Ph. D.

The effects of processing variables on physical and chemical characteristics of sweet potato flours

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ABSTRACT

Sweet potatoes are well known for their high nutritional values such as vitamins, minerals and bioactive compounds. However, the consumption of sweet potatoes has declined in the past several decades. This decline is attributed to difficulties in availability, storage, and handling for food processors as well as limited choices of sweet potato products for consumers beyond the raw root. Thus, one way to expand sweet potato consumption is to develop different processed products. In product development, the final quality of the product is highly dependent on the quality of the raw ingredients used. Most of the researcher focused on the development of new products adding with sweet potato flour. However, they didn't emphasis the flour quality. Therefore, the main purpose of this study was to prepare flour from sweet potatoes using different pretreatments and drying methods. Flours were prepared from peeled and unpeeled yellow color sweet potatoes using hot air drying with sulfite treatment. Sulfite treated peeled and unpeeled flour had higher ΔE values, swelling capacity, ascorbic acid, and total phenolic contents than untreated peeled and unpeeled flour. However, flour from yellow color sweet potato treated with calcium chloride had higher amounts of ascorbic acid and β-carotene than that treated with sodium hydrogen sulfite for both hot air drying and freeze drying. On the other hand, maltodextrin-added flours from purple color sweet potato using hot air drying had higher ΔE values, water soluble index, total phenolic, and anthocyanin contents than those of untreated flours.

However, during spray drying, flours treated with amylase and amylase with maltodextrin had higher anthocyanin and total phenolic contents than control or maltodextrin treated flours. Therefore, the overall study concluded that sweet potato flour could be produced using different pretreatments and drying methods that can be used to enhance the nutritional properties of functional food ingredients.

DEDICATION

DEDICATED TO MY PARENTS, MY SISTERS AND MY BROTHER

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CHAPTER I

GENERAL INTRODUCTION

Sweet potatoes are highly nutritious vegetables rich in calories and biologically active phytochemicals produced worldwide. They are originated in Central America and were brought to Western Europe after first of Columbus in 1492 (Srisuwan *et al.*, 2006). Based on the production volume, sweet potato ranks as seventh and fifth most important food crops in the world and developing countries, respectively (CIP, 2009). More than 133 million tons are produced globally per year. Asia is the world's largest sweet potato-producing region, with 125 million tons of annual production. China at 117 million tons accounts for 90 percent of worldwide sweet potato production (CIP, 2009). It could be used as s substitute or supplement to corn, rice or wheat or as the main ingredient of traditional, but infrequently consumed dishes in many developing countries (Adella & Benjamin, 2007). Sweet potato root colors range from white to light yellow, dark orange, red, or purple. Various types of cultivars are popular in different regions of the world and breeding programs are currently working to select for certain desirable flesh root and yield traits in those regions (Kotecha & Kadam, 1998). Yellow color sweet potato roots are on of the major sources of carotenoids along with apricots, carrot and peaches (Van Hall, 2000). Kays (1992) reported the total carotene to range from 0.5 to 44.6 mg/100g (dry basis). Carotenoids have nutritional implication because of their provitamin A activity. Carotenoids are produced by plants and transferred into vitamin A in the human body. Several epidemiological studies have shown associations between carotenoids such as carotene, and decreased risk for cancer, heart disease and age related macula degeneration (Kohlmeier & Hastings, 1995; Niizu &Rodriguez-Amaya, 2005). On the

other hand, anthocyanins are a large group of water-soluble pigments responsible for the red, purple and blue colors of fruits and vegetables (Plata *et al.*, 2003). Several researchers have shown anthocyanins have demonstrated ability to protect human diseases such as liver dysfunction, hypertension, vision disorders, microbial infections, and diarrhea (Rice-Evans & Packer, 1998; Smith *et al.*, 2000; Wang *et al.*, 2000). The high concentration of anthocyanin and β-carotene in sweet potato combined with the high stability of the color extract make it a promising and healthier alternative to synthetic coloring agents in food systems. Antioxidants can be used to help the human body to reduce oxidative damage. In recent years, there has been a global trend toward the use of natural phytochemical, as antioxidants and functional ingredients, which are present in natural resources such as vegetables, fruits, oilseeds and herbs, (Elliott, 1999; Kaur and Kapoor, 2001; Larson, 1988; Namiki, 1990). Sweet potato had intermediate antioxidant activity among 43 vegetables (Tsushida *et al.*, 1994). Antioxidant activity of purple sweet potato was observed to be 3.2 times higher than that of blueberry (Cevallos Casals & Cisneros-Zevallos, 2002). The purple-fleshed sweet potato genotypes have antioxidant activity, radical-scavenging activity (Oki *et al.*, 2002), antimutagenicity (Konczak-Islam *et al.*, 2003; Yoshimoto *et al.*, 1999) and have been shown to reduce liver injury induced by carbon tetrachloride (Suda *et al.*, 1997).

Generally most sweet potatoes are consumed in fresh form, cooked by baked, boiled or steamed. However, the consumption of sweet potatoes has declined in the past several decades. This decline is attributed to difficulties in availability, storage, and handling for food processors as well as limited choices of sweet potato products for consumers beyond the raw root (Collins & Walter, 1992). Thus, one way to

expand sweet potato consumption is to develop appealing processed products or alternative uses of sweet potato roots (Van Hall, 2000).

The preparation of sweet potato foods has several drawbacks. Discoloration is a major problem in the quality of the products and arises from two different sources. The first is the formation of brown discoloration caused by the oxidase reaction of polyphenol groups in enzymes the second is the non-enzymatic browning that results when reducing sugars condense with amino groups (Utomo *et al.*, 2005). Several methods have been developed to eliminate discoloration. Hoover and Miller (1973) used sodium acid pyrophosphate blanch treatment to eliminate greying. Olorunda and Kitson (1977) and Mais and Brennan (2008) eliminated discoloration in chips and biscuits prepared from sweet potatoes by dipping them in sodium sulfite and potassium metabisulphite respectively. On the other hand, peel is discarded during the manufacture of dried sweet potato product. Peel is the major by-products obtained during the processing of various fruits and vegetables and are good sources natural antioxidants and high dietary fiber that have various beneficial effects on human health (Nicoli *et al.*, 1999).

Preservation of food by drying is one of the oldest techniques, and has been translated into technology in the last century. The drying process is very important, as it greatly affect the sensory and nutritional characteristics of the end product. Among the different drying processes, freeze-drying and spray drying generally yields the highest product quality, but its relatively high production cost is a major drawback (Litvin *et al.*, 1998). The relatively cheaper hot air-drying is commonly used in food production, but the longer drying time usually results in inferior product quality. The goals of the drying process can be summarized as the retention of product quality, the

reduction of cost (for investment and operation processing), and the protection of the environment (Chou & Chua, 2001). To reduce the drying time and to retain the quality of fruits and vegetables, various pretreatment methods (chemical, thermal and physical) have been investigated (Chen *et al.*, 2005; Dimatteo *et al.*, 2000a, 2000b). Sweet potatoes flour is generally prepared by drying the peeled slices in a hot air drier or by drum drying of cooked sweet potato mash into flakes followed by milling and sieving (Woolfe, 1992). However, these sweet potatoes have an undesirable brown color and limited functionality (Collins & Walter, 1992). Grabowski *et al.* (2006) demonstrated that yellow color sweet potatoes can be spray dried using different concentration maltodextrin and amylase treatment. However, this drying technology has not been applied to purple color sweet potatoes.

Flour can prepared from peeled and unpeeled sweet potato roots. Sammy (1970) compared the proximate composition of spray-dried flours obtained from peeled and unpeeled roots. He concluded that peeling had little effect on this composition.

Sweet potato flours, powder and flakes processed by steaming and dehydration are ingredients used in formulated foods (Manlan *et al.*, 1985; Yadav *et al.*, 2006). Purple sweet potato powder has been used in noodles, bread and beverage (Yamakawa, 1998; Youshinaga *et al.*, 1999). Deep purple sweet potato flour and paste are used as coloring materials for bread, snakes and noodles (Knaes, 1995). Recently it has been observed that steamed or kneaded to enhance the some antioxidant activity of sweet potato flour (Huang *et al.*, 2006).

Sweet potato flour can serve as a source of energy and nutrients (carbohydrate, beta carotene, and anthocyanin), mineral (Ca, P, Fe and K) (Van Hall,

2000). Sweet potatoes can also be processed into flour, which is less bulky and more stable than the highly perishable fresh root. This flour can be used as a thickener in soup, gravy, fabricated snacks and bakery products. It can also serve as a substitute for cereal flours, especially for individuals diagnosed with celiac disease; celiac disease is intolerance to certain cereals, including wheat and wheat starch, and the only effective treatment known to date involves complete exclusion of wheat and wheat-based products from the diet (Caperuto *et al.*, 2000). Sweet potato flour can also be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients. However, the functional properties of flours are particular depend on the method of preparation.

Furthermore, many dried flour ingredients used in the food system. Most of the researcher focused on the development of new products using sweet potato flour than efficient method to produce the flour. Therefore, the objectives of the present study were:

1. To evaluate peeling, drying temperature and sulfite treatment on physicochemical properties and nutritional quality of yellow color sweet potato flour.
2. To evaluate the effects of hot air-drying and freeze-drying on yellow color sweet potato flour quality.
3. To determine quality properties of flour from purple sweet potato as affected by maltodextrin concentration and drying temperature.
4. To investigate the effects of various levels of maltodextrin, amylase and combined with matodextrin and amylase on the physicochemical properties of spray dried purple sweet potato flour.

CHAPTER II

LITERATURE REVIEW

The origin and production of sweet potatoes

Sweet potatoes (*Ipomoea batatas*) originated in Central America and were brought Western Europe after the first Voyage of Columbus in 1492 (Srisuwan *et al.*, 2006). Sweet potatoes are widely distributed throughout the world, but chiefly in tropical countries and sub-tropical countries where they are considered as major vegetable crop. Sweet potatoes are considered the seventh most important crop in the world (Woolfe, 1992). The total world production of sweet potato is approximately 130 million tons (FAOSTAT, 2005). It is estimated that 98% of the total world sweet potato production and utilization are in the developing countries (Scott, 1998). Asia is the world's largest sweet potato- producing region with 125 million metric tons of annual production. China is the leading producer of sweet potatoes with production reaching 117 million metric tons in 2004, which accounts for approximately 90% of global production (CIP, 2009).

Nutritional composition of sweet potato

Sweet potatoes are excellent sources of nutrients such as carbohydrates, fiber, pro-vitamin A, ascorbic acid, carotenes, thiamine, riboflavin, niacin, calcium, iron, potassium and zinc (Bhattiprolu, 2000).

Table 1. 1. Chemical composition of sweet potato.

Protein	2.15 g
Carbohydrate	31.56 g
Dietary Fiber	3.9 g
Sodium	16.9 g
Potassium	265.2 mg
Calcium	28.6 mg
Folate	18.2 mg
Vitamin C	29.51 mg
Vitamin A	26081.91 IU

(Source: Bhattiprolu, 2000)

Nutritional importance of sweet potato

Sweet potato roots are rich sources of crude protein, minerals and carotenoids (Picha, 1985). The high beta-carotene content of orange-fleshed roots may help to prevent vitamin A deficiency in developing countries. Besides these components sweet potatoes contain phenolic compounds, which may act as antioxidants to safeguard the human body from certain chronic diseases (Hayase & Kato, 1984). The term antioxidant is generally used for those compounds that scavenge the free radicals oxygen species formed in the human body. Phenolic compounds may play an important role in preventing chronic illnesses such as cardiovascular diseases, certain type of cancers, neurodegenerative disease and diabetes (Surh, 2003; Scalbert *et al.*, 2005). Recently, Rabah *et al.* (2004) showed that extracts from baked sweet potato had potential chemo preventive properties. Juice extract from purple-fleshed sweet potatoes had an ameliorative effect against carbon tetrachloride induced liver injury in rats (Suda *et al.*, 1997). Huang *et al.* (2004) reported that the inhibition of cancer cell

proliferation by sweet potato could be attributed to synergistic effect of phenolics with other phytochemicals.

Sweet potato varieties

Sweet potato varieties exist in many colors of skin and flesh, ranging from almost pure white and yellow-orange or pink, deep purple although white and yellow-orange flesh are the most common (Adella & Benjamin, 2007).

Yellow-fleshed sweet potatoes

The Intensity of the yellow or orange flesh color of the sweet potato is correlated to the carotenoid content. This color of sweet potato is an excellent source of carotenoid because its major carotenoid is all trans-β-carotene, which exhibits highest provitamin A (Adella & Benjamin, 2007).

Purple-fleshed sweet potatoes

Purple-fleshed sweet potatoes have intense purple color in the skins and flesh of the storage root due to the accumulation of anthocyanins (Philpott *et al.*, 2003; Terahara *et al.*, 2004).

Chemical composition of sweet potato

Dry matter

The chemical composition of sweet potato roots varies widely depending on the cultivar, growing conditions, maturity, and storage duration. Overall, sweet potatoes have a high moisture level with an average dry matter content range of 25 to 30%.

Carbohydrates

Most of the dry matter in sweet potatoes consists of carbohydrates. Total carbohydrates of the sweet potato in roots are approximately 80% starch and 20% simple sugars (Woolfe, 1992). Sugars are the next category of carbohydrate found in sweet potatoes and much variability exists between sweet potato samples. Using HPLC analysis, Truong *et al.* (1986) found total sugars to vary from 5.6% in a Filipino cultivar to 38% in a Louisiana cultivar on a dry weight basis (db). Sucrose, glucose, and fructose made up the majority of the total sugars while maltose was present to a lesser extent. Woolfe (1992) reported values between 2.9 to 5.5% on a fresh weight basis (fwb) for American cultivars and 0.38 to 5.64% for cultivars from the South Pacific.

Minerals & Vitamins

Mineral content in sweet potatoes are 56, 36, 0.9, 2.0 and 387 mg/100g for phosphorous, calcium, iron, zinc and manganese, respectively. Sweet potatoes also contain other vitamins such as thiamin (B1), riboflavin (B2), niacin (B6), pantothenic acid (B5), folic acid and some vitamin E. Sweet potatoes also contain a substantial amount of ascorbic acid or vitamin C. Woolfe (1992) summarized the work of several researchers and several cultivar types and reported the ascorbic acid content in the range of 17 to 35 mg/100g.

Protein

Protein content of sweet potato ranged from 1.73 to 11.8% (Purcell *et al.*, 1989). Sweet potatoes also contain non-protein nitrogen (NPN). NPN is defined as peptides

too small to be coagulated by the reagents that react with true protein. These nitrogen sources may impact protein values determined through Kjeldahl analysis. Additionally, non-protein nitrogen may provide usable nitrogen to the body but little in the form of essential amino acids (Purcell *et al.*, 1989; Woolfe, 1992). Sweet potato protein overall, however, is of good quality and the levels of essential amino acids compare significantly to the FAO reference protein (Purcell *et al.*, 1972; Walter *et al.*, 1984).

Lipids

The lipid content of sweet potatoes is low and slightly variable. Different researchers reported values between 0.1 and 0.8% (Woolfe, 1992). However, lipids become a component of interest due to their role in off-flavor formation through oxidation in dehydrated sweet potato flakes. Walter *et al.* (1974) identified and quantified the lipids in the Centennial variety. The total lipid content was 2.7% and the lipid fraction was categorized into phospholipids (27.1%), glycolipids (30.8%), and neutral lipids (42.1%).

Dietary fiber

Huang *et al.* (1999) reported that the total dietary fiber content of orange fleshed sweet potato ranged from 2.0 to 3.2 g/100g fresh weight. Components of dietary fiber include soluble, non-starch polysaccharides and insoluble plant cell wall materials such as pectin, cellulose, hemicellulose, and lignin.

Carotenoids

Carotenoid pigments are recognized in sweet potatoes for both color and nutrition. These pigments impart cream, yellow, orange and deep orange color in sweet potato roots (Woolf, 1992). Kays (1992) reported the total carotene content to range from 0.5 to 44.6 mg/100g.

Anthocyanins

Purple-fleshed sweet potatoes have intense purple color in the skins and flesh of the storage root due to the accumulation of anthocyanins (Philpott *et al.*, 2003; Terahara *et al.*, 2004). The content of anthocyanin of raw, steamed or kneaded sweet potato flours (3.6 to 545.9 mg kg^{-1}dry matter, Huang *et al.*, 2006).

Health benefits of sweet potatoes

Sweet potatoes have long been depended upon as a valuable source of energy in developing countries. Because of their non-specific growing conditions, they are also valuable in times of civil crisis and natural disasters. Furthermore, they are well known as a nutritionally rich crop, complete with vitamins (B_1 B_2, C and E) minerals (calcium, magnesium, potassium and zinc), dietary fiber (Suda *et al.*, 2003).

Carotenoids

Carotenoids have nutritional implications because of their provitmin A activity. This pigment is responsible for yellow or orange-fleshed sweet potatoes and represents 86.4 to 89.0% of the carotenoids in sweet potatoes (Woolf, 1992). Beta-carotene is important because of its role as a vitamin A precursor, which maintains

and protects eye tissues. Humans cannot synthesize carotenoids; therefore dietary sources have to provide sufficient levels (Kopsell & Kopsell, 2006).

Anthocyanins

Anthocyanins are a large group of water-soluble pigments responsible for the attractive orange, red, purple and blue colors of fruits and vegetables deep purple sweet potato flour and paste are also used as coloring materials for bread, snacks and noodles (Philpott *et al.*, 2003; Terahara *et al.*, 2004).Various studies have reported the relationship between consumption of anthocyanin-rich foods and improved health. Health benefits associated with anthocyanin extract include chemopreventive activities such as antimutagenicity and antioxidative potential (Suda *et al.*, 1997; Yoshimoto, 2001).

Ascorbic acid

Sweet potatoes are also a substantial source of vitamin C and several minerals (Woolfe, 1992). Vitamin C has ability to perform antioxidant functions. It can help prevent the cell damage done by "free radical" molecules as they oxidize protein, fatty acids and deoxyribonucleic acid (DNA) in the body. Free radical damage has been implicated in the progression of several diverse and important disease states including cancer, cardiovascular disease and cataract formation (Gershoff, 1993; Harats *et al.*, 1998; Jacques *et al.*, 1997).

Phenolic in sweet potato

Phenolics are compounds having an aromatic ring with one or more hydroxyl groups and functional derivatives (Shahidi & Naczk, 2003). Sweet potato leaves are consumed as a leafy vegetable in many parts of the world and can be harvested many times during a season (Villareal *et al.*, 1982; Islam *et al.*, 2002). In 2002, six caffeic acid derivatives were isolated from sweet potato leaves, including chlorogenic acid and the total phenolic content was found to be range from 1.42 to 17.1 g/100 g dry weight in 1,389 cultivars collected worldwide. It was also found that the quantity of total phenolic compounds present in the leaves was greater than concentrations in the stems and storage roots (Islam *et al.*, 2002). Due to concentration of phenolic compounds in the leaves of sweet potatoes, their antioxidant capacity is much higher than other vegetables.

Sweet potato processing

Despite the demonstrated health benefits of sweet potatoes, worldwide production and consumption has been in a continued state of decline for the past 42 years (Kays, 2005). Now a day different kinds of sweet potato products are available in the market such as frozen patties, purees, dehydrated flakes, chips, French fries, a ready-to-eat product, and a fruit-leather. Unfortunately, many of these products have not been successfully marketed (Collins & Walter, 1992).Processed products include canned sweet potatoes, purees, dehydrated flakes, chips, patties, breads, beverages and specialty products including candies and baby food (Kays, 1985). Puree and dehydrated flakes are two products with unique uses, characteristics, and processing

techniques and have been significantly investigated by various researchers and marketed as processed sweet potato products.

Puree production

Sweet potato puree can be used in products such as baby foods and pie fillings and as the basis for frozen patties and dehydrated flakes. The major advantage to pureeing is that roots of all sizes and shapes can be processed to make acceptable puree and therefore, the entire crop is utilized. Other advantages include reduced storage space requirements and a year-round supply (Kays, 1985). Over the years, different techniques have developed for puree processing. The first sweet potato purees were simply made by cooking the roots and then pureeing; however, the aforementioned challenges became an issue. The second technique added alpha-and beta-amylase after cooking and pureeing to obtain the desired amount of starch conversion – this, however, introduced a food additive to the process. The third method employs the "enzyme activation technique" using the native amylolytic enzymes and is now widely used in the food industry as described below (Kays, 1985). The process of making puree starts with thorough washing with cold pressurized water in a drum washer. The peels are then removed by hot lye (56 minute exposure to 10-20% lye solution at 104°C) or high pressure steam and rewashed and then inspected and trimmed to remove defects. Next, steam injection is used to increase the temperature to between 74 and 85°C which gelatinizes the starch and activates the amylases. This heat treatment gelatinizes the starch and then the enzymes partially degrade it to maltose and dextrins. In order to control the process to produce a consistent product, the length of conversion time is varied from 2 to 60 minutes depending on the root.

