, temperature conditions and reaction times which have been done for grains, such corn. The starch of sweet potatoes is considered more complex than cereal starches, making it more challenging to hydrolyze into fermentable sugars. Besides, the digestibility of starch by enzymes varies among different cultivars (Duvernay et al., 2013).

Ethanol is an ideal fuel supplement or substitute for petrol, and starch from sweet potato can produce 400- 450 litres (ethanol)/ton of starch (equivalent to 160-180 litre. ethanol/tonne of raw sweet potato roots) (Ray and Naskar*,* 2008). Ethanol production potential of sweet potato is nearly 40% higher than other starchy crops such as Jerusalem artichoke (*Helianthus tuberosus* L.), potato (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris* L.), sweet sorghum (*Sorghum bicolor* L.) and Fodder beet (*Beta vulgaris* L.) (Mays et al., 1990). However, the basic processes in the production of ethanol from sweet potato are somewhat cumbersome as compared to

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molasses, because of the requirement to hydrolyse the starch and include the following processes:

1. Milling sweet potato chips or flour through sieve of 0.4 mm.
2. Liquefaction (using dilute inorganic acid or thermostable α-amylase).
3. Saccharification (using amyloglucosidase).
4. Fermentation, and
5. Distillation

The other approach to make sweet potato ethanol cost effective is to genetically engineer the crop to increase significantly the starch content and consequently conversion to ethanol. Starch is chemically composed of two types of glucan polymers-amylase and amylopectin. The ADP glucose is the precursor for synthesis of both amylase and amylopectin. Therefore, the regulation of ADP glucose pyrophosphorylase (ADPGase) would determine the sink strength (capacity to accumulate photosynthesis products) of the roots in potato, sweet potato and other root crops and its over-expression would produce roots with higher starch content. Transgenic potato expressing *Escherichia coli glg 16* gene coding the bacterial ADPGase showed remarkably high starch content (60% more than the normal) in tubers (Stark et al., 1992). Researchers of North Carolina State University (USA) are re-engineering sweet potato to make it better suited for producing ethanol. By incorporating genes from bacteria from deep sea thermal vents, the group is studying to create an industrial sweet potato with double the starch content and enriched with liquefying and saccharifying enzymes, i.e. α-amylases and amyloglucosidase. They propose that the special genes incorporated could reduce the costs of the enzymes those are used by biofuel processors to breakdown starch to sugars which are then converted to alcohol by fermentation (Ray et al., 2010).

Biohydrogen Production

Biohydrogen, a high energy clean fuel, is regarded as anattractive future energy carrier due to its conversion to energy yielding only pure water. It is a promising alternative to conventional fossil fuels because it has the potential to eliminateall of the problems that the fossil fuels create. Hydrogen gas has been proposed as the ultimate transport fuel for vehiclesand vesselsbecause of its non-polluting characteristics (Show et al., 2012).

Hydrogen can be produced biologically by four different processes: direct and indirect biophotolysis, photo fermentation and dark fermentation. Fermentative hydrogen production not only provides higher gas production rates compared to photosynthetic processes, but is also light independent and can utilize various carbon sources, including wastewaters (Vardar-Schara et al., 2008). Yokoi et al. (2001) used dried sweet potato starch residue for microbial hydrogen production by the mixed culture of *Clostridium butyricum* and *Entrobacter aerogenes*.

CONCLUSIONS

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 many parts of the world. Value addition of sweet potato by bioprocessing has the potential to lead to newer food, feed and beverage products and also contribute to biofuel production. Newer foods include anthocyanin-rich sweet potato wine and vinegar, β-carotene rich lacto-pickle and lacto-juice which have potential functional and nutraceutical properties. The study of fermentation microorganisms could lead to the identification of microbial strains particularly suited for the over-secretion of

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valuable biological products such as enzymes, amino acids, vitamins, antibiotics and flavor enhancers such as monosodium glutamate.

FUTURE PERSPECTIVES

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 channeling 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. Among the bioderived products, bioethanol from sweet potato has the potential to contribute to the demand for biofuels. However, research is needed to develop improved fermentation processes such as combined liquefaction-saccharification-fermentation by application of process engineering and biotechnology, and genetically engineering the crop with high starch content and self-processing genetic attributes to reduce the cost of ethanol production to compete successfully with sugarcane, sugar beet or other cheaper substrates. Yet there is still a need to establish a more defined biologically based approach to sweet potato starch conversion and evaluate the enzymes and processing conditions suitable for effective fermentable sugar production.