After starch conversion, the temperature of the puree is raised to between 88 and 100°C in a heat exchanger to inactivate the enzymes. After that, puree packaged aseptically, in cans, or frozen (Kays, 1985; Collins & Walter, 1992).

Flakes

Sweet potato flakes can be used for mashed potatoes, pies, and other products. Dehydrated flakes present several advantages such as a decrease in the weight of the product, the ability to be stored at ambient temperature, and a convenient product able to be reconstituted and prepared. However, the flakes do have some limitations such as an undesirable dark brown color (Kays, 1985). Dehydrated sweet potato flakes also undergo rapid oxidative degradation which leads to the development of off flavors and loss of provitamin A activity. Deterioration can only be prevented by storing in a nitrogen atmosphere (Walter & Purcell, 1974).

Powder

Sweet potatoes can also be processed into flour, which is less bulky and more stable than the highly perishable fresh root. This flour can be used as a thickener in soup, gravy, fabricated snacks and bakery products. It can also serve as a substitute for cereal flours, especially for individuals diagnosed with celiac disease; celiac disease is intolerance to certain cereals, including wheat and wheat starch, and the only effective treatment known to date involves complete exclusion of wheat and wheat-based products from the diet (Caperuto *et al.*, 2000). Sweet potato flour can also be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients. Recently, grabowski *et al.* (2006) demonstrated that yellow

color sweet potatoes can be spray dried using different concentration maltodextrin and amylase treatment.

Sweet potato utilization as value added products

Sweet potato flour can easily promoted as substituted for wheat potato flour in sweet baked products. Many researchers have produced different product using sweet potato flour. Sweet potato flour has been fermented to make products such as soy sauce and alcohol (Adella & Benjamin, 2007). Sing *et al.* (2003) produced chips from sweet potato. However, Chen *et al.* (2002) made starch noodle from three typical Chinese sweet-potato starches. On the other hand, Mais and Brennan (2008) prepared biscuit using sweet potato flour, starch and fiber.

Effect of processing on sweet potato quality

Nutritional value

Change due to soaking were a decrease of yield due to losses of some solubles, moisture content of the flour due to reduction of evaporation by the solute sodium bisulfite a decrease of total sugar content starch and amylase and ash content as well as shrinkage of the slices due to plasmolysis (Van Hall, 2000). Sammy compared the chemical composition of spray-dried and cabinet-dried sweet potato flours and found that the products were similar except for the higher moisture content of the cabinet-dried and the higher sugar content of the spray-dried flour. Heat processing treatments have a negative influence on protein quality and quality depending on the period and temperature of heat exposure.

Purcell and Walter (1989) reported that the baking was considered to be the least serve heat treatment compare to the canning and drum drying.

Carotenoids

Beta-carotene is one of the major pigments present in especially yellow color sweet potato. Beta-carotene destruction is through isomerization or oxidation. Both can occur during thermal processing. Oxidative degradation of Beta-carotene occurs through a free-radical process with losses in highest in baked samples (31.4%) and substantially in drum dried (20.5%) and micro waved (22.7%) samples (Van Hall, 2000). Collins and Gurkin (1990) reported that Beta-carotene is increased due to an increased extractability of the pigments because synthesis of Beta-carotene is very unlikely in dry flour. In the contrast Woolfe (1992) they found no influence of storage temperature (at 0, 7, 14 or 21 ^{o}C) on Beta-carotene content.

Ascorbic acid

Woolfe (1992) reported that the ascorbic acid content of sweet potato in the range of 17 to 35 mg/100g. However, ascorbic acid reduced by thermal processing. Grabowski *et al.* (2006) reported that baking sweet potatoes for 30 min reduced 45-55% ascorbic acid. A 50-70% decrease in vitamin C was reported for drum dried flakes at high temperature.

Color

Discoloration of sweet potato slices is the most important factor changes of quality during processing. It produces a low quality, i.e. brown color flour and is

enhanced by mechanical of heat treatment. However, temperature and presence of oxygen, moisture absorption can also lead to bleaching of the pigment, resulting in a colorless product. Prevention of color loss can be achieved with proper packaging and storage of the flour.

Anthocyanins

Anthocyanins are natural, nontoxic and water soluble pigments displaying orange, red, purple or blue color in plants and foods (Yang & Gadi, 2007). Purple sweet potato contains a high level of anthocaynins compared to white, yellow and orange ones (Fan *et al.*, 2007). Purple sweet potato anthocyanin extraction is depending on several factors, including structure and concentration of the pigment, pH and temperature in the extraction process. Purple sweet potatoes are good sources of acylated anthocyanins with aromatic acids. The acylated anthocyanins are more stable than non acylated ones in aqueous solution (Yang & Gadi, 2007).

Processing of raw materials

Peeling

Peeling removes the skin from the root and can be carried out manually or mechanically. Usually peeling methods are lye peeling and steam peeling. For lye peeling temperature 103-104°C and concentration of lye 10-12% for 3-7 min were used (van Hall, 2000). Peel dependent only on consumer acceptance because unpeel sweet potato created browner color compared to the peel sweet potato.

Blanching

Blanching is generally used to process vegetables to inactivate enzymes. This is not a method of preservation but it is considered as pre-treatment for raw vegetables prior to other processing. Jangchud *et al.* (2003) reported that for both yellow and purple color sweet potato blanching affected the pasting properties, swelling power, solubility and chemical composition such as protein, fat, starch and reducing sugar component.

Chemical preservatives

Different chemical preservative used such as sodium sulfite, sodium metabisulfite, citric acid, acetic acid or potassium to prevent browning. Sing *et al.* (2003) produced sweet potato chip using the potassium metabisulfite, citric acid and sodium chloride. Hoover and Miller (1973) used sodium acid pyrophosphate blanch treatment to eliminate greying. Olorunda and Kitson (1977) and Mais and Brennan (2008) eliminated discoloration in chips and biscuits prepared from sweet potatoes by dipping them in sodium sulfite and potassium metabisulphite respectively.

Drying

Drying is one of the oldest methods of food preservation technique and it represents a very important aspect of food processing. During drying two processes take place simultaneously such as heat transfer to the product from the heating source and mass transfer of moisture from the interior of the product to its surface and from the content of the surrounding air. The advantages of dried foods are described by Somogyi and Luh (1986):

- Extended shelf life because of inhibition of microbial and enzymatic reactions.
- Providing consistent product and the seasonal variation and diminished.
- Substantially lower cost of handling, transportation and storage.
- The dried products size, shape and form are modified and the price is constant throughout the year.
- The dried foods can be used as snacks and other processed foods.

Hot air drying

Air-drying in particular, is an ancient process used to preserve foods in which the solid to be dried is exposed to a continuously flowing hot air where moisture evaporated. Air-drying offers dehydrated products that can have an extended life of a year. Hot air drying is the cheapest amongst other drier. Sweet potato flours are prepared by hot-air drying technique (Mais & Brennan, 2008; Yadav *et al.*, 2006a; 2006b; Woofle, 1992; Van Hall, 2000).

Freeze dryer

In freeze-drying, a stable product can be achieved by the reduction of water activity without heating the food (Fellows, 2002). The water vapor is removal from the food by keeping the pressure in the chamber below the vapor pressure at the refrigeration coils (Fellows, 2002). Heat transfer that occurs through a frozen

product layer will be rapid and not rate- limiting. The absence of air during freeze prevents oxidation and chemical modification of the product (Fellows, 2002). However, this drying technology has not been applied to sweet potatoes.

Drum drying

Drum drying is that process where the material is dried on the surface of an internally heated revolving drum. Sweet potato flours are prepared by drum-drying techniques (Woolfe, 1992; Yadav *et al.*, 2004).

Spray drying

Spray drying is a unique drying process that involves both particle formation and dehydration. Basically, spray drying is accomplished by atomizing feed liquid into a drying chamber, where the small droplets are subjected to a stream of hot air and converted t powder particles.

Spray drying offers the following advantages (Masters, 1991)

- When drying conditions are held constant, powder quality and specifications will remain constant.
- Spray drying is a continuous and easy drying operation and is adaptable to full automatic control

Spray drying is a process widely used to produce fruit juices powders and provided powder with good quality, low water activity and easier transport and storage (Abadio *et al.*, 2004; Cano-Chauca *et al.*, 2005; Quek *et al.*, 2007). Yellow color sweet potato flour is prepared using spray drying (Grabowski *et al.*, 2006).

However, spray drying has not been used to purple color sweet potato. Powders obtained by spray drying may have some problems in their properties, such as stickiness, hygroscopicity and solubility due to the presence of low molecular weight sugars and acids, which have low glass transition temperature. Parts of these problems

can be solved by the addition of some carrier agents, like maltodextrin (MD), polymers and gums which increase the glass transition temperature of the products during spray drying. Additionally, MD was added to the puree in various concentrations to act as a drying aid. MD facilitates product recovery by raising the glass transition temperature of the product to reduce stickiness and partially encapsulating the material (Abadio *et al.*, 2004; Cano-Chauca *et al.*, 2005; Quek *et al.*, 2007). It has also been found maltodextrin has more capable of retention of some food properties such as nutrients, color and flavor during spray-drying (Rodríguez-Hernández *et al.*, 2005). Maltodextrins have been used in spray drying of various sugar-rich foods such as blackcurrant, raspberry and apricot juice. Recently, Grabowski *et al.* (2006) demonstrated of yellow color sweet potatoes can be spray dried using different concentration maltodextrin and amylase treatment.

Alpha-amylase action was used as pre drying treatment to reduce viscosity. Amylase reduces the viscosity of sweet potato puree by hydrolyzing starch molecules to dextrin (Grabowski *et al.*, 2006). Enzymatic treatment is known to enhance the extractability of phenolic and anthocyanin components from the cell wall matrix (Ramadan *et al.*, 2007)

CHAPTER III

PEELING, DRYING TEMPERATURE AND SULFITE TREATMENT AFFECT PHYSICOCHEMICAL PROPERTIES AND NUTRITIONAL QUALITY OF SWEET POTATO FLOUR

Abstract

The effects of peeling, drying temperature (55-65°C) and pretreatment on the physicochemical properties and nutritional quality of sweet potato flour were investigated. The flours were prepared from peeled and unpeeled sweet potatoes dipped in 0.5% sodium hydrogen sulfite ($NaHSO_3$). There were significant differences ($p<0.05$) in ΔE values and browning index between flours from peeled and unpeeled sweet potatoes without sulfite treatment (PF and UF). On the other hand, flours from peeled and unpeeled sweet potatoes with sulfite treatment (PSF and USF) had higher color values, swelling capacity, ascorbic acid and total phenolic contents than PF and UF. However, USF and UF had higher β-carotene content than PSF and PF. β-carotene and ascorbic acid contents decreased with increasing drying temperature for all flours, whereas total phenolic content increased for PSF and USF. Therefore, the best quality product was obtained when samples were pretreated with sulfite before drying at any drying temperature.

Introduction

Sweet potatoes *(Ipomoea batatas* L. lam.) are highly nutritious vegetables that are rich in calories and biologically active phytochemicals such as beta-carotene, polyphenols, ascorbic acid and dietary fiber (Van Hal, 2000). Dehydrated sweet potato has commonly been obtained by hot-air drying, which allows rapid and massive processing, although it greatly affects the sensory and nutritional characteristics of the end product. To reduce the drying time and to retain the quality of fruits and vegetables, various pretreatment methods (chemical, thermal and physical) have been investigated (Dewanto *et al.*, 2002a; Dewanto *et al.*, 2002b).

Sweet potatoes are cheaper than other crops, yet this abundant resource is still not properly utilized. The preparation of sweet potato foods has several drawbacks. Discoloration is a major problem in the quality of the products and arises from two different sources. The first is the formation of brown discoloration caused by the oxidase reaction of polyphenol groups in enzymes; the second is the non-enzymatic browning that results when reducing sugars condense with amino groups (Utomo *et al.*, 2005). Several methods have been developed to eliminate discoloration. Hoover and Miller (1973) used sodium acid pyrophosphate blanch treatment to eliminate greying. Olorunda and Kitson (1977) eliminated discoloration in chips prepared from white flesh potatoes by dipping them in sodium sulfite.

Sweet potato roots can be processed into products, such as cookies, biscuits, muffins, noodles, breakfast foods and pies, with longer shelf-life and improved characteristics. Sweet potatoes can also be processed into flour, which is less bulky and more stable than the highly perishable fresh root. This flour can be used as a thickener in soup, gravy, fabricated snacks and bakery products. It can also serve as a

substitute for cereal flours, especially for individuals diagnosed with celiac disease; celiac disease is intolerance to certain cereals, including wheat and wheat starch, and the only effective treatment known to date involves complete exclusion of wheat and wheat-based products from the diet (Caperuto *et al.*, 2000). Sweet potato flour can also be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients. In product development, the final quality of the product is highly dependent on the quality of the raw ingredients used. If sweet potato flour is to be incorporated into products, it must be high quality. Therefore, the objective of the present investigation was to study the effects of peeling, drying temperature and pretreatment on the quality parameters of sweet potato flour.

Materials and Methods

Raw material

Sweet Potato (*Ipomoea batatas* Lam cv. Sinhwangmi) was purchased from a local farm. Roots were washed with tap water to remove dirt and soil and, after drying its surface, the washed sweet potato was stored at 14°C until used.

Sample preparation and treatment

Sweet potato roots were divided into two groups. In the first group, sweet potatoes were peeled with a hand peeler (Han Sung 27 stainless, Gwangju, Korea). Peeled samples were kept in tap water to prevent enzymatic darkening. Peeled and unpeeled samples were then cut into slices (1 mm thickness) using a slicing machine (HFS 350G, Fujee, Korea).

For the second group, peeled and unpeeled slices were dipped in aqueous 0.5% (w/v) sodium hydrogen sulfite ($NaHSO_3$) at room temperature for 2 min.

Preparation of sweet potato flour

The slices were dried using a convection drying oven (Dasol Scientific Co. Ltd., Seoul, Korea) at different temperatures 55, 60, and 65°C for 7-8 hr. The flour (moisture content 6-7%) was obtained by milling the dried slices using a blender (FM-681C, Hanil, Gwangju, Korea), and sieved through an 80-mesh (Seoul, Korea) screen to obtain sweet potato flour.

Proximate compositions of sweet potato flour

Proximate compositions of the sweet potato flours were evaluated. Moisture, crude protein, ash and crude fiber contents of flours were determined by official methods (AOAC, 1998). The total sugar content of the sample was determined using the phenol-sulfuric acid method (Dubois *et al.*, 1956).

Hunter color values

The color attributes (Hunter L*, a*, and b* values) were measured with a colorimeter (CM-3500d, Minolta, Japan). Color change was calculated as $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$

Water solubility index (WSI), water absorption index (WAI), and swelling capacity (SWC)

WSI and WAI were determined according to the method described by Anderson (1982). Two and a half grams of sweet potato flour and 30 mL of water were

vigorously mixed in a 50-mL centrifuge tube; the mixture was incubated in a water bath at 30°C for 30 min and centrifuged at 3000 g for 15 min. The supernatant was collected in a pre-weighed Petri dish and the residue was weighed after oven-drying overnight at 105°C. The amount of solids in the dried supernatant as a percentage of the total dry solids in the original 2.5 g sample was an indicator of water solubility index. WAI was calculated as the mass of the solid pellet remaining after centrifugation divided by the mass of dry sample.

Swelling capacity (SWC)

Swelling capacity was determined according to Lai and Cheng (2004) using the equation

SWC= weight of sediment / [dry weight of sample x (1-ws%/100)].

Browning index

Browning index was determined using the method described by Youn and Choi (1996). One gram of dehydrated sweet potato flour was extracted with 40 mL of distilled water and 10 mL of 10% trichloroacetic acid solution in a beaker. The extract was filtered through a Buchner funnel with Whatman No. 2 filter paper. After the solution stood for 2 hr at room temperature, its concentration was determined based on its absorbance at 420 nm (UV-1201, Shimazu, Japan).

Determination of β-carotene content

β-carotene content was determined using the modified method of Park (1987). Dehydrated sweet potato flour (0.5g) was extracted with a mixture of hexane and

acetone (7: 3, 25 mL). The extracts were filtered through a Buchner funnel with Whatman No. 1 filter paper. The residue was re-extracted until it became colorless. The filtrates were combined in a separatory funnel and washed with 50 mL of distilled water. The water phase was discarded and a pinch of Na_2SO_4 was added as desiccant. The hexane phase was transferred to a volumetric flask. The concentration of carotene in the solution was determined from the absorbance at 450 nm (UV-1201, Shimazu, Japan). The β-carotene content was determined from the standard curve for prepared β-carotene.

Determination of total phenolics

Total phenolic content in the sweet potato flours was determined with Folin-Ciocalteu reagent according to a slightly modified method described by Swain and Hills (1959). The sample (0.1 g) was extracted 3 times with 20 mL of 75% methanol and filtered through Whatman No.2 filter paper. Extracts were combined and concentrated in a rotary vacuum evaporator (Rikakikai Co. Ltd, Tokyo, Japan) at 40°C; the volume was adjusted to 20 mL with 75% methanol. One mL of extract, 5 mL of distilled water and 2 mL of 10% Folin-Ciocalteau reagent were added into a Falcon tube. After 3 minutes at room temperature, 2 mL of 7.5% Na_2CO_3 solution were added and the sample was diluted to 20 mL with distilled water. Each sample was allowed to stand for 1 hr at room temperature and absorbances were measured at 760 nm (UV-1201, Shimadzu, Japan). Total phenolics were calculated on the basis of standard curves of gallic acid, and expressed as mg gallic acid per 100g.

Determination of ascorbic acid content

Ascorbic acid was determined according to a slight modification of the method described by Doner and Hickts (1981). Sweet potato flour (2 g) was mixed with 10 mL of 5% metaphosphoric acid solution, and extracted by vortexing at room temperature for 1 min. The mixture was centrifuged for 15 min at 3000 rpm and the supernatant was filtered using a 0.45-μm PVDF syringe filter; 20 μL of this sample was injected onto the liquid chromatograph. Vitamin C was separated on an ODS C18 column (4.6× 250 mm, YMC Inc., Kyoto, Japan) using a mobile phase of Acetronitrile: 0.005 M KH_2PO_4 (60:40 v/v) (A) and 100% HPLC water (B) at a flow rate of 1 mL min^{-1}. A UV detector (Jasco UV-975, Kyoto, Japan) was used and the detection wavelength was 254 nm. Vitamin C content was calculated by comparing the peak area at 254 nm with those of standard solutions and expressed as milligrams per 100 g.

Scanning electron microscopy (SEM)

Slices and flour granule morphology were examined by scanning electron microscopy. A sample was mounted on the aluminium specimen holder with double-sided tape. The specimen holder was loaded in an Emitech K550 sputter coater (Emitech, UK). The sample was coated with gold palladium, at thickness of about 15 nm and viewed under SEM (S-2400 Hitachi, Japan) operated at an accelerating voltage of 10 KV.

Statistical analysis

All measurements were performed in triplicates for each sample. Data were analyzed using statistical software (SPSS for Windows Version 14.0). Two-way ANOVA was carried out to determine the overall effect of treated, untreated and drying temperatures and interaction (treated × untreated × drying temperatures) on each of the assays. Individual effects and interactions between the factors have been calculated. Significant differences between the means were estimated using Duncan's multiple range tests. Differences were considered significant at $P < 0.05$.

Results and Discussion

Proximate compositions of sweet potato flour

Proximate compositions of peeled and unpeeled sweet potato flour prepared with sulfite pretreatment and different drying temperatures are shown in Table 3.1. Moisture, ash and fat contents of sweet potato flours ranged from 6.18 to 8.67%, 3.16 to 4.25%, and 0.59 to 1.29%, respectively, which were similar to those reported by Van Hal (2000). Moisture contents of flours from peeled and unpeeled sweet potatoes without sulfite treatment (PF and UF) and from peeled and unpeeled sweet potatoes with sulfite treatment (PSF and USF) were similar to each other. USF and UF had higher ash content than PSF and PF. The higher values may be due to the higher solids in unpeeled samples compared to the peeled samples. During drying, ash content increased with increasing drying temperature; the increased ash content could also be due to increased overall sweet potato solid. There were no significant differences in fat, protein and total sugar contents of all samples at different drying

temperatures. Fat content decreased with increasing drying temperature for all flours. This might be due to oxidation of fat content. The protein content in sweet potato flour is generally low, ranging from 1.0 to 8.5% (Van Hal, 2000). In this study, protein content ranged from 3.41 to 3.69%. The total sugar content of sweet potato flour ranged from 3.00 to 3.57 g/100 g. This observation was similar to those of Van Hall (2000).

Table 3.1. Effect of pre-treatment and drying temperatures on proximate analysis of peeled and unpeeled sweet potato flours

Parameter	Drying temperature (°C)											
	55				60				65			
	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]
Moisture (%)	$^{b}8.67^{B}$	$^{ab}7.99^{B}$	$^{ab}7.69^{B}$	$^{a}7.01^{A}$	$^{b}6.98^{A}$	$^{c}7.47^{A}$	$^{a}6.45^{A}$	$^{ab}7.17^{A}$	$^{a}6.18^{A}$	$^{c}7.77^{B}$	$^{b}6.82^{A}$	$^{b}7.14^{A}$
Ash (%)	$^{a}3.16^{A}$	$^{a}3.31^{A}$	$^{a}3.61^{A}$	$^{a}3.64^{A}$	$^{a}3.39^{B}$	$^{b}4.20^{C}$	$^{a}3.53^{A}$	$^{b}4.25^{B}$	$^{a}3.89^{C}$	$^{a}4.00^{B}$	$^{b}4.19^{B}$	$^{b}4.21^{B}$
Protein (%)	$^{a}3.48^{A}$	$^{a}3.61^{A}$	$^{a}3.51^{A}$	$^{a}3.51^{A}$	$^{a}3.59^{A}$	$^{a}3.69^{A}$	$^{a}3.32^{A}$	$^{a}3.28^{A}$	$^{a}3.47^{A}$	$^{a}3.60^{A}$	$^{a}3.41^{A}$	$^{a}3.50^{A}$
Fat (%)	$^{a}1.27^{B}$	$^{a}0.87^{B}$	$^{a}1.29^{B}$	$^{a}0.95^{A}$	$^{a}0.86^{AB}$	$^{a}0.74^{AB}$	$^{a}0.80^{AB}$	$^{a}0.99^{A}$	$^{a}0.59^{A}$	$^{a}0.60^{A}$	$^{a}0.60^{A}$	$^{b}0.90^{A}$
Total sugar(g/100g)	$^{a}3.00^{A}$	$^{a}3.14^{A}$	$^{a}3.26^{A}$	$^{a}3.48^{A}$	$^{a}3.39^{A}$	$^{a}3.41^{A}$	$^{a}3.29^{A}$	$^{a}3.39^{A}$	$^{a}3.49^{A}$	$^{a}3.29^{A}$	$^{a}3.57^{A}$	$^{a}3.30^{A}$

[a-c] Means followed by different in each row are significantly different among flour samples ($p<0.05$)

[A-C] Means followed by different in each row are significantly different among drying temperatures ($p<0.05$)

[1]PF: Flour from peeled sweet potatoes without sulfite treatment.

[2]PSF: Flour from peeled sulfite-treated sweet potatoes.

[3]UF: Flour from unpeeled sweet potatoes without sulfite treatment.

[4]USF: Flour from unpeeled sulfite-treated sweet potatoes.

Hunter color values

The Hunter color parameters, L^*, a^*, b^*, and ΔE, have been widely used to describe color changes during dehydration of fruit and vegetable products. L^*, a^*, b^*, and ΔE values of peeled and unpeeled sweet potato flours were measured following pretreatment and different drying temperatures (Table 3. 2). PF had higher L^* values than UF. Usually peel is the brown and dull color, so peel is the main factor that contributes to these differences. Mondy and Gosselin (1988) found that high levels of phenols were associated with discolorations. On the other hand, PSF and USF had significantly higher lightness than PF and UF. This could be due to the retarding of enzymatic and non-enzymatic reactions. Sulfite is a good color preservative of fruits and vegetables, as it retards both enzymatic and non-enzymatic reactions (Yongjie & Meiping, 2005). Hunter L^* values decreased with increasing drying temperature for all flours. The decrease might be due to changes in carotenoids, caramelization, oxidation or phenol action (Michael & Wilson, 1997). Hunter a^* and b^* values were higher in PSF and USF than in PF and UF. At different drying temperatures, a^* and b^* values were higher at 65°C than at 55°C for all flours except PSF. The changes in a^* and b^* values may be due the influence of the peel on the color of these products. The flour colors can best be described by the change in ΔE values. PSF and USF had higher ΔE values than PF and UF. ΔE values decreased with increasing drying temperatures for all flours. Still, PSF was not significantly different at a higher drying temperature. The lower ΔE values may be due to loss, oxidation or isomerization of carotenoids, caramelization or enzyme action (Michael & Wilson, 1997).

Table 3. 2. Effect of pre-treatment and drying temperatures on Hunter color values of peeled and unpeeled sweet potato flours

Hunter color values	Drying temperature (°C)											
	55				60				65			
	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]
L*	$^{c}85.84^{C}$	$^{d}88.16^{B}$	$^{a}82.58^{B}$	$^{b}84.44^{C}$	$^{c}84.91^{B}$	$^{d}88.09^{B}$	$^{a}82.80^{B}$	$^{b}83.53^{B}$	$^{a}82.51^{A}$	$^{d}87.56^{A}$	$^{a}80.68^{A}$	$^{c}82.83^{A}$
a*	$^{a}2.42^{A}$	$^{c}3.18^{C}$	$^{b}2.48^{B}$	$^{b}2.75^{A}$	$^{b}2.37^{A}$	$^{c}2.83^{A}$	$^{a}2.26^{A}$	$^{d}2.91^{B}$	$^{a}2.88^{B}$	$^{a}2.92^{B}$	$^{a}2.94^{C}$	$^{b}3.07^{C}$
b*	$^{b}25.49^{A}$	$^{c}26.72^{A}$	$^{a}23.23^{B}$	$^{a}23.25^{A}$	$^{c}25.68^{A}$	$^{d}26.70^{A}$	$^{a}22.12^{A}$	$^{b}23.31^{A}$	$^{b}25.95^{A}$	$^{b}26.48^{A}$	$^{a}24.09^{C}$	$^{a}24.27^{A}$
⊿E	$^{c}89.57^{C}$	$^{d}91.97^{AB}$	$^{a}85.82^{B}$	$^{b}87.62^{B}$	$^{c}88.73^{B}$	$^{d}92.08^{B}$	$^{a}85.73^{B}$	$^{b}86.77^{A}$	$^{b}86.54^{A}$	$^{c}91.50^{A}$	$^{a}84.26^{A}$	$^{b}86.37^{A}$

[a-d] Means followed by different in each row are significantly different among flour samples ($p<0.05$)

[A-C] Means followed by different in each row are significantly different among drying temperatures ($p<0.05$)

[1]PF: Flour from peeled sweet potatoes without sulfite treatment.

[2]PSF: Flour from peeled sulfite-treated sweet potatoes.

[3]UF: Flour from unpeeled sweet potatoes without sulfite treatment.

[4]USF: Flour from unpeeled sulfite-treated sweet potatoes.

Water absorption index (WAI), Water solubility index (WSI), and Swelling capacity (SWC)

Water absorption index, water solubility index and swelling capacity are shown in Table 3. 3. PSF and USF had higher WAI than PF and UF at different drying temperatures. PF and UF had lower WAI at 55°C; WAI increased with increasing drying temperature. On the other hand, PSF and USF had lower WAI at 60°C compared to that at 55°C; WAI then increased with increasing drying temperature. The variation in WAI could be due to differences in the degree of engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chains. The increase in water absorption index has always been associated with the loss of starch crystalline structure (Gunaratne & Hoover, 2002)

PSF and USF had lower WSI than PF and UF. All samples had lower WSI at 55°C, except PSF; WSI was lower at 60°C and increased with increasing drying temperature. According to Eliasson and Gudmundsson (1996), the low solubility at low temperature could be attributed to the semi-crystalline structure of the starch granules and the hydrogen bonds formed between hydrogen groups in the starch molecules. As the temperature increased, the solubility increased due to the disruption of starch granules and exposure of hydrophilic groups.

SWC was higher in PSF and USF than in PF and UF. Swelling capacity of PF and UF was lower at 55°C and increased with increasing drying temperature. On the other hand, PSF and USF had lower SWC at 60°C than at 55°C; SWC then increased with increasing drying temperature. Low swelling capacity is caused by the presence of a large number of crystallites, which increase granular stability, thereby

reducing the extent of granular swelling. When starch is gelatinized at a certain temperature, the molecular organization is disrupted within the granules and the starch-water interactions increase, resulting in a substantial increase in the swelling (Eliasson & Gudmundsson, 1996; Gunaratne & Hoover, 2002).

Browning index

Table 3. 3 shows the effects of pretreatment and different drying temperatures on browning index of sweet potato flours. PSF had significantly lower browning index than PF. On the other hand, USF had lower browning index than UF, although the USF and UF values were not significantly different. The browning inhibition by sulfite is caused by the reaction between sulfite ions and quinines, inhibition of PPO activity and depletion of oxygen (Sapers *et al.*, 1997). All flours had higher browning index at 55°C and decreased with increasing drying temperatures. Decrease in browning index may be explained by inactivation of PPO. Elevated temperatures have been reported to deactivate PPO (Akyildiz & Ocal, 2006). Moreover, the browning index of PF and UF highly correlated with the phenolic content compared with that of PSF and USF (data not shown). Browning appears to be a complex process involving several factors including substrate levels, enzymatic activity, presence of ascorbic acid and other inhibitors or promoters influencing the browning reaction, in addition to tissue damage (Zhang *et al.*, 2005).

Table 3. 3. Effect of pre-treatment and drying temperatures on water absorption index, water-solubility index, swelling capacity and browning index of peeled and unpeeled sweet potato flours

Parameter	Drying temperature (°C)											
	55				60				65			
	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]
WAI	$^{a}2.18^{A}$	$^{b}2.53^{B}$	$^{a}2.19^{A}$	$^{b}2.52^{AB}$	$^{a}2.21^{AB}$	$^{bc}2.39^{A}$	$^{b}2.32^{B}$	$^{c}2.44^{A}$	$^{a}2.27^{B}$	$^{b}2.54^{AB}$	$^{a}2.28^{AB}$	$^{c}2.61^{B}$
WSI (%)	$^{b}23.37^{A}$	$^{b}23.35^{B}$	$^{c}25.37^{A}$	$^{a}22.40^{A}$	$^{c}25.75^{B}$	$^{a}23.20^{A}$	$^{c}25.53^{B}$	$^{b}24.68^{B}$	$^{b}27.23^{B}$	$^{ab}25.87^{C}$	$^{b}27.17^{C}$	$^{a}25.06^{B}$
SWC	$^{a}2.85^{A}$	$^{b}3.31^{B}$	$^{a}2.94^{A}$	$^{b}3.27^{A}$	$^{a}2.99^{AB}$	$^{b}3.12^{A}$	$^{ab}3.05^{AB}$	$^{c}3.24^{A}$	$^{a}3.13^{B}$	$^{b}3.36^{B}$	$^{a}3.14^{B}$	$^{b}3.49^{B}$
Browning index	$^{b}0.38^{B}$	$^{a}0.34^{A}$	$^{c}0.43^{C}$	$^{c}0.42^{B}$	$^{b}0.38^{C}$	$^{a}0.33^{B}$	$^{c}0.42^{B}$	$^{c}0.40^{B}$	$^{b}0.31^{A}$	$^{b}0.29^{B}$	$^{a}0.24^{A}$	$^{a}0.23^{A}$

[a-c] Means followed by different in each row are significantly different among flour samples ($p<0.05$)

[A-C] Means followed by different in each row are significantly different among drying temperatures ($p<0.05$)

[1]PF: Flour from peeled sweet potatoes without sulfite treatment.

[2]PSF: Flour from peeled sulfite-treated sweet potatoes.

[3]UF: Flour from unpeeled sweet potatoes without sulfite treatment.

[4]USF: Flour from unpeeled sulfite-treated sweet potatoes.

β-Carotene content

The β-carotene content in sweet potato can vary depending on cultivars, harvesting conditions and maturity (Kosambo *et al.*, 1998). β-Carotene contents of peeled and unpeeled sweet potato flour obtained following pretreatment and at different drying temperatures are shown in Table 3. 4. The β-carotene content in sweet potato flours ranged from 2.51 to 3.49 mg/100g. This value was consistent with previous measurements of 0.5 to 45 mg/100g of β-carotene in field-grown sweet potatoes of selected cultivars (Grabowski, Truong, & Daubert, 2007). However, presently, the values of β-carotene for all flour samples were lower than those previously reported by Grabowski et al. (2007). This may be due to the use of different operating conditions and variety of sweet potato. β-Carotene content is highly variable in sweet potato flour due to cultivars or processing method (Van Hal, 2000). β-Carotene contents of PSF, PF, USF and UF were not significantly different. For all flours, β-carotene content decreased with increasing drying temperatures.

Total phenolic content

The total phenolic content of sweet potato flours ranged from 4.03 to 7.74 mg/100g (Table 3. 4). The phenolic contents of the flour were comparable to that of raw sweet potato flour (4.79 to 5.52 mg/100g) and steamed and kneaded sweet potato flour (< 8 mg/100g) (Huang *et al.*, 2006). UF had higher total phenolic content than PF. Peels are known to be high in phenolic content (Mondy *et al.*, 1988), thus the higher phenolic content of the UF was due to the skin of the sweet potatoes. On the other hand, PSF and USF had higher phenolic content than PF and UF. One possible explanation for this difference is interference of sulfur with the phenolic compounds

during analysis (Akyildiz *et al.*, 2004). Shahidi *et al.* (1992) proposed that the major losses of phenolics during processing occur through the action of oxidative enzymes such as polyphenoloxidase and peroxidases. Total phenolic content decreased at a higher drying temperature for PF and UF whereas it increased for PSF and USF. In this case, total phenolic content could increase due to inactivation of polyphenol oxidase. However, total phenolic content of PSF and PF were not significantly different at higher drying temperature.

Ascorbic acid content

Table 3. 4 shows the effects of pre-treatment and drying temperature on the ascorbic acid content of sweet potato flours. The ascorbic acid content of sweet potato flours ranged from 14.84 to 24.41 mg/100 g, which was similar to previous reports (Huang *et al.*, 2006). USF and UF showed higher retention of ascorbic acid content than PSF and PF. The peel and $NaHSO_3$ solution may act as a shield against heat and oxidation. It is well known that ascorbic acid is relatively unstable to heat, oxygen and light. Drying temperature had a detrimental effect on the retention of ascorbic acid since heated air inherently exposes the products to oxidation, reducing their ascorbic acid content. Ascorbic acid decreased with increasing drying temperature for all samples. However, PSF and USF had higher ascorbic acid content than PF and UF. This investigation demonstrates that sweet potato slices immersed in $NaHSO_3$ solution, before drying, retain more ascorbic acid. The results may indicate that the immersion solution prevents chemical deterioration (Oxidation) by turning ascorbic acid into dehydroascorbic acid.

Table 3. 4. Effect of pre-treatment and drying temperatures on beta-carotene, total phenolic and ascorbic acid contents of peeled and unpeeled sweet potato flours

Parameter (mg/100g)	Drying temperature (°C)											
	55				60				65			
	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]	PF[1]	PSF[2]	UF[3]	USF[4]
Beta-carotene	$^{a}3.43^{C}$	$^{a}3.47^{B}$	$^{a}3.57^{C}$	$^{a}3.79^{B}$	$^{a}3.43^{C}$	$^{a}3.47^{B}$	$^{a}3.57^{C}$	$^{a}3.79^{B}$	$^{a}2.68^{B}$	$^{a}2.73^{A}$	$^{b}2.95^{B}$	$^{b}2.95^{A}$
Total phenolic	$^{a}4.19^{A}$	$^{b}4.70^{A}$	$^{c}6.13^{C}$	$^{d}6.50^{A}$	$^{a}4.59^{A}$	$^{c}5.72^{B}$	$^{b}5.43^{B}$	$^{d}7.74^{C}$	$^{a}4.03^{A}$	$^{a}4.81^{A}$	$^{a}4.23^{A}$	$^{b}7.22^{B}$
Ascorbic acid	$^{a}19.06^{C}$	$^{ab}22.70^{B}$	$^{ab}21.51^{C}$	$^{b}24.41^{B}$	$^{a}16.11^{A}$	$^{c}19.43^{AB}$	$^{b}17.92^{B}$	$^{d}21.24^{AB}$	$^{a}14.84^{A}$	$^{b}18.15^{A}$	$^{a}15.74^{A}$	$^{b}19.34^{A}$

[a-c] Means followed by different in each row are significantly different among flour samples ($p<0.05$)

[A-C] Means followed by different in each row are significantly different among drying temperatures ($p<0.05$)

[1]PF: Flour from peeled sweet potatoes without sulfite treatment.

[2]PSF: Flour from peeled sulfite-treated sweet potatoes.

[3]UF: Flour from unpeeled sweet potatoes without sulfite treatment.

[4]USF: Flour from unpeeled sulfite-treated sweet potatoes

Microstructure

Fig. 3. 1 and Fig. 3. 2 show the scanning electron micrographs of peeled and unpeeled sweet potato slices and flour prepared after pretreatment and at different drying temperatures. The granules from the dried slices of PF and UF (Fig. 3.1a-c and 3.1g-i) were more pronounced than those of PSF and USF slices (Fig. 3.1d-f and 3.1j-l). On the other hand, PSF and USF granules (Fig. 3.2d-f and 3.2j-l) were more aggregated and disrupted than those of PF and UF (Fig. 3.2a-c and 3.2g-i). This variation might be attributed to the internal modification of starch granules through the action of $NaHSO_3$ during processing. These results are in agreement with Hoover and Perera (1999) who reported that potato starch granules are affected by treatments such as NaOH and Na_2SO_4. Wootton and Manatsathit (1984) reported that, under alkali conditions, the inter- and intra-molecular hydrogen bonds of the starch chain can be destroyed, thereby weakening the granular structure. The fusion of granules were higher in PSF and USF (Fig. 3.2d-f and Fig. 3.2j-l) than PF and UF (Fig. 3.2a-c and Fig. 3.2g-i). This could be attributed to the introduction of hydrophilic groups to the starch molecules, which resulted in increase of hydrogen bonding (Singh, Chawla, & Singh, 2004). The PSF and USF starch granules swelled more than PF and UF due to interaction between amylase chains. Svihus, Uhlen, and Harstad (2005) reported that the swelling is accompanied by a loss of polysaccharide, due to the amylase, from the granule structure. It was seen that at higher temperature PSF and USF granules (Fig. 3.2e-f and Fig. 3.2k-l) could be increased the hydrogen bonding than PF and UF (Fig. 3.2b-c and Fig. 3.2h-i) which leads starch to fusion granules.