ABBREVIATIONS

ADP Adenosine diphosphate

AMG Amyloglucosidase

CIP Centro Internacional de la Papa

CTCRI Central tuber crops research institute

DEAE Diethyl amino ethyl

FAO Food and Agriculture Organization of the United Nations

FAOSTAT Food and Agriculture Organization of the United NationsStatistics

LAB Lactic acid bacteria

MSG Monosodium glutamate Polymerase Chain Reaction

SCP Single Cell Protein

SmF Submerged fermentation

SSF Solid state fermentation

USDA United States Department of Agriculture

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Table 1 Nutritional value of raw sweet potato

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, by difference	g	20.12
Fiber, total dietary	g	3.0
Calcium	mg	30
Iron	mg	0.61
Magnesium	mg	25
Phosphorus	mg	47
Potassium	mg	337
Sodium	mg	55
Zinc	mg	0.30
Vitamin C	mg	2.4
Niacin	mg	0.56
Vitamin B6	mg	0.21
Vitamin A	IU	14187

Source: USDA (2014).

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Table 2 Food crops and their vitamins, minerals and calorie contribution per capita/day

Food crop	Calorie cost ($)	Vitamins (mg)		Minerals (mg)	
		B1	C	Ca	Fe
Rice	2.75	0.69	0	486	2.78
Maize	1.38	1.34	0	901	8.45
Cassava	0.94	236	0.48	318	5.57
Sweet potato	1.34	224	0.91	498	7.11

Source: Adapted from Scott et al. (2000).

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Table 3 Global vision of the fermented (Bio)-products from sweet potato

Product	Bio-processing category	Substrate	Bio-processing conditions	Reference
Sour Starch	Submerged Fermentation (SmF)	Starch	A mixed population of lactic acid bacteria (LAB), *Leuconostoc dextranicum* and *Lc. mesenteroides* dominated the dough along with several lactobacilli, which included *Lactobacillus. brevis*, *Lb. casei*, *Lb. acidophilus* and *Lb. buchneri*	Timmins et al. (1991), Miguel et al. (2014)
Bread	Solid State Fermentation (SSF)	Flour	Golden bread bun-fortified with *β*-carotene rich sweet potato flour	Low and Jaarsveld, (2006)
Gari	Solid State Fermentation (SSF)	Root	LAB, yeasts and other bacteria such as *Bacillus* sp. and *Lactobacillus plantarum* cultures in the sweet potato fermentation as a starter for gari production	Osho and Dashiell (2002), El Sheikha and Montet (2014)
Lacto-Pickles	Submerged Fermentation (SmF)	Root	*β*-Carotene rich sweet potato roots were pickled by lactic fermentation by bringing the cut and blanched roots in common salt (NaCl, 2-10%) solution and subsequently inoculated with a probiotic strain of *Lactobacillus plantarum* MTCC 1407 culture for 28 days	Panda et al. (2007, 2009b)
Lacto-Juices	Submerged Fermentation (SmF)	Root	Lacto-juice was prepared by fermentation of β-carotene and anthocyanin-rich sweet potato cultivars by inoculating LAB, *Lb. plantarum* MTCC 1407. β-carotene-rich sweet	Panda and Ray (2008), Panda et al. (2009a)

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			potato roots (non-boiled/fully-boiled) were fermented with *Lb. plantarum* at 28 ± 2°C for 48 h to make lacto-juice	
Acidophilus Milk	Submerged Fermentation (SmF)	Root	Acidophilus milk is a probiotic drink, which is a product of milk fermentation by the bacteria, *Lactobacillus acidophilus*. Addition of sweet potato puree to the acidophilus milk improved the sensory qualities and nutritional values	Perez and Tan (2006)
Sweet Potato Curd and Yogurt	Submerged Fermentation (SmF)	Puree or Root	1- Sweet potato curd was prepared by fermenting boiled β- carotene-rich sweet potato puree and cow milk with curd (starter) culture (*Lactobacillus bulgaricus*, *Streptococcus lactis*, *St. diaceticlactis*, *St. thermophilus,* *Leuconostoc* sp. etc.) 2- Sweet potato- milk mixture co-fermented with yogurt culture	Ray et al. (2005), Panda et al. (2006), Mohapatra et al. (2007) Collins et al. (1991a, 1991b),
Soy Sauce	Solid State Fermentation (SSF)	Flour	Soy sauce, a popular condiment used every day with Asian dishes is traditionally prepared from a mixture of soybeans and as sweet potato flour, fermented by moulds, especially *Aspergillus oryzae* or *A. sojae*, to give a dark brown salty liquid used as a flavoring agent	Data et al. (1986)
Red Vinegar	Submerged Fermentation	Root	Red vinegar was prepared from anthocyanin rich	Terahara et al. (2003)

	(SmF)		sweet potato pulp by an alcoholic fermentation by yeasts (*Saccharomyces cerevisiae*). The next step, oxidation of the alcohol to acetic acid was carried out by acetic acid bacteria(*Acetobacter* sp.). The completed vinegar contained 4 g acetic acid/100 mL	
Shochu	Solid State Fermentation (SSF)	Fresh and unpeeled sweet potato	During fermentation, simultaneous starch conversion to sugar by the koji enzymes and fermentation of sugar to alcohol by the yeast *S. cerevisiae*	Yamanaka et al. (2003)
Wine and Beer	Solid State Fermentation (SSF)	Starch	A process of enzymatically saccharifying the anthocyanin – rich sweet potato pulp (starch) and fermenting the mash into wine using wine yeast *S. cerevisiae*	Ray et al. (2012), Panda et al. (2013)
Silage	Solid State Fermentation (SSF)	Leaf, vine, root	Silage undergoes anaerobic fermentation, which starts about 48 hours after the silo is filled, and converts sugars to acids. Fermentation is essentially complete after about two weeks. Lactic acid bacteria that are regularly associated with silage fermentation such as *Lactobacillus, Pediococcus, Leuconostoc, Enterococcus, Lactococcus* and *Streptococcus*	Yang et al. (1993), Abu et al. (2000), Tinh et al. (2000), Elferink et al. (2002)
Single Cell	Solid State	Bagassae	Sweet potato bagassae	Yang et al.

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Protein (SCP)	Fermentation (SSF)		can be fermented to SCP; the yeasts or fungi usually employed are *Endomycopsis fibuligera*, *Candida utilis*, *Trichoderma koningiivia*, *Pichia burtonii* and *Saccharomyces* sp.	(1993), Tian (2006)
Protease and Proteinase	Solid State Fermentation (SSF)	Bagassae	Several strains of *Aspergillus*, *Rhizopus*, *Actinomucor* and *Mucor* were tested as fermentation culture. *Aspergillus* and *Rhizopus* sp. showed higher proteinase activity than *Mucor* sp.	Yang and Huang (1994)
Lactic Acid	Submerged Fermentation (SmF)	Flour	Lactic acid could be produced by amylolytic lactic acid bacterium, *Lactobacillus plantarum* as the microbial culture and sweet potato flour as the carbohydrate source	Panda and Ray (2008)
Citric Acid	Solid State Fermentation (SSF)	Starch	Sweet potato has been used a substrate for citric acid production using *Aspergillus niger* in solid-state fermentation	Lu et al. (1995, 1997), Bindumole et al. (2000)
Monosodium Glutamate (MSG)	Submerged Fermentation (SmF)	Starch, flour	The starch has first to be degraded to sugars, which are then converted by microorganisms such as *Brevibacterium glutamicum* to glutamic acid. This is then converted to MSG salt	Jiang et al. (1993)
Glucose Syrup	Solid State Fermentation (SSF)	Starch	Glucose syrup could be produced by bacterial amylase	Ray and Ward (2006)
Baker's Yeast	Submerged Fermentation (SmF)	Dried sweet potato	-	Nishida et al. (2004)
Oxytetracycline	Solid State	Sweet	-	Yang and

	Fermentation (SSF)	potato		Yuan (1990)
Chitosan	Solid State Fermentation (SSF)	Sweet potato shochu waste water	Fungal treatment (*Absidia atrospora* and *Gongronella butleri*) of sweet potato shochu waste water. Chitosan production was highest from *G. butleri* strain	Yokoi et al. (1998), Nitar and Stevens (2002)
Bio-hydrogen	Solid State Fermentation (SSF)	Bagassae	Dried sweet potato starch residue used for microbial hydrogen production by the mixed culture of *Clostridium butyricum* and *Entrobacter aerogenes*	Yokoi et al. (2001)
Bio-ethanol	Submerged Fermentation (SmF)	Flour, starch, tuber	1- Flour was simultaneously saccharified and fermented by thermotolerant *S. cerevisiae* strain 2- Flour was saccharified and fermented by co-culturing *Trichoderma* and *S. cerevisiae*	Ray and Naskar (2008) Swain et al. (2013)