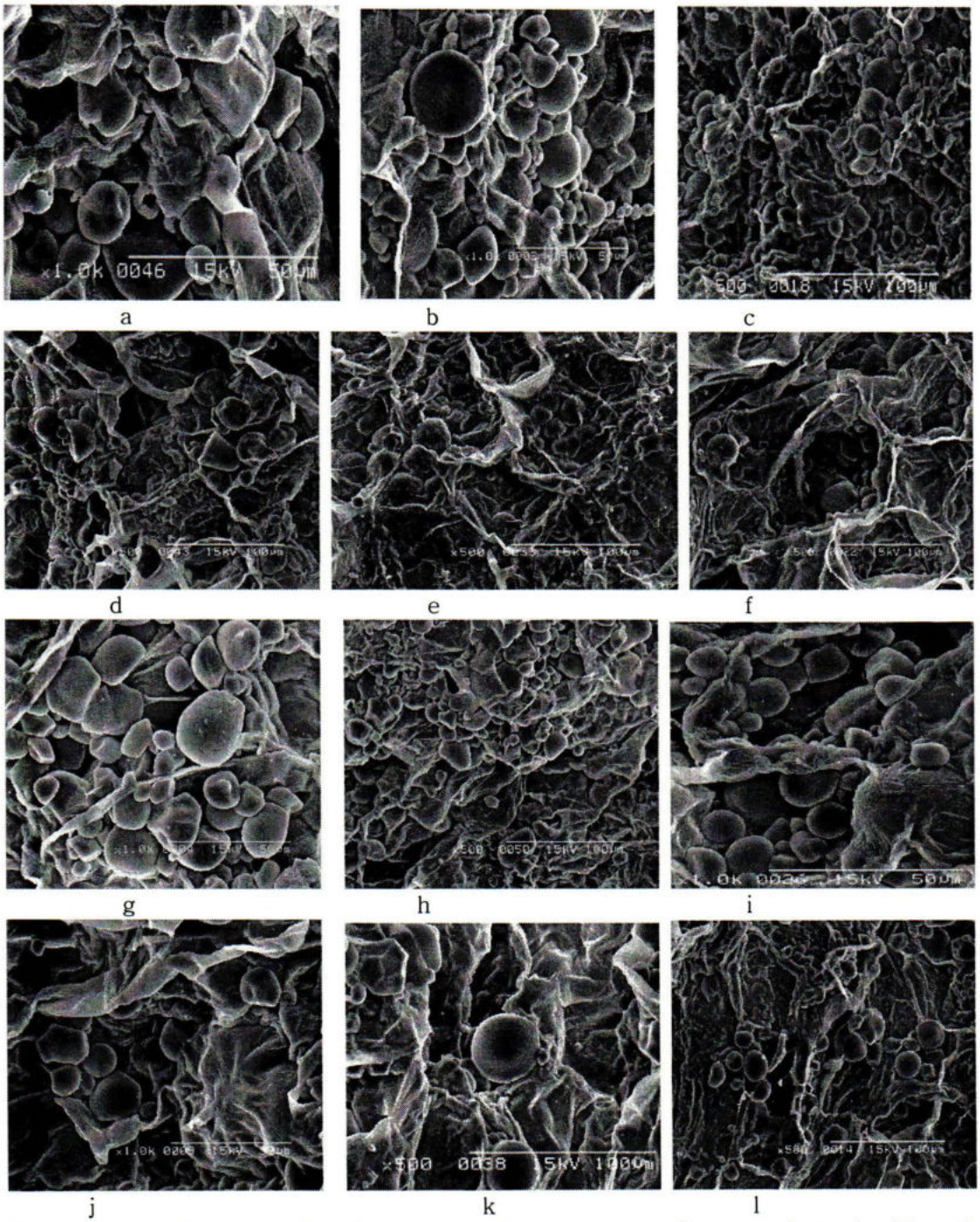

Fig. 3.1. Scanning electronic microstructure of sweet potato slices manufactured with various pretreatment at different drying temperatures. a, b and c: Peeled and dried at 55, 60 and 65°C; d, e, f: Peeled and dried at 55, 60 and 65°C after treatment with $NaHSO_3$ solution. g, h, i: Unpeeled and dried at 55, 60 and 65°C respectively; j k, l: Unpeeled and dried at 55, 60 and 65°C after treatment with $NaHSO_3$ solution.

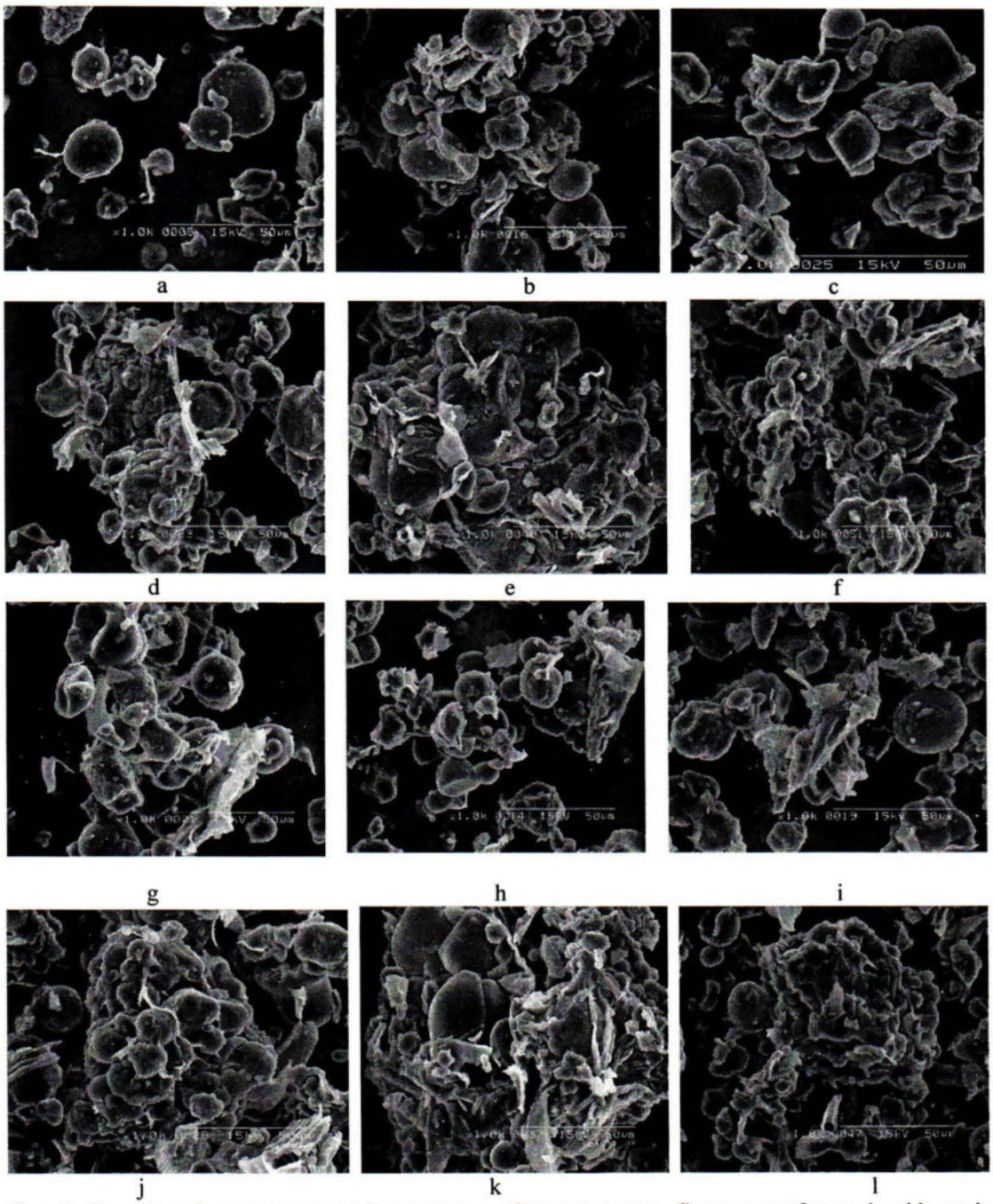

Fig. 3. 2. Scanning electronic microstructure of sweet potato flours manufactured with various pretreatment at different drying temperatures. a, b and c: Peeled flours dried at 55, 60 and 65°C; d, e, f: Peeled flours dried at 55, 60 and 65°C after treatment with $NaHSO_3$ solution. g, h, i: Unpeeled flours dried at 55, 60 and 65°C respectively; j k, l: Unpeeled flours dried at 55, 60 and 65°C after treatment with $NaHSO_3$ solution.

Conclusions

The effect of $NaHSO_3$ treatment on the quality characteristics of sweet potato flour were compared with untreated samples. Sweet potato flour could be used to enhance the quality of food products such as color, flavor, natural sweetness and supplemented nutrients. Therefore, the sulfite treated flour improved the quality of product that is favor to product developers and consumers.

CHAPTER IV

EFFECTS OF PRETREATMENT AND DRYING TEMPERATURE ON PHYSICOCHEMICAL PROPERTIES OF SWEET POTAOTO FLOUR

Abstract

The effects of pretreatments (1% w/v, sodium hydrogen sulfite and 1% w/v, calcium chloride) and drying temperatures (55, 60 and 65°C) on sweet potato flour were investigated. Flour treated with calcium chloride had higher amounts of ascorbic acid and β-carotene (12.54-10.61 and 3.26-3.46 mg/100g, respectively) than that treated with sodium hydrogen sulfite (11.47-9.47 and 3.02-3.43 mg/100g, respectively). Total phenolic content was highest at 65°C treated with sodium hydrogen sulfite (10.44 mg/100g) and calcium chloride (9.52 mg/100g). However, water absorption index and swelling capacity was highest at 60°C treated with calcium chloride (2.82 g/g and 2.96 g/g respectively) whereas treated with sodium hydrogen sulfite (2.71 g/g and 2.85 g/g respectively) was highest at 55°C. Freeze-dried samples treated with $NaHSO_3$ had higher lightness, total phenolic content and water absorption index, while $CaCl_2$-treated samples had higher β-carotene and ascorbic acid. Therefore, the results showed that good quality flour could be produce after soaking in calcium chloride and dried at 65°C .

Introduction

Sweet potatoes (*Ipomoea batatas* L. Lam) are highly nutritious vegetables that are rich in calories and biologically active phytochemicals such as beta-carotene, polyphenols, ascorbic acid and dietary fiber (Van Hall, 2000). Sweet potato consumption is progressively declining, especially in industrialized nations. Thus, one way to expand sweet potato consumption is to develop appealing processed products or alternative uses of sweet potato roots (Van Hall, 2000). Preservation of food by drying is one of the oldest techniques, and has been translated into technology in the last century. The drying process is very important, as it greatly affect the sensory and nutritional characteristics of the end product. Among the different drying processes, freeze-drying generally yields the highest product quality, but its relatively high production cost is a major drawback (Litvin *et al.*, 1998). The relatively cheaper hot air-drying is commonly used in food production, but the longer drying time usually results in inferior product quality. The goals of the drying process can be summarized as the retention of product quality, the reduction of cost (for investment and operation processing), and the protection of the environment (Chou & Chua, 2001). To reduce the drying time and to retain the quality of fruits and vegetables, various pretreatment methods (chemical, thermal and physical) have been investigated (Chen *et al.*, 2005; Dimatteo *et al.*; 2000a; Dimatteo *et al.*, 2000b). Sulfites can reportedly cause health problems such as asthmatic reactions in sensitive individuals (Taylor *et al.*, 1986). Consequently, alternative-processing techniques should be considered to improve the quality of products. Sweet potato is cheaper than other crops, yet this abundant resource is still not properly utilized. Sweet potato roots can be processed into products with longer shelf life and improved characteristics. Sweet potatoes can be

processed into flour, which is less bulky and more stable than the highly perishable fresh root (Collado & Cork, 1999). Processing the sweet potato into flour increases its storage ability and value (Dawkins & Lu, 1991). It can be used as a thickener in soup, gravy, fabricated snacks and bakery products (Van Hal, 2000). It can also be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients. In product development, the final quality of a product is highly dependent on the quality of the raw ingredients used. Therefore, if sweet potato flour is to be incorporated into products, it must be of high quality. Therefore, the objectives of the present investigation were i) to study the effects of pre-treatments on the quality characteristics of sweet potato flour ii) to evaluate the effects of hot air-drying and freeze-drying on sweet potato flour quality iii) to determine the optimum hot air drying temperature for sweet potato flour.

Materials and Methods

Material and sample preparation

Sweet Potato (*Ipomoea batatas* L. Lam cv. Sinhwangmi) was purchased from a local farm and stored at 14°C until used. The sample was washed with tap water to remove dirt and soil and peeled with a hand peeler (Han Sung 27 stainless, Gwanju, Korea) while immersed under water. The samples were then cut into slices (1 mm thickness) using a slicing machine (HFS 350G, Fujee, Korea).

Pre-treatment for dehydration of sweet potatoes

Sweet potatoes slices were treated as follows: a) Dipped in 1% (w/v) calcium chloride ($CaCl_2$) in water at room temperature for 1 min; b) Dipped in 1% (w/v)

sodium hydrogen sulfite ($NaHSO_3$) in water at room temperature for 1 min; c) Dipped in distilled water for 1 min at room temperature (control).

Preparation of sweet potato flour

The slices were dried under different drying conditions after the various pretreatments. The drying conditions were as follows: For freeze-drying, pre-treated sweet potato slices were dried in a freeze-dryer (Model: SFDTSLOK, Samwon Co. Ltd. Seoul, Korea) was set at 1.6 mm Hg with condenser plate temperature -50°C and chamber pressure 5 Pa, for 48 h. For hot air-drying, pre-treated slices were dried on a meshed wire tray using a convection drying oven (Dasol Scientific Co. Ltd. Seoul, Korea) at different temperatures 55, 60 and 65°C for 7-8 hr. The flour (moisture content 6-7%) was obtained by milling the dried slices using a blender (FM-681C, Hanil, Gwangju, Korea), and sieved through an 80-mesh (Seoul, Korea) screen to obtain sweet potato flour.

Proximate compositions of sweet potato flour

Proximate compositions of the sweet potato flour were evaluated. Moisture, crude protein, total ash and crude fat contents of flours were determined by the AOAC (1993). The total sugar content of the samples was determined using a modified procedure of the phenol-sulfuric acid method by Dubois *et al.* (1956).

Hunter color values

The color attributes (Hunter L*, a*, and b* values) were measured with a colorimeter (CM-3500d, Minolta, Japan). $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. The

color change was calculated for the maltodextrin treated samples as compared to the control sample.

Water solubility index (WSI) and water absorption index (WAI)

WSI and WAI were determined according to the method described by Anderson (1982). Two and a half grams of sweet potato flour and 30 mL water were vigorously mixed in a 50-mL centrifuge tube; the mixture was incubated in a water bath at 30°C for 30 min, and centrifuged at 3000 g, for 15 min. The supernatant was collected in a pre-weighed petri dish and the residue was weighed after oven drying over night at 105°C. The amount of solids in the dried supernatant as a percentage of the total dry solids in the original 2.5 g sample was an indicator of water solubility index. WAI was calculated as the weight of the solid pellet remaining after centrifugation divided by the amount of dry sample.

Swelling capacity (SWC)

Swelling capacity was calculated from the following equation describe by Lai and Chang (2004).

SWC= weight of sediment/[dry weight of sample x (1-ws%/100)]

Browning index

Browning index was determined using the method described by Youn and Choi (1996). One gram of dehydrated sweet potato flour was mixed with 40 mL distilled water and 10 mL of 10% trichloroacetic acid solution in a beaker. The mixture was filtered through a Buchner funnel with Whatman No. 2 filter paper. After 2 hr at room

temperature, its concentration was determined based on its absorbance at 420 nm (UV-1201, Shimazu, Japan).

Determination of β-carotene content

β-carotene content was determined using the modified method of Park (1987). Dehydrated sweet potato flour (0.5g) was extracted with a mixture of hexane and acetone (7: 3, 25 mL). The extract was filtered through a Buchner funnel with Whatman No. 1 filter paper. The residue was re-extracted until it became colorless. The filtrates were combined in a separatory funnel and washed with 50 mL distilled water. The water phase was discarded and a pinch of Na_2SO_4 was added as desiccant. The hexane phase was transferred to a volumetric flask. The concentration of carotene in the solution was determined from the absorbance at 450 nm (UV-1201, Shimazu, Japan). The total carotenoid content as β-carotene was determined from the standard curve for prepared β-carotene.

Determination of total phenolics

Total phenolic compounds in the sweet potato flours were determined with Folin-Ciocalteu reagent according to a slightly modified method described by Swain and Hillis (1959). The sample (0.1g) was extracted 3 times with 20 mL of 75% methanol and filtered through Whatman No.2 filter paper. Extracts were combined and concentrated in a rotary vacuum evaporator (Rikakikai Co. Ltd, Tokyo, Japan) at 40°C; the volume was adjusted to 20 mL with 75% methanol. One mL of extract, 5mL of distilled water and 2 mL of 10% Folin-Ciocalteau regent were added into a falcon tube. After 3 minutes at room temperature, 2 mL of 7.5% Na_2CO_3 solution was added

and the sample was diluted to 20 ml with distilled water. Each sample was allowed to stand for 1 hr at room temperature and absorbances were measured at 760 nm (UV-1201, Shimadzu, Japan). Total phenolics were calculated on the basis of standard curves of gallic acid, and expressed as mg gallic acid per 100g.

Ascorbic acid

Ascorbic acid was determined according to a slightly modified method described by Doner and Hickts (1981). Sweet potato flour (2 g) was mixed with 10 mL of 5% metaphosphoric acid solution, and extracted by vortexing at room temperature for 1 min. The mixture was centrifuged for 15 min at 3000 rpm and the supernatant was filtered using a 0.45-μm PVDF syringe filter; 20μL of this sample was injected on-to the liquid chromatograph. Vitamin C was separated by a ODS C18 column (4.6× 250mm, YMC Inc., Kyoto, Japan) using a mobile phase of Acetronitrile: 0.005 M KH_2PO_4 (60:40 v/v) (A) and 100% HPLC water (B), at a flow rate of 1 ml/min. The detection wavelength was 254 nm. Vitamin C content was calculated by comparing the peak area at 254 nm with those of standard solutions and expressed as milligrams per 100g.

Scanning electron microscopy (SEM)

Flour granule morphology was examined by scanning electron microscopy. A Small amount of flour was mounted on the aluminium specimen holder with double-sided tape. The specimen holder was loaded in an Emitech K550 sputter coater (Emitech, UK). It was coated with gold palladium, at a thickness of about 15 nm and viewed under SEM (S-2400 Hitachi, Japan) operated at an accelerating voltage of

10KV.

Statistical analysis

Each experiment included three replications. Data were analysed using a statistical software (SPSS for Windows Version 14.0). A multifactorial analysis of variance was carried out. Individual effects and interactions between the factors have been calculated. Differences were considered to be significant at $P < 0.05$.

Results and Discussion

Proximate composition of sweet potato flours

Proximate compositions of sweet potato flours manufactured with different pretreatments and drying methods are shown in Table 4. 1. The moisture, ash and fat contents of sweet potato flour ranged from 2.20 to 5.66%, 2.15 to 2.95% and 0.50 to 0.75%, respectively, which were similar to those reported by Van Hal (2000). The protein content in sweet potato flour is generally low, ranging from 1.0 to 8.5% (Van Hal, 2000). In this study, protein content ranged from 0.95 to 2.95%. The total sugar content of sweet potato flour ranged from 16.20 to 19.78 g/100g. These results were similar to those of Van Hal (2000) who showed that total sugar content of sweet potato flour ranged from 7.3 to 23 g/100g. Samples treated with $NaHSO_3$ and control samples were not significantly different at any drying temperatures used in this study. The slightly higher sugar content in the $CaCl_2$-treated samples could be due to the complexing effect of $CaCl_2$ on sugars.

Table 4. 1. Effect of pre-treatment on proximate composition of sweet potato flours prepared by different drying methods

Drying condition	Parameter														
	Moisture (%)			Ash (%)			Protein (%)			Fat (%)			Total sugar (%)		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Freeze drying	$^{a}2.36^{D}$	$^{a}2.43^{D}$	$^{b}2.20^{C}$	$^{a}2.88^{A}$	$^{a}2.95^{A}$	$^{a}2.80^{A}$	$^{a}2.31^{B}$	$^{b}1.90^{C}$	$^{c}1.50^{C}$	$^{B}0.64^{a}$	$^{B}0.63^{a}$	$^{B}0.61^{a}$	$^{C}17.42^{b}$	$^{C}17.93^{a}$	$^{C}17.33^{b}$
Hot air-drying at 55°C	$^{c}4.62^{A}$	$^{b}5.36^{A}$	$^{a}5.66^{A}$	$^{b}2.17^{B}$	$^{a}2.30^{B}$	$^{a}2.26^{C}$	$^{b}2.44^{A}$	$^{a}2.53^{A}$	$^{c}1.56^{B}$	$^{A}0.73^{a}$	$^{A}0.75^{a}$	$^{A}0.69^{b}$	$^{D}16.41^{b}$	$^{D}16.78^{a}$	$^{D}16.20^{b}$
Hot air-drying at 60°C	$^{c}4.44^{B}$	$^{b}4.76^{C}$	$^{a}5.23^{B}$	$^{a}2.16^{B}$	$^{a}2.46^{B}$	$^{a}2.50^{B}$	$^{a}1.63^{D}$	$^{a}1.64^{D}$	$^{b}0.95^{D}$	$^{C}0.58^{b}$	$^{B}0.65^{a}$	$^{C}0.50^{c}$	$^{A}19.20^{b}$	$^{A}19.78^{a}$	$^{A}19.14^{b}$
Hot air-drying at 65°C	$^{c}3.95^{C}$	$^{b}4.94^{B}$	$^{a}5.58^{A}$	$^{b}2.16^{B}$	$^{b}2.15^{B}$	$^{a}2.49^{B}$	$^{a}2.05^{C}$	$^{a}2.12^{B}$	$^{b}1.63^{A}$	$^{C}0.55^{b}$	$^{C}0.59^{a}$	$^{C}0.50^{c}$	$^{B}18.58^{b}$	$^{B}18.88^{a}$	$^{B}18.52^{b}$

$^{a-c}$ Means followed by different superscript alphabets in each row are significantly different ($p<0.05$)

$^{A-C}$ Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

All data, expressed in wet basis

1. Soaked in 1% $NaHSO_3$ solution for one min before drying.
2. Soaked in 1% $CaCl_2$ solution for one min before drying.
3. No treatment

Hunter color values

The Hunter color parameters L^*, a^*, and b^* have been widely used to describe color changes during thermal processing of fruit and vegetable products. L^*, a^*, and b^* values of sweet potato flours obtained with different soaking treatments and drying methods are shown in Table 4. 2. The freeze-dried flours produced higher L* values than those dried with hot air; this is probably due to heat exposure during this drying process. Among hot air-dried, samples those treated with $NaHSO_3$ had higher lightness compared to the control and $CaCl_2$-treated samples. This could be due to the retarding of polyphenol oxidase (PPO). Sulfite inhibits PPO through the reaction between sulfite ions and quinines, inhibition of PPO activity and depletion of oxygen (Sapers *et al.*, 1997). Less color loss was observed with increasing drying temperature for all treatments, again possibly due to inactivation of PPO. A strong PPO activity in sweet potato has been reported (Van Hal, 2000). Furthermore, elevated thermal processing has also been reported to inactivate PPO (Dewanto *et al.*, 2002a). The highest L^* value was observed in samples treated with $NaHSO_3$ at 65°C. The Hunter a^* value was higher in hot air-dried samples than in freeze-dried samples. The browning, which was greater in hot air-dried samples, may be responsible for this. Control samples had higher a^* values compared to those treated with $CaCl_2$ and $NaHSO_3$. Hunter b^* values were lower in freeze-dried samples than in those dried with hot air, which might be due to carotenoid loss. The yellow color of sweet potato is attributed to carotenes (Michael & Wilson, 1997). During hot air-drying, control samples had lower b^* values than $CaCl_2$-and $NaHSO_3$-treated samples. Samples treated with $NaHSO_3$ had lower b^* values than $CaCl_2$-treated samples. The decrease in b^* values or yellow color correlates with the loss of β-carotene content during hot air

drying. However, this loss of pigment is not correlated with the b^* values following freeze-drying. Among freeze-dried samples, those treated with $NaHSO_3$ had higher b^* values than $CaCl_2$-treated samples. There may be an interaction between carotenoid degradation and structural changes that occur during soaking with $NaHSO_3$ solution and drying (Lin *et al.*, 1998). The color difference among samples could be best described by the change in ΔE values. The lower ΔE values may be due to loss of phenolic and anthocyanin content.