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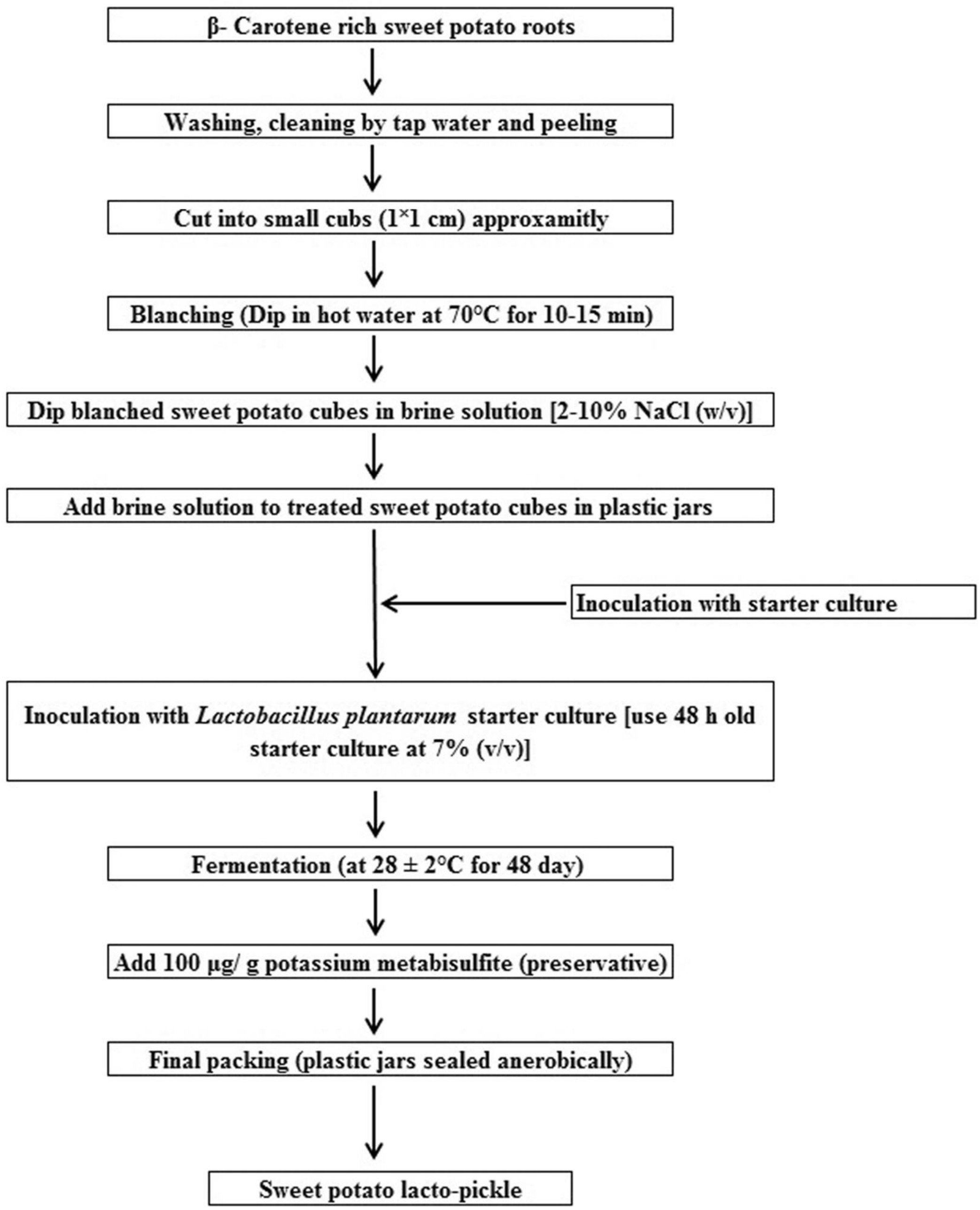

Figure 1 Flow chart of sweet potato lacto-pickle preparation (Source: Panda et al., 2009b).

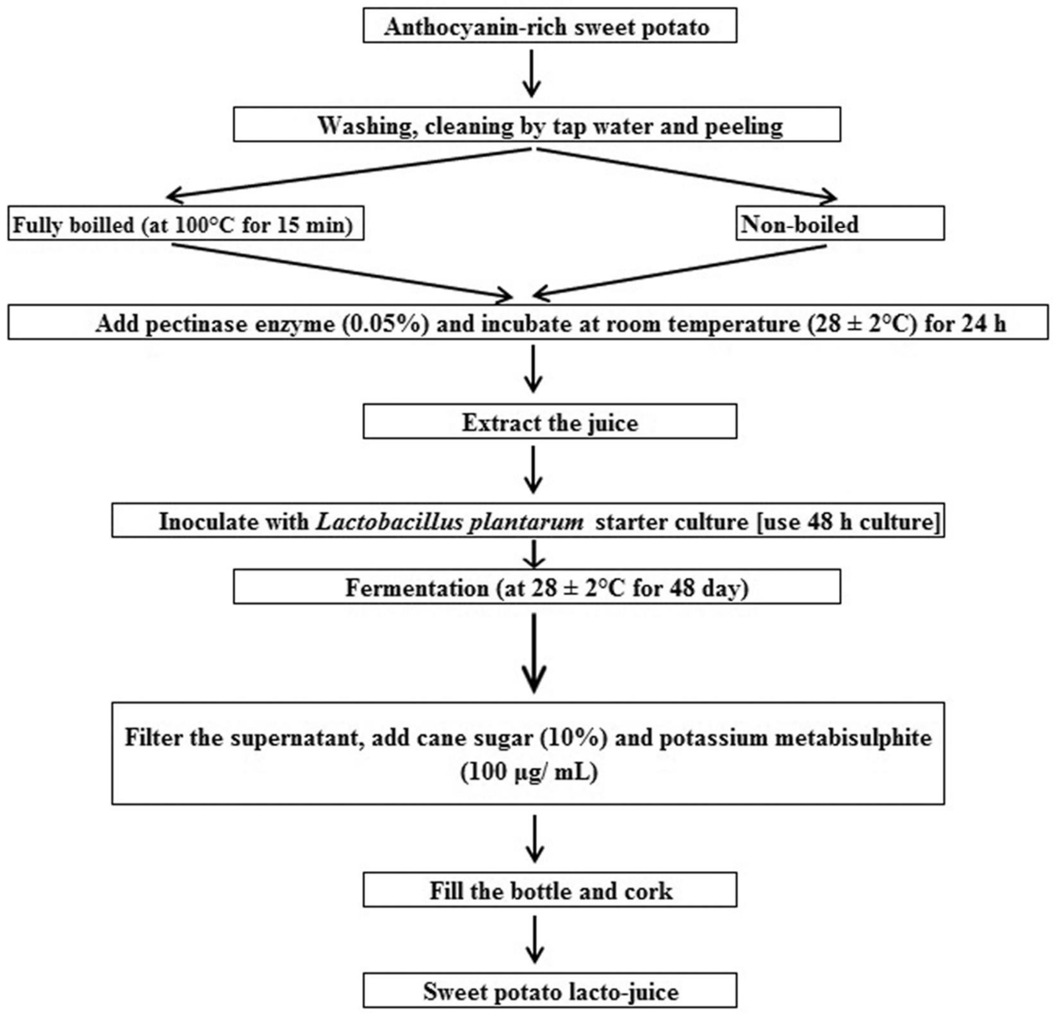

Figure 2 Flow sheet of sweet potato lacto-juice preparation (Source: Panda et al., 2009a).

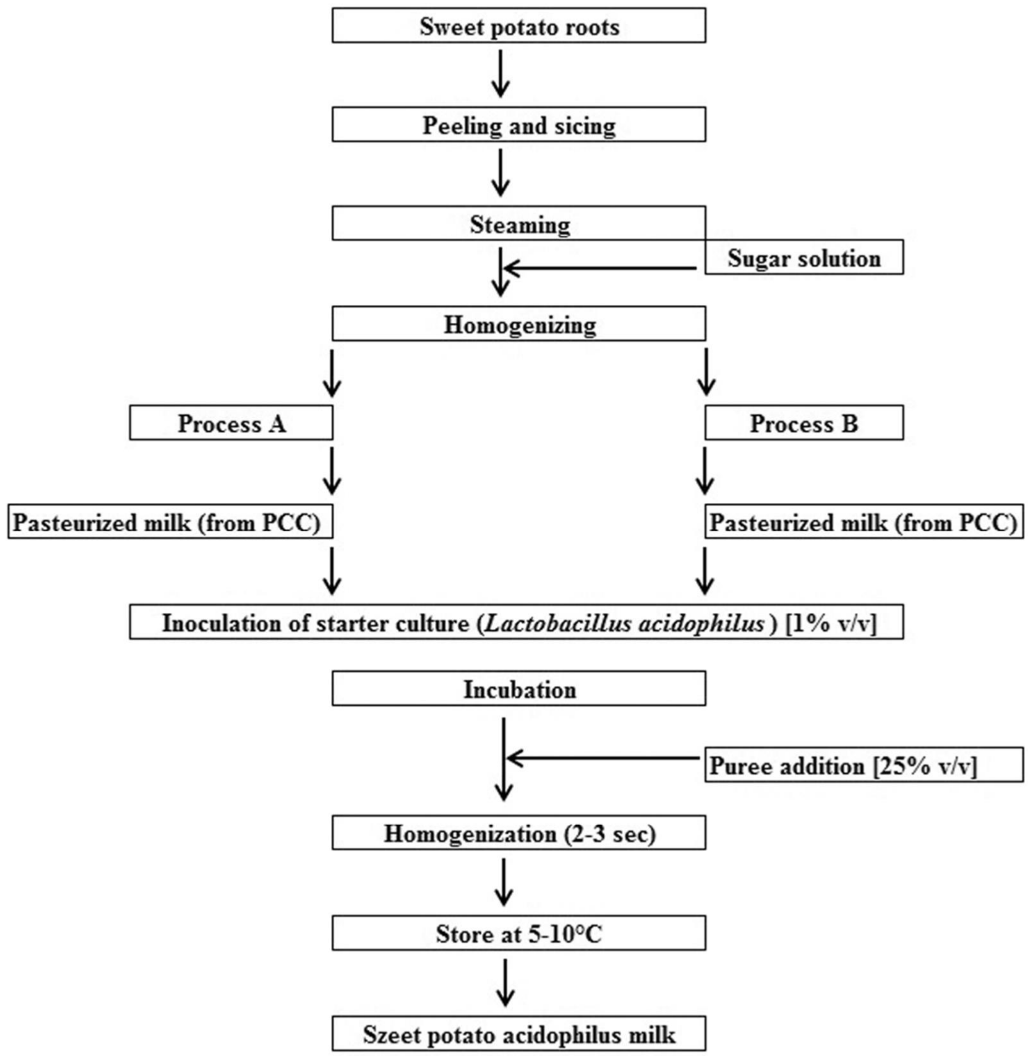

Figure 3 Production steps of acidophilus milk from sweet potato (Source: Perez and Tan, 2006).