Table 4. 2. Effect of pre-treatment on Hunter color values of sweet potato flours prepared by different drying methods

Drying condition	Hunter colour values											
	L*			a*			b*			ΔE		
	1	2	3	1	2	3	1	2	3	1	2	3
Freeze drying	$^{A}86.58^{a}$	$^{A}84.94^{b}$	$^{A}84.86^{c}$	$^{D}2.32^{c}$	$^{D}2.59^{b}$	$^{A}3.36^{a}$	$^{C}22.10^{c}$	$^{C}21.74^{b}$	$^{C}21.15^{a}$	$^{C}2.23^{a}$	$^{D}0.973^{b}$	-
Hot air-drying at 55°C	$^{B}83.96^{a}$	$^{D}83.65^{a}$	$^{B}83.85^{a}$	$^{C}3.29^{a}$	$^{C}3.21^{a}$	$^{A}3.37^{a}$	$^{B}26.62^{a}$	$^{B}28.08^{c}$	$^{A}25.20^{a}$	$^{D}1.43^{b}$	$^{C}2.89^{a}$	-
Hot air-drying at 60°C	$^{A}86.55^{b}$	$^{C}83.86^{a}$	$^{AB}84.24^{a}$	$^{B}3.47^{b}$	$^{B}3.28^{c}$	$^{A}3.62^{a}$	$^{B}26.63^{b}$	$^{A}28.86^{c}$	$^{B}24.66^{a}$	$^{B}3.03^{b}$	$^{B}4.23^{a}$	-
Hot air-drying at 65°C	$^{A}86.58^{b}$	$^{B}83.97^{a}$	$^{AB}84.37^{a}$	$^{A}3.82^{a}$	$^{A}3.39^{b}$	$^{A}3.85^{a}$	$^{A}27.53^{b}$	$^{A}28.99^{c}$	$^{B}24.68^{a}$	$^{A}3.60^{b}$	$^{A}4.35^{a}$	-

$^{a-c}$ Means followed by different superscript alphabets in each row are significantly different ($p<0.05$)

$^{A-D}$ Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

1. Soaked in 1% $NaHSO_3$ solution for one min before drying.
2. Soaked in 1% $CaCl_2$ solution for one min before drying.
3. No treatment

Water absorption index (WAI) and Water solubility index (WSI)

Water absorption index and water solubility index are shown in Table 4. 3. The WAI measures the volume occupied by the starch after swelling in excess water, and indicates the integrity of the starch in aqueous dispersion (Mason & Hoseney, 1986). Among freeze-dried samples, the WAI for treated samples were not significantly different. On the other hand, among samples dried with hot air, the control samples had lower WAI than the samples pre-treated with $CaCl_2$ and $NaHSO_3$. Samples treated with $NaHSO_3$ had highest WAI at a drying temperature of 55°C, and WAI decreased with increasing drying temperatures in these samples. However, samples treated with $CaCl_2$ had lower WAI at 55°C that increased with increasing temperatures. Higher WAI is probably due to greater starch swelling capacity. Structural modification of the fiber components may also explain this result (Hashimoto & Grossman, 2003). The molecular structure of the starch, including the crystalline structure and chemical composition, could also influence the water absorption capacity of the flours (Tester & Morrison, 1990). Indeed, based on scanning electron microscopy, pretreated sweet potato flour had different structures (Fig 1). WSI reflects the extent of starch degradation (Cai & Diosady, 1993). Among samples dried with hot air, WSI of the pretreated samples were not significantly different. Control had higher WSI than pre-treated samples. Among freeze-dried samples, those treated with $CaCl_2$ had lower WSI; however, pre-treated and control samples were not significantly different. High WSI means that the starch component was disrupted into broken polysaccharides that contribute to the soluble fraction (Cai & Diosady, 1993).

Swelling capacity (SWC)

The swelling capacities of sweet potato flours are shown in Table 4. 3. The low swelling power is caused by the presence of a large number of crystallites, which increase granular stability, thereby reducing the extent of granular swelling (Hoover & Ratnayake, 2002). When starch is gelatinized at a certain temperature, the molecular organization is disrupted within the granules, and the starch-water interactions increase, resulting in a substantial increase in the swelling (Liu *et al.*, 2003). Among the freeze-dried samples, SWC of treated samples were not significantly different. On the other hand, the hot air-dried samples treated with $NaHSO_3$ had highest SWC at the drying temperature of 55°C, the SWC of these samples decreased with increasing drying temperature. However, samples treated with $CaCl_2$ had lower SWC at 55°C, their SWC increased with increasing temperatures. Moreover, there were no significant differences in the control at various drying temperatures.

Browning index

The effects of different pre-treatments and drying methods on the browning index of sweet potato flours are shown in Table 4.3. Hot air-drying resulted in higher browning index than freeze-drying. Samples treated with $CaCl_2$ and $NaHSO_3$ did not differ significantly at various drying temperatures. A higher degree of browning occurs during hot air drying. During freeze-drying, there is no oxygen in the drying chamber and the main cause of browning can only be the Maillard reaction. During hot air drying, the browning index increases with increasing drying temperature. The highest browning index was found in control samples dried at 65°C. Samples treated with $CaCl_2$ had slightly lower browning compared to the $NaHSO_3$-treated samples.

$CaCl_2$ can reduce browning in dried carrot (Baloch *et al.*, 1981) and is currently in use to reduce browning in tomato slices (Mehdi *et al.,* 2006). Since sulfite is very reactive, its effectiveness decreases as it is lost during storage or becomes damaged, as shown in carrot (Baloch *et al.*, 1987). Calcium may be acting in some manner to block the amino group, such that the latter is restrained from entering into the browning reaction. It is also believed that calcium is capable chelating organic substances that have an alpha amino carboxylic acid (Mehdi *et al.*, 2006).

Table 4. 3. Effect of pre-treatment on water absorption index, water soluble index, swelling capacity and browning index of sweet potato flours prepared by different methods

Drying condition	Parameter											
	WAI (g/g)			WSI (%)			SC (g/g)			Browning index		
	1	2	3	1	2	3	1	2	3	1	2	3
Freeze drying	$^{a}2.20^{B}$	$^{a}2.16^{C}$	$^{a}2.09^{B}$	$^{a}1.97^{B}$	$^{c}1.38^{D}$	$^{b}1.80^{B}$	$^{a}2.25^{C}$	$^{a}2.19^{C}$	$^{a}2.13^{B}$	$^{a}0.20^{C}$	$^{b}0.14^{C}$	$^{a}0.23^{C}$
Hot air-drying at 55°C	$^{b}2.37^{A}$	$^{a}2.55^{A}$	$^{b}2.41^{A}$	$^{c}2.40^{A}$	$^{a}3.17^{C}$	$^{b}2.92^{A}$	$^{a}2.85^{A}$	$^{ab}2.64^{B}$	$^{b}2.50^{A}$	$^{b}0.22^{BC}$	$^{b}0.20^{B}$	$^{a}0.27^{A}$
Hot air-drying at 60°C	$^{b}2.41^{A}$	$^{a}2.82^{A}$	$^{b}2.42^{A}$	$^{c}2.43^{A}$	$^{a}3.38^{B}$	$^{a}2.94^{A}$	$^{b}2.46^{B}$	$^{a}2.96^{A}$	$^{b}2.50^{A}$	$^{b}0.23^{B}$	$^{c}0.20^{B}$	$^{a}0.27^{A}$
Hot air-drying at 65°C	$^{b}2.49^{A}$	$^{a}2.85^{A}$	$^{b}2.44^{A}$	$^{c}2.47^{A}$	$^{a}3.50^{A}$	$^{b}3.18^{A}$	$^{b}2.54^{B}$	$^{a}2.73^{B}$	$^{c}2.45^{A}$	$^{b}0.28^{A}$	$^{b}0.27^{A}$	$^{a}0.39^{B}$

$^{a-c}$ Means followed by different superscript alphabets in each row are significantly different ($p<0.05$)

$^{A-D}$ Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

All data, expressed in wet basis

1. Soaked in 1% $NaHSO_3$ solution for one min before drying.
2. Soaked in 1% $CaCl_2$ solution for one min before drying.
3. No treatment

β-Carotene content

Raw sweet potatoes contain between 0.5 and 45 mg/100g of β-carotene (Purcell & Walter, 1968). The β-carotene content in sweet potato can vary depending on cultivars, harvesting condition and maturity (Kosambo *et al.*, 1998). Freeze-dried samples had lower β-carotene content than hot-air dried samples (Table 4. 4). The heat treatment may have caused this increase due to the breakdown of cellular constituents (Chandler & Schwartz, 1988). Carotene content increased slightly in pretreated samples with increasing drying temperatures. However, carotene content decreased in control samples with increasing drying temperatures. Presumably, the tissue morphology changed, thereby allowing greater penetration of organic solvents into the cells and enhancing the release of carotenes (Chandler & Schwartz, 1988). Microscopic examination of raw sweet potatoes showed β-carotene within the chromoplasts. After heating, the chromoplasts and cell wall were disrupted and pigment droplets formed (Purcell *et al.*, 1969). Control samples had lower β-carotene content than $CaCl_2$- and $NaHSO_3$- treated hot-air dried samples, probably due to greater oxidation in the control samples (Goldman *et al.*, 1983). Among hot air-dried samples, β-carotene content was higher in $CaCl_2$-treated samples than in $NaHSO_3$-treated samples, but did not differ significantly with elevated temperatures. The $CaCl_2$ may have provided a protective effect on oxidation (Lewicki, 1998). Carotene degradation can reportedly be caused by oxidation (Wagner & Warthesen, 1995). The highest β-carotene content was found in samples treated with $CaCl_2$ at 65°C.

Total phenolic content

The total phenolic content of sweet potato flours ranged from 5.24 to 10.44 mg/100g (Table 4. 4). These results are in agreement with Huang *et al.* (2006) who reported that total phenolic contents of sweet potato flour were affected by treatments such as kneading and steaming. Dewanto *et al.* (2002b) also found that the free phenolic content of sweet corn increased with increasing heating temperature and time. However, thermal processing had no effect on the phenolic content of tomato (Dewanto *et al.*, 2002a). In freeze-dried flours, samples treated with $NaHSO_3$ had higher total phenolic content than control and $CaCl_2$-treated samples. The breakdown of cell constituents by the pretreatments may be responsible for this effect. Phenolic or bound phenolic content is released during the breakdown of cellular constituents (Dewanto *et al.*, 2002a). In pretreated, hot air-dried samples, total phenolic content were higher than untreated samples. Samples treated with $NaHSO_3$ total phenolic content increased with increasing drying temperatures. However, treated with $CaCl_2$ and control samples, total phenolic content were dependent on temparature. Total phenolic content was highest in samples treated with $CaCl_2$ and $NaHSO_3$ at 65°C. Treated samples may release more bound phenolic compounds from the breakdown of cellular constituents. The increased number of free hydroxyl phenol groups may also result from the hydrolysis of flavonoid glycosides or the release of cell wall phenolic (Lavelli *et al.*, 1999). The effect of drying temperatures and pretreatments on the structure of sweet potato flour is shown in Fig 1. Clearly, cell disruptions were affected by pretreatments and the drying process.

Ascorbic acid

The effects of different pre-treatments and drying methods on the ascorbic acid content of sweet potato flours are shown in Table 4. 4. The ascorbic acid content of sweet potato flours ranged from 7.60 to 16.79 mg/100g. The ascorbic acid content of sweet potato flours was lower than that reported previously (Huang *et al.*, 2006). The lower acid content found in this study could be attributed to the pre-treatments. In this investigation, the ascorbic acid content of hot air-dried samples was significantly lower than that of freeze-dried samples. The heating process speeds up ascorbic acid oxidation, thus thermal processing often results in loss of vitamin C content in fruits and vegetables (Gregory, 1996). Therefore, the hot air-drying temperatures had a detrimental effect on ascorbic acid retention as heated air inherently exposes the products to oxidation, reducing their ascorbic acid content. $CaCl_2$-treated samples exhibited higher ascorbic acid retention compared to $NaHSO_3$-treated samples; this could be attributed to the protective effect of $CaCl_2$ on oxidation (Lewicki, 1998). Among hot air-dried samples, the highest amount of ascorbic acid was obtained in samples treated with $CaCl_2$ at 55°C. Ascorbic acid is relatively unstable to heat, oxygen and light (Lin *et al.*, 1998). Untreated samples had lower ascorbic acid content than samples treated with $CaCl_2$ and $NaHSO_3$, probably due to more oxidation in the untreated samples (Gregory, 1996).

Table 4. 4. Effect of pre-treatment on beta-carotene, total phenolic and ascorbic acid contents of sweet potato flours prepared by different drying methods

Drying condition	Parameter (mg/100g)								
	Beta-carotene			Total phenolics			Ascorbic acid		
	1	2	3	1	2	3	1	2	3
Freeze drying	$^{b}2.63^{C}$	$^{a}3.11^{C}$	$^{c}2.13^{B}$	$^{a}10.10^{A}$	$^{b}8.49^{C}$	$^{c}7.21^{A}$	$^{a}15.75^{A}$	$^{a}16.79^{A}$	$^{b}14.21^{A}$
Hot air-drying at 55°C	$^{a}3.05^{B}$	$^{a}3.26^{B}$	$^{b}2.68^{A}$	$^{b}8.00^{B}$	$^{a}9.21^{B}$	$^{c}6.74^{A}$	$^{b}11.47^{B}$	$^{a}12.54^{B}$	$^{b}9.24^{B}$
Hot air-drying at 60°C	$^{a}3.40^{A}$	$^{a}3.39^{AB}$	$^{b}2.63^{A}$	$^{a}8.21^{B}$	$^{a}8.32^{C}$	$^{b}7.23^{A}$	$^{b}10.61^{BC}$	$^{a}11.61^{C}$	$^{c}8.57^{B}$
Hot air-drying at 65°C	$^{a}3.43^{A}$	$^{a}3.46^{A}$	$^{b}2.48^{A}$	$^{a}10.44^{A}$	$^{b}9.52^{A}$	$^{c}5.24^{B}$	$^{b}9.47^{C}$	$^{a}10.61^{D}$	$^{c}7.61^{C}$

$^{a-c}$ Means followed by different superscript alphabets in each row are significantly different ($p<0.05$)

$^{A-C}$ Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

All data, expressed in wet basis

1. Soaked in 1% $NaHSO_3$ solution for one min before drying.
2. Soaked in 1% $CaCl_2$ solution for one min before drying.
3. No treatment

Microstructure of sweet potato flours

Fig. 4.1 shows the scanning electron micrographs of sweet potato flour prepared with different pretreatments and drying methods. The morphological features of freeze-dried and hot air- dried granules were similar, although the process conditions and heat treatments differ. In the freeze-dried and the hot air-dried samples, the structures of untreated flour granules were larger than those of pretreated samples. Pretreated sample granules were more disrupted than untreated granules. This variation was attributed to the internal modification of the starch granules through the action of $NaHSO_4$ and $CaCl_2$ during processing. These results are in agreement with Hoover & Perera (1999), who reported that potato starch granules are affected by treatments such as NaOH and Na_2SO_4. Wootton and Manatsathit (1984) reported that, under alkali conditions, the starch chains can destroy inter-and intra-molecular hydrogen bonds, thereby weakening the granular structure. At higher temperatures, pretreated samples (Fig.1i and 1l) progressively lost granular morphology, likely due to gelatinization.

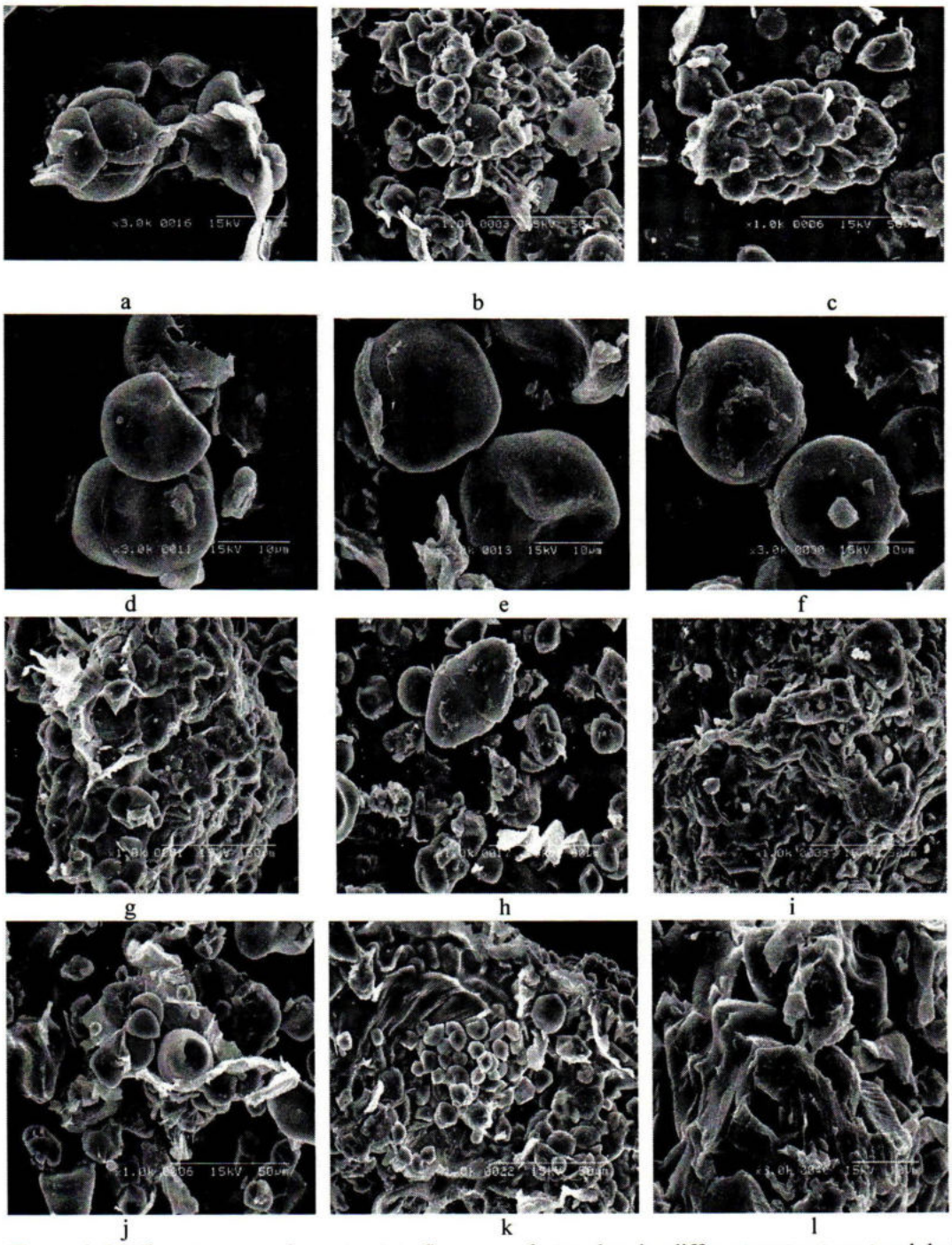

Figure 4. 1. Microstructure of sweet potato flour manufactured under different pretreatment and drying conditions (SEM). a, b, and c: freeze-dried after treatment with distilled water, $NaHSO_3$ and $CaCl_2$. d, e, and f: air-dried at 55, 60 and 65°C after treatment with distilled water. g, h, and i: air-dried at 55, 60 and 65°C after treatment with $NaHSO_3$. j k, and l: air- dried at 55, 60 and 65°C after treatment with $CaCl_2$.