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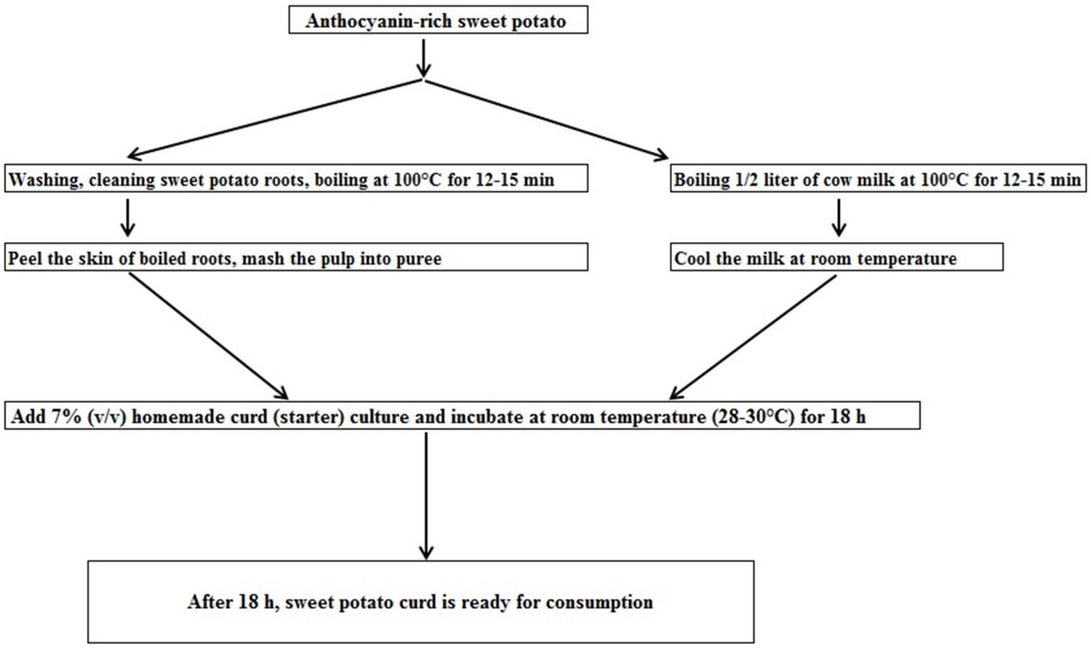

Figure 4 Flow chart for preparation of sweet potato curd (Source: Panda et al., 2006).

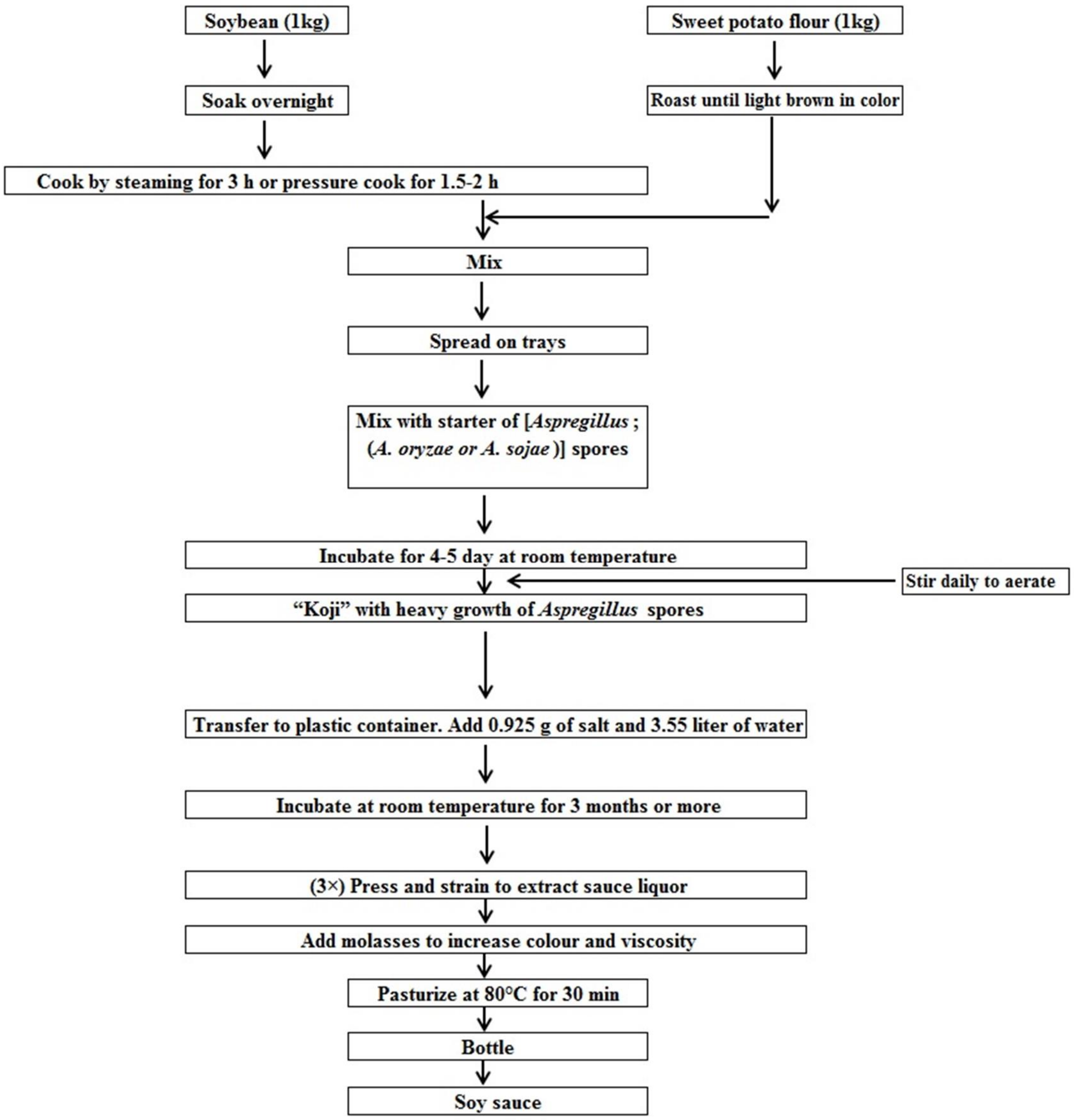

Figure 5 Flow chart for production of soy sauce using sweet potato flour (Source: Data et al., 1986).