Conclusions

The effects of pre-treatments on the quality properties of sweet potato flours were evaluated. Samples treated with $CaCl_2$ better retained ascorbic acid and β-carotene content than those treated with $NaHSO_3$. Total phenolic content, water absorption index and swelling capacity were dependent on the drying temperature. However, samples prepared by freeze-drying showed significantly higher L^* values and ascorbic acid content than hot air-dried samples. The results also showed that good quality flour could be made from, sweet potato slices dried at 65°C after soaking in calcium chloride solution.

CHAPTER V

EFFECT OF MALTODEXTRIN CONCENTRAITON AND DRYING TEMPERATURE ON QUALITY PROPERTIES OF PURPLE SWEET POTATO FLOUR

Abstract

The effects of drying temperature (55-65°C) and addition levels of maltodextrin (10-30%) on the physicochemical properties and nutritional quality of purple sweet potato flour were investigated. Maltodextrin-added flours had higher L^* values, water soluble index, total phenolic and anthocyanin content than those of untreated flours. However, a^* and b^* value, water absorption index and swelling capacity were depended on drying temperature and maltodextrin concentrations. On the other hand, untreated flours had higher ascorbic acid content compared to the maltodextrin treated flours. Ascorbic acid contents decreased whereas anthocyanin content was not significantly different with increasing drying temperatures. It was found that maltodextrin had positively correlated with phenolic content, anthocyanin, hue angle and water soluble index. However, there was no correlation between quality parameters and glass transition temperature. Therefore, the best quality product was obtained when samples were pretreated with maltodextrin before drying at any drying temperatures.

Introduction

Purple-fleshed sweet potatoes have an intense purple color in their storage roots due to the accumulation of anthocyanins (Terahara *et al.*, 2004). The anthocyanins in purple sweet potato are mono-or-di-acylated forms of cyanidin and peonidin (Yang & Gadi, 2008). Purple sweet potato flour anthocyanins are biologically beneficial, by virtue of their free radical scavenging, and antimutagenic, anticarcinogenic and antihypertensive effects (Oki *et al.*, 2002). Sweet potatoes can be processed into flour, which is less bulky and more stable than the highly perishable fresh root. The flour can be used as a thickener in soup, gravy, fabricated snacks and bakery products (Cho & Yoo, 2008). It can also be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients. Sweet potato flour can substitute for wheat and other cereal flours, especially for individuals diagnosed with celiac disease (Caperuto *et al.*, 2000).

Preservation of food by drying is an oldest technique, which has been translated into technology in the last century. Dehydrated sweet potato has commonly been obtained by hot air drying, which allows rapid and massive processing although it has a great effect on the sensory and nutritional characteristics of the end product. To reduce the drying time and to retain the quality of fruits and vegetables, various pretreatment methods (chemical, thermal and physical) have been investigated (Utomo *et al.*, 2005; Hoover & Miller 1973; Oloruda & Kitson 1977). Among different drying process, freeze-drying and spray drying can give the highest product quality but the relatively high production cost is a major drawback.

Carbohydrates have been used as wall material to microencapsulate food ingredients. The food industry is currently emphasizing the use of natural rather than

synthetic ingredients. Maltodextrins (MDs) are polysaccharides consisted of α (1-4) linked D-glucose produced by acid or enzymatic hydrolysis of corn starch (Grabowski *et al.*, 2006). MDs are water-soluble materials that can protect encapsulated ingredients from oxidation (Shahidi & Han, 1993), and which have been used in different drying regimens including spray-, drum- and freeze-drying (Desobry *et al.*, 1997).). MD also facilitates retention of some food properties such as nutrients, color, anthocyanin and flavor during drying and storage (Desobry *et al.*, 1997; Righetto & Netto, 2005; Dib *et al.*, 2003). Some studies have explored the use of carrier agents such as MD and gum arabic to protect sensitive compounds like vitamin C in fruit juice and to increase product stability in powder (Desobry *et al.*, 1997; Righetto & Netto, 2005; Dib *et al.*, 2003). But, there are no reports on hot air-drying using MD to produce flour from purple sweet potato

Therefore, the objective of the present study was to investigate the effects of drying temperatures and exposure to different MD concentrations on the physicochemical properties and nutritional qualities of purple sweet potato flour.

Materials and Methods

Raw material

Sweet Potato (*Ipomoea batatas* L. Lam cv. Sinjami) was purchased from a local farm and stored at 14°C until used. The samples were washed with tap water to remove dirt and soil and peeled with a 27 stainless hand peeler (Han Sung, Gwangju, Korea). Peeled samples were kept in tap water to prevent enzymatic darkening. The samples were then cut into s1 mm thick slices using a HFS 350G slicing machine (Fujee, Korea).

Sample preparation and Treatment

Sweet potatoes slices were treated by dipping in 10%, 20% and 30% (w/v) Maltodextrin DE 20 (Samyang Genex, Seoul, Korea) in water at room temperature for 2 min. Controls were dipped in distilled water at the same temperature and time conditions.

Preparation of sweet potato flour

The slices were dried with a drying oven (Dasol Scientific, Seoul, Korea) 55, 60 and 65°C for 7~8 h. The flour (moisture content 6%) was obtained by milling the dried slices using a FM-681C blender (Hanil, Gwangju, Korea) and sieveing through an 80-mesh screen (Seoul, Korea) to obtain sweet potato flour.

Proximate compositions of sweet potato flour

Proximate compositions of the sweet potato flour were evaluated. Moisture, crude protein, total ash and fat contents of flours were determined by AOAC method (1998).

Hunter color values

The color attributes (Hunter L*, a* and b* values) were measured with a CM-3500d spectrophotometer (Minolta, Tokyo, Japan). Color change was calculated as $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. The color change was calculated for the maltodextrin treated samples as compared to the control sample.

Water solubility index (WSI) and water absorption index (WAI)

WSI and WAI were determined according to the method described by Anderson (1982). Sweet potato flour (2.5 g) and 30 mL water were vigorously mixed in a 50 mL centrifuge tube; the mixture was incubated in a water bath at 30°C for 30 min, and centrifuged at 3000g for 15 min. The supernatant was collected in a pre-weighed Petri dish and the residue was weighed after oven-drying overnight at 105°C. The amount of solids in the dried supernatant as a percentage of the total dry solids in the original 2.5 g sample was an indicator of water solubility index. WAI was calculated as the weight of the solid pellet remaining after centrifugation divided by the amount of dry sample.

Swelling capacity (SWC)

Swelling capacity was determined according to Lai and Cheng (2004) using the equation

SWC= weight of sediment (ws) / [dry weight of sample x (1-ws%/100)]

Determination of total phenolics content

Total phenolics in the sweet potato flours were determined with Folin-Ciocalteu reagent according to a slightly modified method described by Swain and Hills (1959). The sample (0.1 g) was extracted three times with 20 mL of 75% methanol and filtered through Whatman No.2 filter paper. Extracts were combined and concentrated in a rotary vacuum evaporator (Rikakikai, Tokyo, Japan) at 40°C; the volume was adjusted to 20 mL with 75% methanol. One milliliter of extract, 5 mL of distilled water and 2 mL of 10% Folin-Ciocalteau reagent were added to a Falcon tube. After 3

min at room temperature, 2 mL of 7.5% Na_2CO_3 solution was added and the sample was diluted to 20 mL with distilled water. Each sample was allowed to stand for 1 h at room temperature and absorbance was measured at 760 nm using a model UV-1201 spectrometer (Shimadzu, Tokyo, Japan). Total phenolics were calculated on the basis of the calibration curves of gallic acid, and expressed as mg gallic acid per 100g of sample.

Anthocyanin content

Content of anthocyanins was determined by following the procedures of Proctor (1974) and Huang *et al.* (2006). The sweet potato flour (1 g) was treated with 15 mL HCL-methanol (0.15% HCL: methanol = 15:85) for 4 h. The extract was filtered and its absorbance was determined at 530 nm. Anthocynin content (mg/100g dry weight) was calculated on the basis of the following equation:

$(A \times MW \times DF \times 100) \div (\varepsilon \times W)$

where A = absorbance, MW = molecular weight of cyanidin-3 glucoside chloride ($C_{21}H_{21}ClO_{11}$, 484.84Da), DF = dilution factor, ε = molar absorptivity (34,300), W = sample weight (g)

Ascorbic acid

Ascorbic acid content was determined according to the method of Egoville *et al.* (1998). Sweet potato flour (1 g) was treated with 20 mL of 0.4% oxalic acid at room temperature for 5 min and filtered through Whatman No. 4 filter paper. The filtrate (1 mL) was mixed with 9 mL of 2, 6- dichlorophenolindophenol and the absorbance was read within 15 min at 520 nm against a blank. Ascorbic acid content was calculated

on the basis of the calibration curves of ascorbic acid, and was expressed as mg/kg of ascorbic acid.

Glass transition temperature:

A DSC S-650 differential scanning calorimeter (Scinco, Seoul, Korea) equipped with a thermal analysis station was calibrated using mercury. Approximately 5~10 mg of sample was prepared in aluminum pans. The heating program increased the sample temperature from -70°C to 120°C at a rate of 10°C/min followed by cooling to 30°C at the same rate. Heating and cooling were performed in an atmosphere of nitrogen gas. An empty pan was used as a reference. Glass transition was analyzed using a Differential Scanning Calorimeter (DSC) equipped with Pyris thermal analysis with Infinity PRO software version 4.2.64 (Scinco). Glass transition was taken at the midpoint of the glass transition range. Thermograms were examined for onset temperature (T_{gi}) and end point temperature (T_{ge}) of the glass transition region. The glass transition midpoint (T_{gm}) value was calculated as the average of the onset and end points values and reported as the glass transition temperature (Bhandari *et al.*, 1997).

Scanning electron microscopy (SEM)

Slices and flour granule morphology was examined using SEM. Sample was mounted on an aluminium specimen holder by double-sided tape. The specimen holder was loaded in an Emitech K550 sputter coater (Emitech, East Grinstead, UK). The sample was coated with gold palladium, with a thickness of about 15 nm and viewed using a S-2400 instrument (Hitachi, Tokyo, Japan) operated at an accelerating voltage of 10 KV.

Statistical analyses

All measurements were performed in triplicate for each sample. Data were analyzed using SPSS for Windows Version 14.0 (SPSS, Cary, NC, USA). One way ANOVA was carried out to determine the overall effect of treated, untreated and drying temperatures on each of the assays. Significant differences between the means were estimated using Duncan's multiple range tests. Differences were considered to be significant at $P < 0.05$.

Results and Discussion

Physicochemical properties

Proximate compositions of sweet potato flour prepared with different Maltodextrin (MD) concentrations and drying temperatures are shown in Table 5. 1. Moisture, ash and fat contents of sweet potato flour ranged from 5.16~6.81, 2.49~3.32, and 0.84~1.8%, respectively, which were similar to those reported previously (Van Hal, 2000). Moisture and ash contents of flours from untreated and MD-treated sweet potatoes were similar to each other. During drying, ash content increased with increasing drying temperature. The increased ash content could also be due increased overall sweet potato solid. The protein content in sweet potato flour is generally low, ranging from 1.0~8.5% (Van Hal, 2000). Consistent with this, presently protein content ranged from 2.16~3.22%.

Table 5. 1. Effect of maltodextrin concentration and drying temperatures on proximate analysis of sweet potato flour

Drying temperature (^{0}C)	55				60				65			
Maltodextrin concentration (%)	0	10	20	30	0	10	20	30	0	10	20	30
Moisture (%)	$^{c}6.15^{A}$	$^{a}6.81^{A}$	$^{d}5.74^{A}$	$^{b}6.39^{A}$	$^{b}5.72^{B}$	$^{c}5.43^{B}$	$^{d}5.16^{C}$	$^{a}6.17^{B}$	$^{c}5.20^{C}$	$^{b}5.69^{B}$	$^{b}5.68^{B}$	$^{a}6.18^{B}$
Ash (%)	$^{a}2.84^{B}$	$^{b}2.80^{B}$	$^{c}2.75^{C}$	$^{d}2.49^{C}$	$^{a}3.14^{A}$	$^{d}2.87^{C}$	$^{c}2.96^{B}$	$^{b}3.05^{B}$	$^{b}3.27^{A}$	$^{d}3.13^{A}$	$^{a}3.32^{A}$	$^{c}3.21^{A}$
Protein (%)	$^{d}2.25^{C}$	$^{c}2.53^{A}$	$^{b}2.63^{C}$	$^{a}2.79^{B}$	$^{c}2.70^{A}$	$^{d}2.40^{B}$	$^{b}2.95^{A}$	$^{a}3.05^{A}$	$^{b}2.48^{B}$	$^{c}2.18^{C}$	$^{a}3.22^{A}$	$^{c}2.16^{C}$
Fat (%)	$^{c}1.72^{A}$	$^{b}1.54^{A}$	$^{c}1.76^{A}$	$^{a}1.80^{A}$	$^{c}1.44^{B}$	$^{d}1.28^{B}$	$^{a}1.75^{A}$	$^{b}1.55^{B}$	$^{b}1.16^{C}$	$^{c}0.84^{C}$	$^{d}0.77^{B}$	$^{a}1.31^{C}$

$^{a-c}$ Means followed by different in each row are significantly different among maltodextrin concentrations ($p<0.05$)
$^{A-D}$ Means followed by different in each row are significantly different among drying temperatures ($p<0.05$)

Hunter color values

Hunter color parameters, L^*, a^*, b^* and ΔE have been widely used to describe color change during dehydration of fruit and vegetables products. These values of sweet potato flours were measured with different MD concentrations and drying temperatures (Table 5. 2). MD-treated flours had higher L^* values than did the untreated flours. This observation was similar to that obtained previously (Grabowski *et al.*, 2006). L^* values slightly decreased with increasing MD concentration. In terms of drying temperatures, all flours had higher L^* values at 60°C; with increased drying temperature L^* decreased. This variation may be due to the changes of total phenolic content. Hunter a^* and b^* values were dependent on drying temperature and MD concentrations. The changes of a^* and b^* values may be attributable to formation of polymeric anthocyanin (Yang & Gadi, 2008). Presently, all flours showed color values similar to those reported by Yang and Gadi (2008). The color difference among samples could be best described by the change in ΔE values. The lower ΔE values may be due to loss of phenolic and anthocyanin content.

Table 5. 2. Effect of maltodextrin concentration and drying temperatures on Hunter color values of sweet potato flour

Drying temperature (^{0}C)	55				60				65			
Maltodextrin concentration (%)	0	10	20	30	0	10	20	30	0	10	20	30
L*	$^{c}43.31^{B}$	$^{a}45.58^{C}$	$^{b}44.37^{C}$	$^{a}45.40^{C}$	$^{c}47.36^{A}$	$^{a}51.35^{A}$	$^{b}49.76^{A}$	$^{b}49.44^{A}$	$^{c}42.75^{C}$	$^{a}49.28^{B}$	$^{b}48.80^{B}$	$^{b}48.08^{B}$
a*	$^{a}19.18^{B}$	$^{b}18.84^{B}$	$^{a}19.39^{C}$	$^{c}18.16^{C}$	$^{c}18.84^{C}$	$^{b}18.14^{C}$	$^{a}19.65^{B}$	$^{a}19.67^{A}$	$^{a}21.30^{A}$	$^{d}18.85^{A}$	$^{b}20.08^{A}$	$^{c}19.53^{B}$
b*	$-^{b}6.87^{C}$	$-^{c}6.06^{B}$	$-^{a}7.15^{B}$	$-^{d}5.56^{C}$	$-^{a}7.29^{B}$	$-^{c}6.08^{B}$	$-^{b}6.43^{C}$	$-^{d}5.87^{B}$	$-^{a}7.98^{A}$	$-^{c}6.44^{A}$	$-^{b}7.67^{A}$	$-^{c}6.44^{A}$
ΔE	0	$^{a}2.47^{C}$	$^{b}1.14^{C}$	$^{b}2.09^{B}$	0	$^{a}4.21^{B}$	$^{b}2.68^{B}$	$^{b}2.08^{B}$	0	$^{a}7.13^{A}$	$^{b}6.17^{A}$	$^{c}5.63^{A}$

$^{a-d}$ Means followed by different lowercase letters in each row are significantly different among maltodextrin concentrations ($p<0.05$)

$^{A-C}$ Means followed by different uppercase letters in each row are significantly different among drying temperatures ($p<0.05$)

WAI, WSI and SWC

WAI, WSI and SWC determinations of sweet potato flours are shown in Table 5. 3. MD-treated flours had lower WAI than untreated flours. WAI of untreated flours decreased with increasing drying temperatures. On the other hand, MD-treated flours had lower WAI at 60°C compared to that at 55°C except for 30% MD-treated flour; WAI was lower at 55°C, with WAI subsequently increasing with increasing drying temperature. The variation in WAI could be due to differences in the degree of engagement of hydroxyl groups to form hydrogen and covalent bonds between starch chains. The increase in WAI is associated with the loss of starch crystalline structure (Gunaratne & Hoover, 2002). MD-treated flours had higher WSI than that untreated flours. This variation may be attributed to the fact that MD has superior solubility (Goula & Adamopoulos, 2008). WSI of MD-treated flours increased with increasing MD concentration and drying temperatures for all flours. However, untreated flours had lower WSI at 60°C than at 55°C, with WSI subsequently increasing with increasing drying temperature. According to Eliasson and Gudmundsson (Eliasson & Gudmundsson, 1996), the low solubility at low temperature can be attributed to the semi-crystalline structure of the starch granules and the hydrogen bonds formed between hydrogen groups in the starch molecules. As the temperature increases, the solubility increases due to the disruption of starch granules and exposure of hydrophilic groups. SWC was depended on MD concentration and drying temperature. All samples had lower SWC at 60°C, except for 30% MD-treated flour; SWC was lower at 55°C and increased with increasing drying temperature. Low SWC is caused by the presence of a large number of crystallites, which increase granular stability, thereby reducing the extent of granular swelling. When starch is gelatinized at a

certain temperature, the molecular organization is disrupted within the granules and the starch-water interactions increase, resulting in a substantial increase in swelling (Gunaratne & Hoover, 2002; Eliasson & Gudmundsson, 1996).