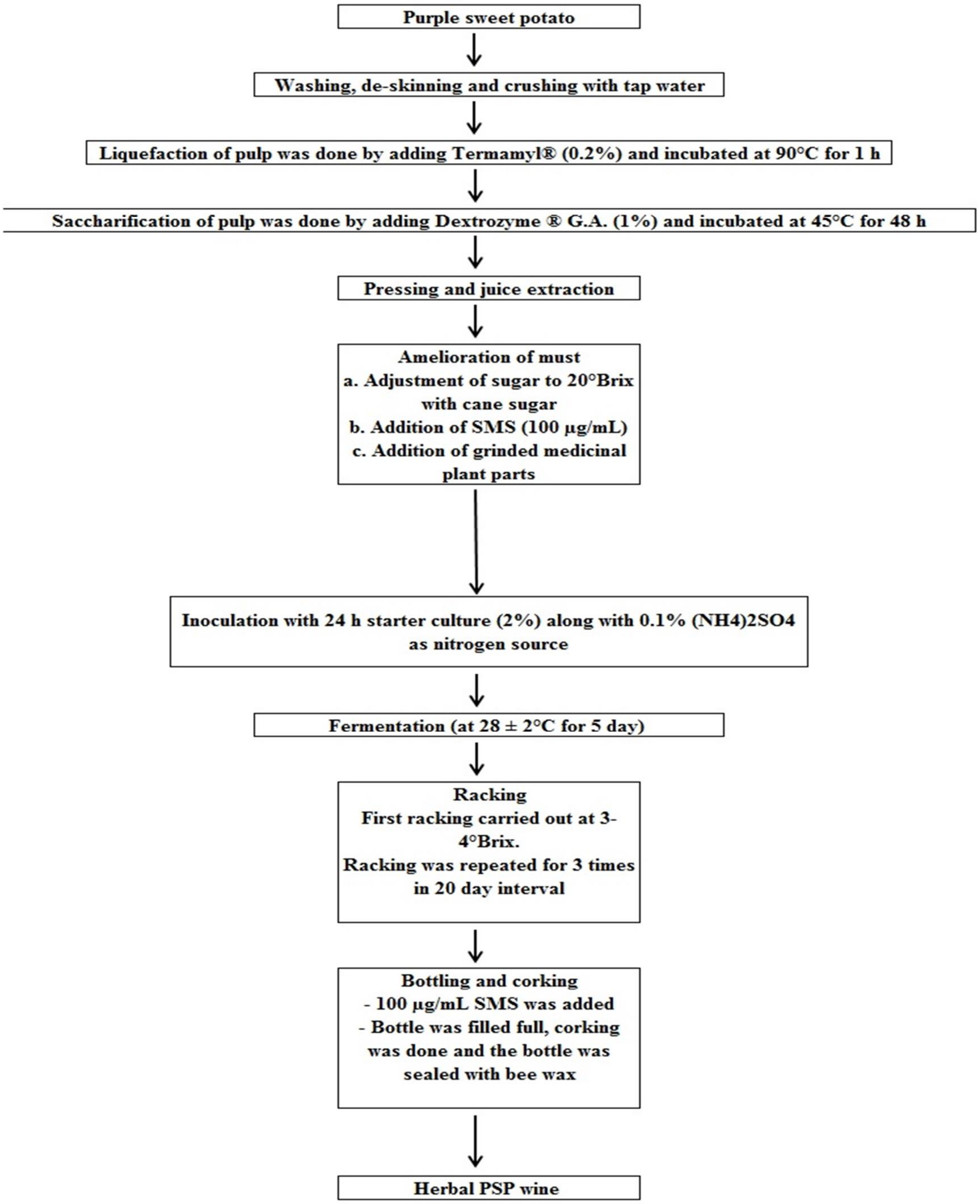

Figure 6 Flow sheet for making sweet potato wine (Source: Ray et al. 2012).

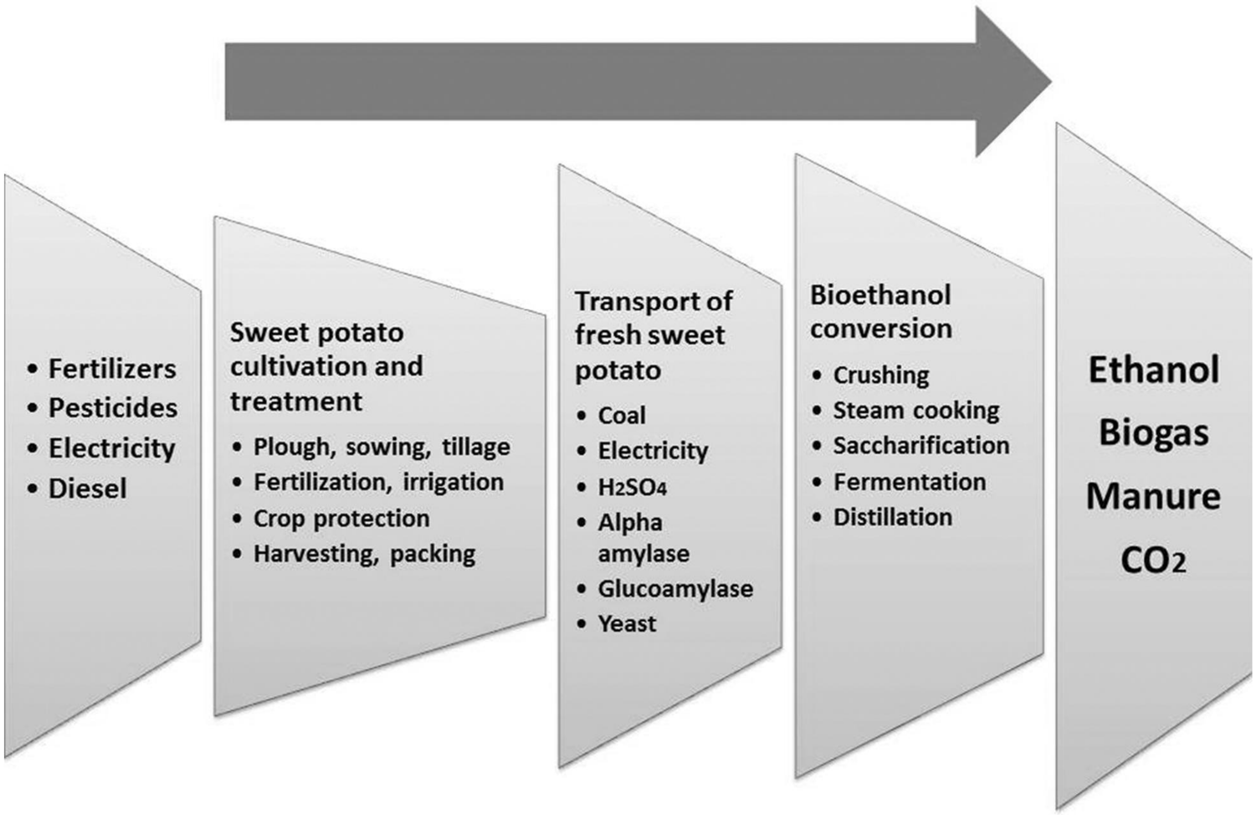

Figure 7 Life cycle of sweet potato-based bioethanol conversion.