Table 5. 3. Effect of maltodextrin concentration and drying temperatures on water absorption index, water-soluble index, and swelling capacity of sweet potato flour

Drying temperature (^{0}C)	55				60				65			
Maltodextrin concentration (%)	0	10	20	30	0	10	20	30	0	10	20	30
WAI	$^{a}2.45^{A}$	$^{b}2.34^{B}$	$^{b}2.36^{A}$	$^{c}2.22^{C}$	$^{a}2.40^{B}$	$^{c}2.23^{C}$	$^{d}2.19^{B}$	$^{b}2.30^{B}$	$^{a}2.39^{B}$	$^{b}2.37^{A}$	$^{c}2.34^{A}$	$^{c}2.33^{A}$
WSI (%)	$^{c}34.65^{B}$	$^{c}34.72^{C}$	$^{b}35.77^{C}$	$^{a}36.94^{C}$	$^{d}32.56^{C}$	$^{c}37.44^{B}$	$^{b}37.50^{B}$	$^{a}40.69^{B}$	$^{c}38.96^{A}$	$^{b}39.62^{A}$	$^{b}39.68^{A}$	$^{a}41.66^{A}$
SWC	$^{a}3.76^{B}$	$^{c}3.59^{B}$	$^{b}3.67^{B}$	$^{d}3.52^{C}$	$^{b}3.57^{B}$	$^{b}3.59^{B}$	$^{c}3.46^{C}$	$^{a}3.89^{B}$	$^{c}3.88^{A}$	$^{a}4.00^{A}$	$^{c}3.86^{A}$	$^{b}3.93^{A}$

$^{a-c}$ Means followed by different letters in each row are significantly different among maltodextrin concentrations ($p<0.05$)

$^{A-C}$ Means followed by different letters in each row are significantly different among drying temperatures ($p<0.05$)

Anthocyanin contents

Table 5.4 shows the anthocyanins content of sweet potato flours treated with different concentrations of MD and different drying temperatures. The anthocyanin content of the flours with treatment of different MD concentrations and drying temperatures ranged from 35.98~41.18 mg/100 g. The content of anthocyanin was much similar than that of steamed or kneaded flours (Huang *et al.*, 2006). MD-treated flours had higher anthocyanin contents than untreated flours. These results are consistent with a previous study (Delgado-Vargas *et al.*, 2000) that reported anthocyanin from pomace was increased by encapsulation with DE20 MD. The same study further reported that MD could stabilize the anthocyanin pigment due to reduction of water activity. Presently, anthocyanin content increased with increasing drying temperatures for all samples, even though the values were not significantly different. This might be due to much higher amounts of acylated anthocynins present in flour samples. Giusti and Wrolstad (2003) indicated that acylated anthocynin exhibits unusual stability in neutral or weakly acidic media. Acylation improves the stability of anthocyanins through intermolecular copigmentation (Giusti & Wrolstad, 2003).

Total phenolic content

The total phenolic content of sweet potato flours ranged from 9.74~12.23 mg/100 g (Table 5. 4). The phenolic contents of the flours were comparable to that of raw sweet potato flour, and steamed and kneaded sweet potato flour (Huang *et al.*, 2006). MD-treated flours had higher total phenolic content as compared to untreated flour. Possible explanations for this difference are interference of MD with phenolic

compounds during analysis (Delgado-Vargas *et al.*, 2000) and that, in untreated samples, some phenolic compounds were more hydrolyzed or oxidized than in treated samples because dispersions were prepared in the presence of ambient oxygen. Shahidi and Han (1993) reported that water-soluble MD protects encapsulated ingredients from oxidation. Presently, total phenolic content was unaltered or slightly decreased with increasing MD concentration. The changes of total phenolic content may be attributed to the destruction of active compounds. Total phenolic content decreased at a higher drying temperature for untreated flour, whereas it increased for MD-treated flours. This may reflect changes in the phenolic composition and contents that might occur upon MD addition and drying. Laine *et al.* (2008) demonstrated that phenolic compounds such as flavonols may form complexes with polysaccharides such as starch, and that the affinity of phenolics to polysaccharides depends on water solubility, molecular size, conformational mobility and shape of the polyphenol.

Ascorbic acid content

As shown in Table 5.4 MD concentrations and drying temperatures affected the ascorbic acid content of sweet potato flours. The ascorbic acid content of sweet potato flours ranged from 10.92~22.08 mg/100 g, similar to previously reported values (Huang *et al.*, 2006). Untreated flours had a higher retention of ascorbic acid than MD-treated flours. The ascorbic acid content was unaltered or slightly decreased with increased MD concentration. These results agree with a previous study (Grabowski *et al.*, 2006) that reported MD addition decreased the overall sweet potato solids, decreasing the amount of vitamin C. Drying of sweet potato flour decreased the ascorbic acid decreased. It is well-known that ascorbic acid is relatively unstable to

heat, oxygen and light. Drying temperatures had a detrimental effect on the retention of ascorbic acid since heated air inherently exposes the products to oxidation, reducing their ascorbic acid content (Lin *et al.*, 1998).

Table 5. 4. Effect of maltodextrin concentration and drying temperatures on anthocyanin content, total phenolic and ascorbic acid content of sweet potato flour

Drying temperature(^{0}C)	55				60				65			
Maltodextrin concentration (%)	0	10	20	30	0	10	20	30	0	10	20	30
Anthocyanin	$^{b}35.98^{A}$	$^{a}38.99^{A}$	$^{a}39.38^{A}$	$^{a}39.90^{B}$	$^{a}36.87^{A}$	$^{ab}36.84^{B}$	$^{ab}39.74^{A}$	$^{ab}41.04^{A}$	$^{b}36.68^{A}$	$^{a}40.20^{A}$	$^{a}39.9^{A}$	$^{a}41.18^{A}$
Total phenolic	$^{b}9.74^{B}$	$^{a}11.76^{B}$	$^{a}11.97^{B}$	$^{a}11.10^{B}$	$^{b}10.04^{A}$	$^{a}11.50^{A}$	$^{a}11.16^{B}$	$^{a}11.37^{B}$	$^{b}9.55^{B}$	$^{a}12.24^{A}$	$^{a}12.11^{A}$	$^{a}12.23^{A}$
Ascorbic acid	$^{a}22.08^{A}$	$^{a}20.35^{A}$	$^{a}21.17^{A}$	$^{c}18.42^{A}$	$^{a}20.92^{A}$	$^{ab}19.65^{A}$	$^{a}20.43^{A}$	$^{c}18.24^{A}$	$^{a}14.47^{B}$	$^{b}11.90^{B}$	$^{b}12.20^{B}$	$^{c}10.92^{B}$

$^{a-c}$ Means followed by different letters in each row are significantly different among maltodextrin concentrations ($p<0.05$)

$^{A-C}$ Means followed by different letters in each row are significantly different among drying temperatures ($p<0.05$)

Correlation

Table 4. 5 shows Pearson's correlation coefficients among all quality attributes of spray dried sweet potato flour. Mondy and Gosselin (1988) found levels of phenols to be associated with the color change, particularly lightness. L^* values were positively correlated with MD and phenolic content. However, ΔE values were highly correlated with phenolic and anthocyanin contents. According to correlation analysis WAI and WSI were negatively and positively correlated with MD, respectively. Anthocyanin and total phenolic were highly correlated with MD.

Table 5. 5. Pearson's correlation coefficient of among quality attributes

	Temperature	L	a	b	Hue	Phenol	WSI	WAI	SWC	Anthocyanin	Vitamin C	T_g
Maltodextrin		0.35*	-0.11	0.34*	0.32*	0.63***	0.48**	-0.44**	0.45	0.77***	-0.41**	-0.07
Temperature		-0.04	0.31	-0.46**	0.01	0.11	0.13	0.11	0.19	0.06	-0.17	-0.17
L			-0.32*	0.049***	0.31	0.48**	0.28**	-0.34**	-0.04	0.78***	-0.04	-0.05
a				-0.42**	0.24	0.11	0.44	-0.08	0.23	-0.09	-0.25	-.000
b					-0.27**	-0.07	-0.58***	-0.72	-0.55***	-0.04	-0.46	0.18
Hue						0.54***	0.41**	-0.37	0.02	0.80***	-0.11	-0.04
Phenol							0.16	-0.07	0.07	0.44*	-0.18	0.16
WSI								-0.33*	0.06	0.44**	-0.32*	0.02
WAI									0.03	-0.15	-0.08	-0.27
SWC										0.25	-0.32*	-0.18
Anthocyanin											-0.146	-0.12
Vitamin C												0.21

*, **, *** = significant at p<0.05, p<0.01and p<0.001respectively

Glass transition temperature

The thermograms of air-dried untreated and MD-treated sweet potato flours at 55, 60, and 65°C are shown in Figs. 5. 1. Glass transition temperatures of treated and untreated flours were approximately 37.5–38.5°C. However, presently, the values of glass transition temperature for all flour samples were lower than those previously reported (Grabowski *et al.*, 2006). This may be due to the use of different operating conditions and variety of sweet potato. Since no clear differences were observed between T_g of samples obtained with and without MD and using different drying temperatures beyond those due to variable moisture content. Small difference of T_g values for MD pre-treated samples can be explained by gain solutes. Telis and Sobral (2001) observed only small differences between T_g of fresh and osmotically-treated tomato, and attributed this result to the short time adopted for the osmotic treatment, which led to low solute gain. Similarly, Del Valle *et al.* (2001) suggested the same behavior was responsible for small differences in T_g resulting from osmotic treatment of apple cylinders in sucrose solutions. Slade and Levine (1991) reported that the addition of sugar resulted in increased mobility of starch mixtures leading to decreased T_g of the amorphous starch-sugar-water matrix. We found no relationship between glass transition temperatures and quality attributes in sweet potato flours. To the best of our knowledge, this is the first report indicating the effect of different MD concentrations and hot air drying temperatures on glass transition temperature in purple sweet potato flour.

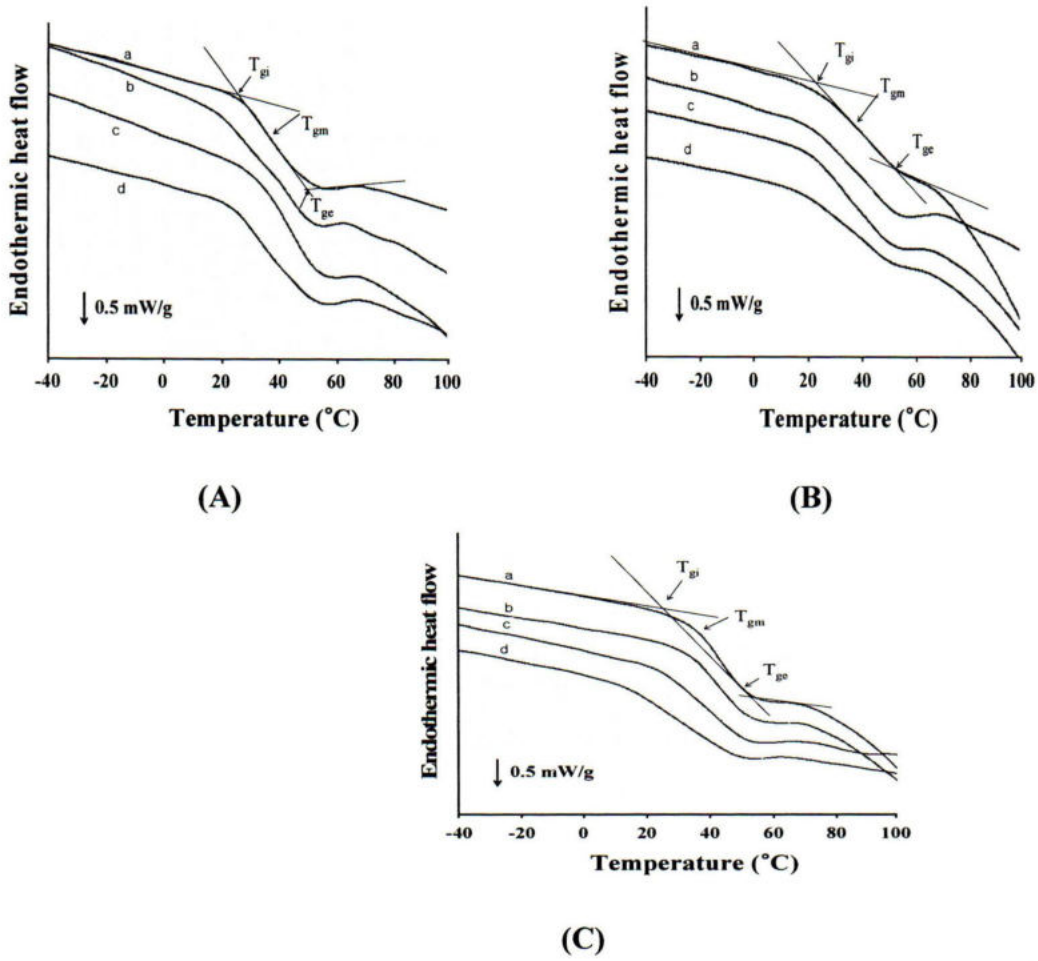

Figure 5. 1. Differential scanning calorimetry (DSC) thermographs showing the glass transition temperature of sweet potato flour with different drying temperature and maltodextrin concentration: A) air-dried at 55°C, and maltodextrin concentration a) 0% b) 10% c) 20% d) 30%. B) Air-dried at 60°C, and maltodextrin concentration a) 0% b) 10% c) 20% d) 30%. C) Air-dried at 65°C, and maltodextrin concentration a) 0% b) 10% c) 20% d) 30%.

Microstructure

Fig. 5.4 shows SEM results of sweet potato flour prepared with different concentrations of MD and using different drying temperatures. The granules from the MD-treated flour were more disrupted than those of untreated flour. This variation might be attributed to the interaction between MD and polysaccharides present in sweet potatoes. At higher drying temperatures, MD-treated flour was more disrupted as compared to lower drying temperatures. This could weaken molecular interactions at elevated temperature. These results agreement with the observations of Grabowski *et al.* (2006), who reported that potato starch granules are disrupted through interaction between MD and polysaccharides present in sweet potatoes

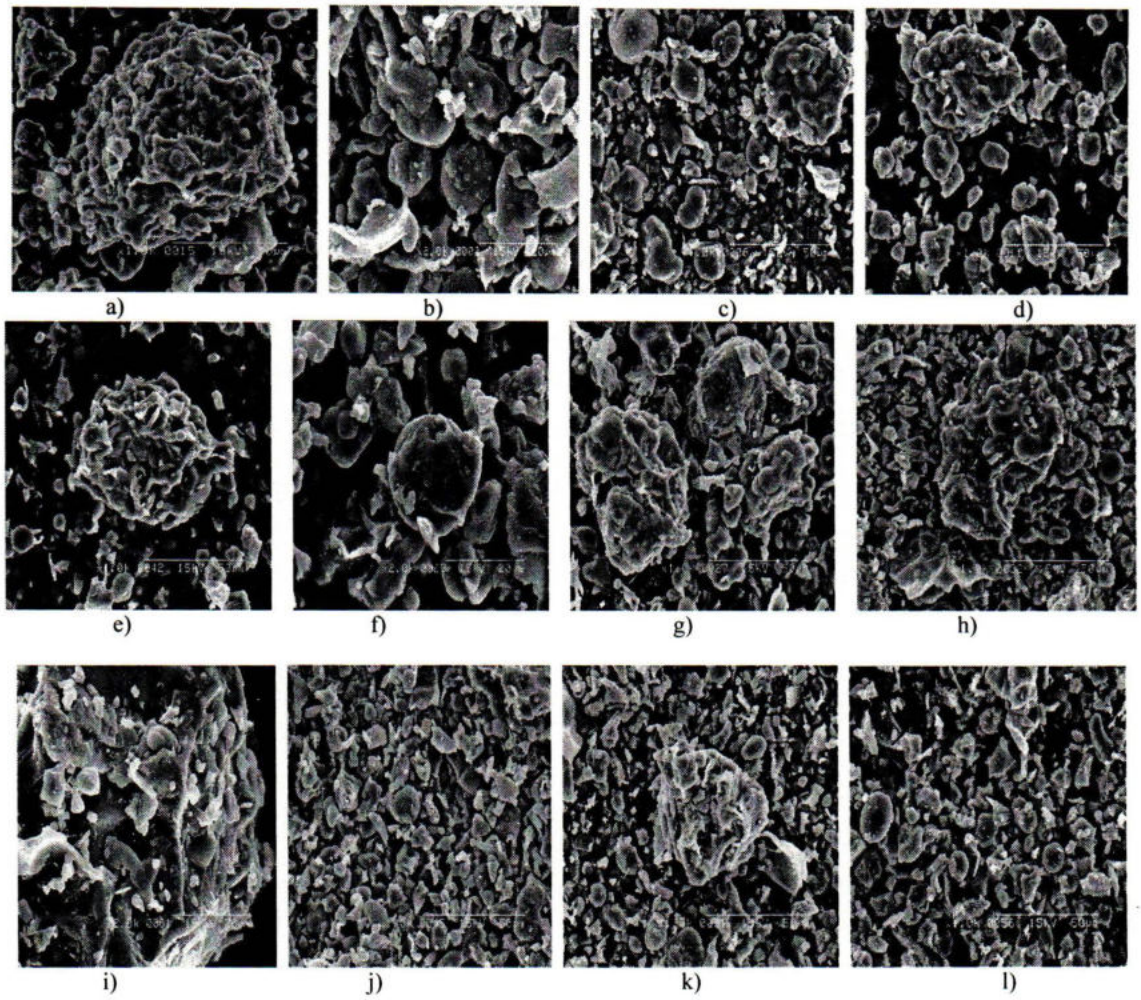

Figure 5. 2. Microstructure of sweet potato flours treated with different concentrations of maltodextrin and drying temperatures.
a, b, c and d: air-dried at 55°C after treatment with different concentration of maltodextrin 0, 10, 20, 30%, respectively. e, f, g and h: air-dried at 60°C after treatment with different concentration of maltodextrin 0, 10, 20, 30%, respectively i, j k and l: air-dried at 65°C after treatment with different concentration of maltodextrin 0, 10, 20, 30%, respectively.

Conclusions

A potential influence of MD treatment on quality characteristics of sweet potato flours were compared to untreated flour. The nutrient composition of MD-treated flour could be used to make a higher quality product that would be more attractive to product developers and consumers.

CHAPTER VI

IMPACT OF ALPHA AMYLASE AND MALTODEXTRIN ON PHYSICOCHEMICAL, FUNCTIONAL AND ANTIOXIDANT PROPERTIES OF SPRAY DRIED PURPLE SWEET POTATO FLOUR

Abstract

This investigation was to evaluate the effect of various levels of maltodextrin (30 and 50 g kg^{-1} w/v), amylase (3 and 7 g kg^{-1} puree) and combined with matodextrin and amylase on the physicochemical, functional and antioxidant capacity of spray dried purple sweet potato flours. Amylase and amylase with maltodextrin treated flours had higher anthocyanin and total phenolic content than control and maltodextrin treated flours. However, antioxidant capacity was higher in control and maltodextrin treated flours compared to the amylase and amylase with maltodextrin treated flours. Control had higher water absorption index and lower water solubility index compared to the maltodextrin and combined with amylase and maltodextrin treated flours. On the other hand, maltodextrin increased whereas alpha-amylase decreased the glass transition temperature. In respect to morphology, the particles of amylase treated flours were smaller than control and maltodextrin treated flours. The results showed that good quality flour could be prepared by combining with 30 g kg^{-1} maltodextrin and 7 g kg^{-1}amylase treatment.

Introduction

Purple-fleshed sweet potatoes have intense purple color in the storage roots due to the accumulation of anthocyanins (Terahara *et al.*, 2004).The anthocyanins in purple sweet potato are mono- or- di-acylated forms of cyanidin and peonidin (Yang & Gadi, 2008). The purple sweet potato flour anthocyanins possess biological functions such as scavenging free radicals, antimutagenicity, anticarcinogen activity and antihypertensive effect (Oki *et al.*, 2002). Sweet potatoes can be processed into flour, which is less bulky and more stable than the highly perishable fresh root. Flour can be used as a thickener in soup, gravy, fabricated snacks and bakery products. It could be used to enhance food products through color, flavor, natural sweetness and supplemented nutrients.

Spray drying is a process widely used to produce fruit juices powders and provided powder with good quality, low water activity and easier transport and storage (Abadio *et al.*, 2004; Cano-Chauca *et al.*, 2005; Quek *et al.*, 2007). Fruit juice powders obtained by spray drying may have some problems in their properties, such as stickiness, hygroscopicity and solubility due to the presence of low molecular weight sugars and acids, which have low glass transition temperature (Bhandari *et al.*, 1997). Parts of these problems can be solved by the addition of some carrier agents, like maltodextrin (MD), polymers and gums which increase the glass transition temperature of the products during spray drying. Additionally, MD was added to the puree in various concentrations to act as a drying aid. MD facilitates product recovery by raising the glass transition temperature of the product to reduce stickiness and partially encapsulating the material (Abadio *et al.*, 2004; Cano-Chauca *et al.*, 2005; Quek *et al.*, 2007). Maltodextrin are water-soluble materials and protect encapsulated

ingredient from oxidation (Rodríguez-Hernández *et al.*, 2005). It has also been found maltodextrin has more capable of retention of some food properties such as nutrients, color and flavor during spray-drying (Rodríguez-Hernández *et al.*, 2005). Alpha-amylase action was used as pre drying treatment to reduce viscosity. Amylase reduces the viscosity of sweet potato puree by hydrolyzing starch molecules to dextrin (Grabowski *et al.*, 2006). Enzymatic treatment is known to enhance the extractability of phenolic and anthocyanin components from the cell wall matrix (Ramadan & Moersel, 2007).

Maltodextrins have been used in spray drying of various sugar-rich foods such as blackcurrant, raspberry and apricot juice. Recently, grabowski *et al.* (2006) demonstrated of yellow color sweet potatoes can be spray dried using different concentration maltodextrin and amylase treatment. However, there are no reports on spray drying using maltodextrin and amylase to produce flour and the affect of anthocyanin, total phenolic content and antioxidant activity of purple fleshed sweet potato. Therefore, the objective of the present study was to investigate the effects of various levels of maltodextrin, alpha-amylase and their combination on the physicochemical, functional properties and antioxidant activity of spray dried purple sweet potato flour.

Materials and Methods

Raw material

Sweet Potato (*Ipomoea batatas* L. Lam cv. Sinjami) roots were harvested in early December 2008 and randomly selected healthy roots from a local farm in South Korea and stored at 14°C until used. Alpha-amylase purchased from Novozymes (Fungamyl

800L, activity 800FAU/g, Novozymes, Bagsvaerd, Denmark) which has optimum pH 5 and temperature 50 to 60°C. Maltodextrin (MD) with a dextrose equivalent DE20 was obtained from (Samyang Genex, South Korea).

Puree production

The samples were obtained from storage and washed with tap water and peeled with a hand peeler (Han Sung 27 stainless, Gwangju, Korea). The samples were then cut into slices (2-3 mm thickness) by a sharp knife. The slices were then blended using a laboratory electrical blender (Molel no: Blixer 5 plus, Robot coupe, USA) to get puree. During puree making, water was added to the slices which adjusted dry matter content to 18% ± 1. After puree making, the samples were stored at -24°C until use.

Sample preparation and spray drying

Maltodextrin (30 g $kg^{-1}$and 50 g kg^{-1}) was added according to the weight of puree. For Alpha-amylase puree was covered with aluminum foil and continuously stirred on a stirrer plate. The enzyme (3 g $kg^{-1}$and 7 g kg^{-1}puree) was added when the puree temperature reached 55 to 60°C. The amylase was allowed to act for 30 min. Then the treated puree was heated in water 90±4°C for 5 min to inactivate the enzyme. For the combination amylase and MD treatment, the puree was treated with amylase and then the enzyme was inactivated. MD was thoroughly mixed with the treated puree before spray drying. The spray drying was conducted in a mini spray dryer EYELA, SD-1000 (Rikakikai, Tokyo Japan) under the following operational conditions: Solid content 11±0.5%, Inlet air temperature 150°C, outlet air temperature 85±4°C, rotary

atomizer14 x10kpa and blower rate 0.60±0.2 m^3/min. water was added to the puree and puree-MD mixture to maintain the solid content .

Proximate compositions of sweet potato flour

Moisture and hygroscopicity

Moisture contents of flours were determined by the AOAC (1998). Hygroscopicity was determined according to the method proposed by Cai and Corke (2000). Samples of each powder (approximately 1 g) were placed at 25°C in an airtight container filled with NaCl saturated solution (70%RH). After one week, samples were weighed and hygroscopicity was expressed as g kg^{-1}.

Hunter color values

The color attributes (Hunter L*, a*, and b* values) were measured with a spectrophotometer (CM-3500d, Minolta, Japan). Color change was calculated as $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. The color change was calculated for the treated samples as compared to the control sample

Water solubility index (WSI) and water absorption index (WAI)

WSI and WAI were determined according to the method described by Anderson (1982).Two and a half grams of sweet potato flour and 30 mL water were vigorously mixed in a 50-mL centrifuge tube; the mixture was incubated in a water bath at 30°C for 30 min, and centrifuged at 3000 g for 15 min. The supernatant was collected in a pre-weighed petri dish and the residue was weighed after oven-drying over night at 105°C. The amount of solids in the dried supernatant as a percentage of the total dry

solids in the original 2.5 g sample was an indicator of water solubility index. WAI was calculated as the weight of the solid pellet remaining after centrifugation divided by the amount of dry sample.

Swelling capacity (SWC)

Swelling capacity was determined according to Lai and Cheng (2004) using the equation

SWC= weight of sediment / [dry weight of sample x (1-ws%/100)]

Determination of total phenolics content

Total phenolics in the sweet potato flours were determined with Folin-Ciocalteu reagent according modified method described by Swain and Hills (1959). The sample (0.1 g) was extracted 3 times with 20 mL of 75% methanol and filtered through Whatman No.2 filter paper. Extracts were combined and was concentrated in a rotary vacuum evaporator (Rikakikai Co. Ltd, Tokyo, Japan) at 40°C; the volume was adjusted to 20 mL with 75% methanol. One mL of extract, 5mL of distilled water and 2 mL of 10% Folin-Ciocalteau reagent were added into a falcon tube. After 3 minutes at room temperature, 2 mL of 7.5% Na_2CO_3 solution was added and the sample was diluted to 20 ml with distilled water. Each sample was allowed to stand for 1 hr at room temperature and absorbances were measured at 760 nm (UV-1201, Shimadzu, Japan). Total phenolics were calculated on the basis of the calibration curves of gallic acid, and expressed as mg gallic acid per 100 g.

Anthocyanins content

Content of anthocyanins was determined by following the procedures of Proctor (1974) and Huang *et al.* (2006)The sweet potato flour (1 g) was treated with 15 ml HCL-methanol (0.15% HCL: methanol = 15:85) for 4 hr. The extract was filtered and its absorbance was determined at 530 nm.

The Anthocynin content was calculated on the basis of the following equation:

Anthocyanins content (mg $kg^{-1}$of dry matter)

$= A \times MW \times DF \times 100/ (\varepsilon \times W)$

Where A = absorbance, MW = molecular weight of cyaniding-3glucoside chloride ($C_{21}H_{21}ClO_{11}$, 484.84Da), DF = dilution factor, ε = molar absorptivity (34,300), W = sample weight (g)

Ascorbic acid content

Ascorbic acid content was determined according to the method of Klein and Perry (1982). The sweet potato flour (100 mg) was treated with 10 ml of 1% metaphosphoric acid at room temperature for 30 min and filtered through Whatman No. 4 filter paper. The filtrate (1 ml) was mixed with 9 ml of 2, 6-dichlorophenolindophenol and the absorbance was within 15 min at 520 nm against a blank. Ascorbic acid content was calculated on the basis of the calibration curves of ascorbic acid, and was expressed as mg kg^{-1}.

Antioxidant capacity

Antioxidant capacity was determined by the DPPH (1, 1-diphenyl-2- picrylhydrazyl) assay according to the method reported by Masuda et al. (2002) with some

modifications. Sweet potato flour was diluted 10-fold in methanol and then 2 ml sample was mixed with 2 ml on freshly prepared methanolic solution containing 0.1mM of DPPH solution. The mixture was shaken vigorously and left to stand for 30 min in the dark. The absorbance was then measure at 517 nm. The DPPH scavenging activity was calculated as follows:

[1- (absorbance of sample / absorbance of blank)] × 100.

Glass transition temperature:

A differential scanning calorimeter (DSC S-650, Scinco, Seoul, Korea) equipped with a thermal analysis station. The instrument was calibrated using mercury. Approximately 5 to 10 mg of sample were prepared in aluminum pans. The heating program increased the sample temperature from -70°C to 120°C at a rate of 10°C/min followed by cooling to 30°C at the same rate. Heating and cooling were performed in an atmosphere of nitrogen gas. An empty pan was used as a reference. Glass transition was analyzed using a Differential Scanning Calorimetry DSC euiped with Pyris thermal analysis with Infinity PRO software version 4.2.64 (Scinco, Seoul, Korea). Glass transition was taken at the midpoint of the Glass transition range. Thermograms were examined for onset temperature (T_{gi}) and end point temperature (T_{ge}) of the glass transition region. The glass- transition midpoint (T_{gm}) value was calculated as the average of the onset and end points values and reported as the glass transition temperature (Bhandari *et al.*, 1997).

Scanning electron microscopy (SEM)

Slices and flour granule morphology was examined using a scanning electron microscope. Sample was mounted on the aluminium specimen holder by double-sided tape. The specimen holder was loaded in a Emitech K550 sputter coater (Emitech, UK). It was coated with gold palladium, with a thickness of about 15 nm and viewed under SEM (S-2400 Hitachi, Japan) operated at an accelerating voltage of 10KV.

Statistical analysis

All measurements were performed in triplicate for each sample. Analysis of variance (ANOVA), Duncan's multiple range tests (at $p<0.05$) and regression analysis were performed by using the SPSS.

Results and Discussion

Moisture content and hygroscopicity:

Moisture contents and hygroscopicity of sweet potato flour ranged from 770 to 857 g kg^{-1} and 2.8 to 5.2 g kg^{-} respectively (Table 6.1). Moisture content decreased with increasing maltodextrin concentration and increased at high levels of amylase treatment. This observation was similar to that obtained by Grabowski *et al.* (2006) He also reported that amylase treatment as water more interacts with dextrins created by alpha-amylase action. The hygroscopic moisture of spray dried flours treated with maltodextrin had lower higroscopicity than control samples. This is due to the fact that maltodextrin as a carrier and coating agent could reduce hygroscopicity of the flours. These results are in agreement with Tonon *et al.* (2008) He showed that spray drying of acai powder hygroscopicity decrease by increasing the amount of added maltodextrin. Hygroscopicity of the flours increased at high levels of amylase treatment. The reasons might be related to lower glass transition temperature. According to Goula and Adamopoulos (2008) hygroscopocity at high-sugar dehydrated powdered are attributable to the glass transition temperature.

Hunter Color values:

The Hunter color parameters L^*, a^*, b^* and ΔE values of sweet potato flours were measured with different concentration of maltodextrin and amylase treatment (Table 6. 1). Maltodextrin and amylase treated flours had higher L^* values than the control. This observation was similar to that obtained by Grabowski *et al.* (2006). This variation may be due to the changes of total phenolic and anthocyanin content. Phenols have been associated with the color changed particularly lightness as reported by Mondy

and Gosselin (1988). Hunter a^* values of maltodextrin and amylase treated flours were slightly lower than control samples. However, b* values were higher in amylase treated flours compared to control and maltodextrin treated flours. The changes of a^* and b^* values may be attributed to the variation of phenolic and anthocyanin content (Yang & Gadi, 2008). On the other hand, maltodextrin and amylase treated flours had higher ΔE values compared to untreated flours. The lower ΔE values may be due loss of phenolic and anthocyanin content.

Table 6. 1. Effect of α-amylase and maltodextrin concentration on moisture content, hygroscopicity and color values of spray dried sweet potato flour

Types of treatment	Parameter					
	Moisture content ($g\ kg^{-1}$)	Hygroscopicity ($g\ kg^{-1}$)	L^*	a^*	b^*	ΔE
Control[1]	85.7^{a}	3.3^{b}	43.52^{f}	21.31^{a}	-0.28^{e}	0
30 $g\ kg^{-1}$ maltodextrin	77.1^{a}	3.0^{b}	46.73^{e}	20.36^{b}	-0.016^{d}	3.38^{h}
50 $g\ kg^{-1}$ maltodextrin	73.4^{a}	2.9^{b}	47.86^{d}	20.39^{b}	-0.06^{d}	4.46^{g}
3 $g\ kg^{-1}$ amylase	78.0^{a}	3.3^{b}	50.76^{bc}	17.92^{e}	1.14^{a}	8.04^{d}
3 $g\ kg^{-1}$ amylase + 30 $g\ kg^{-1}$ maltodextrin	77.3^{a}	3.3^{b}	51.12^{b}	18.41^{de}	1.00^{a}	8.17^{c}
3 $g\ kg^{-1}$ amylase + 50 $g\ kg^{-1}$ maltodextrin	77.4^{a}	2.8^{b}	50.78^{bc}	18.33^{e}	1.12^{a}	7.90^{e}
7 $g\ kg^{-1}$ amylase	78.3^{a}	5.2^{a}	50.08^{c}	19.75^{c}	0.22^{c}	6.73^{f}
7 $g\ kg^{-1}$ amylase + 30 $g\ kg^{-1}$ maltodextrin	77.6^{a}	3.5^{b}	52.57^{a}	18.48^{d}	0.19^{c}	9.47^{a}
7 $g\ kg^{-1}$ amylase + 50 $g\ kg^{-1}$ maltodextrin	85.7^{a}	2.9^{b}	51.46^{b}	19.00^{d}	0.04^{c}	8.25^{b}

[1] Flour prepared without treatment.

Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

Water absorption index (WAI), Water solubility index (WSI), and Swelling capacity (SWC)

Water absorption index, water solubility index, and swelling capacity are shown in Table 2. The increase in maltodextrin concentration leads to increased WSI but decrease in WAI. Similar results were found in spray dried yellow color sweet potato flour as reported by Grabowski *et al.*(2006) Maltodextrin can form outer layers on the drop and alters the surface stickiness of particles due to the transition into glassy state. On the other hand, higher level of amylase treatment flour had higher WAI and lower WSI except the 7 g kg^{-1} puree with the addition of 50 g kg^{-1} maltodextrin compared to the lower level of amylase treatment flours. This effect may be due to the different structure of flours. Agglomerates of particle would contribute to a smaller WAI subsequently increased the WSI of flours. Che man *et al.* (1999) mentioned that the durian fruit flours of water absorption index are closely related to the structure. There were no significant differences in SWC between control and maltodextrin treated flours. However, amylase treated flours had higher than those of control and maltodextrin treated flours. Moreover, higher level of amylase treated flours had lower SWC than the lower level of amylase treatment flours. Low swelling capacity is caused by the presence of a large number of crystallites, which increase granular stability, thereby reducing the extent of granular swelling. When starch is gelatinized at a certain temperature, the molecular organization is disrupted within the granules and the starch-water interactions increase, resulting in a substantial increase in the swelling swelling (Gunaratne & Hoover, 2002; Dewanto *et al.*, 2002b).

Table 6. 2. Effect of α-amylase and maltodextrin concentration Water absorption index, water-soluble index, and swelling capacity of spray dried sweet potato flour

Types of treatment	Parameter		
	WAI ($g\ ml^{-1}$)	WSI ($g\ kg^{-1}$)	SWC ($g\ ml^{-1}$)
Control[1]	1.22^{a}	417.2^{c}	2.11^{b}
30 $g\ kg^{-1}$ maltodextrin	1.20^{a}	449.7^{c}	2.20^{b}
50 $g\ kg^{-1}$ maltodextrin	1.03^{a}	483.3^{c}	2.00^{b}
3 $g\ kg^{-1}$ amylase	0.51^{c}	821.9^{a}	3.07^{ab}
3 $g\ kg^{-1}$ amylase + 30 $g\ kg^{-1}$ maltodextrin	0.65^{c}	821.6^{a}	3.87^{a}
3 $g\ kg^{-1}$ amylase + 50 $g\ kg^{-1}$ maltodextrin	0.64^{c}	744.8^{a}	2.54^{b}
7 $g\ kg^{-1}$ amylase	0.75^{bc}	657.0^{b}	2.24^{b}
7 $g\ kg^{-1}$ amylase + 30 $g\ kg^{-1}$ maltodextrin	0.79^{bc}	662.9^{b}	2.34^{b}
7 $g\ kg^{-1}$ amylase + 50 $g\ kg^{-1}$ maltodextrin	0.59^{d}	752.7^{a}	2.38^{b}

[1] Flour prepared without treatment.

Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

Total phenolic, anthocyanin, ascorbic acid content, and antioxidant capacity

Table 3 shows the results of different concentration of maltodextrin and amylase treatment on total phenolic, anthocyanins, ascorbic acid content, and antioxidant capacity of sweet potato flours. The total phenolic content of sweet potato flours ranged from 10.68 to 15.69 g kg^{-1} wet weight basis. These results were much higher than that reported in literature (2.69 to 5.01 g kg^{-1} dry weight basis) for fresh and steamed sweet potato flours (Huang *et al.*, 2006). It was found that there were no significant differences in total phenolic content between control and maltodextin treated flours. However, amylase treated flours had higher total phenolic content than those of control and maltodextrin treated flours. This might be due to the degradation of cell wall by enzymatic treatment which could be enhanced the extractability of phenolic components from the cell matrix (Ramadan & Moersel, 2007). Huang *et al.* (2006) also found that steaming treatment increased the total phenolic content of purple sweet potato flour. Dewanto *et al.* (2002b) also found that the free phenolic content of sweet corn increased with increasing heating temperature and time. However, thermal processing had no effect on the phenolic content of tomato (2002a). On the other hand, total phenolic content increased with increase in amylase concentration. Although, there were no significant differences between amylase and amylase with maltodextrin treated flours. The higher content of total phenolic may be attributed to the higher amount of vitamin C.

The anthocyanin content in treated and untreated flours ranged from 0.66 to 0.96 g kg^{-1} wet weight basis or 71.53 to 104.15 g kg^{-1} dry weight basis. The contents of anthocyanin were much higher than that of sweet potato puree (3.0 g kg^{-1}dry weight basis, Steed and Truong, 2008) and steamed or kneaded flours (0.36 to 5.459 g

kg^{-1} dry weight basis, Huang *et al.*, 2006). This variation may be due to those authors used different treatment and variety of sweet potato. Maltodextin treated flours had lower anthocyanin contents than control flour. This can be attributed to the fact that addition of maltodextrin could increase the total solid content. Possibly because reacting molecules become closer when a product is concentrated.[31] However, amylase treated flours had higher anthocyanin content compare to the control and maltodextrin treated flours. On the other hand, increase in amylase concentration leads to increase in anthocyanin content. It might be due to the amylase treatment flours release bound anthocyanin from the cell damage. Huang *et al.* (2006) and yang and Gadi (2008) observed that steaming increased the anthocynin content of purple sweet potato flour. It has also been found different enzyme treatment increased the anthocynin content of various fruit juice juice (Jin *et al.*, 1999; Buchert *et al.*, 2005).

Ascorbic acid content of sweet potato flours ranged from 0.07 to 0.16 g kg^{-1} wet weight basis or 8.02 to17.49 g kg^{-1} dry weight basis. These values were much higher with those obtained by other authors, who reported that ascorbic acid content of (0.18 to 0.32 g kg^{-1} dry weight basis, Huang *et al.*, 2006) in steamed sweet potato flours. Control and maltodextrin treated flours did not show significant effect on the retention of ascorbic acid content. On the other hand, amylase treated flours had lower ascorbic acid content than that of control and maltodextrin treated flours. The lower content of ascorbic acid could be attributed to the fact that the ascorbic acid is relatively unstable to heat, oxygen and light. However, no significant differences were observed amongst higher levels of amylase, control and maltodextrin treated flours. On the other hand, higher level of amylase treated flours had higher ascorbic acid content than the lower level of amylase treated flours. The ascorbic acid might be

protected by the ascorbic-sparing effect of the phenol. The antioxidant capacity observed in all flours ranged from 715.2 to 788.9 g kg^{-1} wet weight basis. Similar results were reported by Huang *et al.* (2006) for raw, steamed and kneaded sweet potato flours. Maltodextrin flours had higher antioxidant capacity than that of control and amylase treated flours. This difference could be related to the lower anthocyanin content found in maltodextrin treated flours. Musuda *et al.* (2002) reported that the dominant antioxidant activity in purple flesh sweet potato flour was attributed to anthocynin. At least one caffeoyl group acylated to anthocyanins contributes to high radical-scavenging activity (Suda *et al.*, 2002). Huang *et al.* (2006) found that total antioxidant activity was highly correlated with total phenolic and anthocyanin content. On the other hand, Shih *et al.* (2009) reported that total antioxidant had no correlation with total phenolic and anthocyanin content. However, in this study the antioxidant capacity was negatively correlated with amylase and phenol. Eventhough, amylase treated flours had higher total phenolic content than those of control and maltodextrin treated flours. Possibly, other phytochemicals than phenolics may potentially play a role in the antioxidant capacity in amylase treated flours.

Table 6. 3. Effect of α-amylase and maltodextrin concentration Antocyanin, total phenolic, ascorbic acid content, and antioxidant capacity (g kg^{-1} wet weight basis) of spray dried sweet potato flour

Types of treatment	Parameter			
	Anthocyanin	Total Phenolic	Ascorbic acid	Antioxidant capacity
Control[1]	0.73^{d}	10.75^{c}	0.16^{a}	769.30^{c}
30 g kg^{-1} maltodextrin	0.67^{g}	11.46^{c}	0.16^{ab}	781.50^{b}
50 g kg^{-1} maltodextrin	0.68^{f}	10.68^{c}	0.16^{a}	788.90^{a}
3 g kg^{-1} amylase	0.89^{c}	13.35^{abc}	0.07^{b}	727.60^{g}
3 g kg^{-1} amylase + 30 g kg^{-1} maltodextrin	0.70^{e}	13.59^{abc}	0.13^{a}	715.20^{h}
3 g kg^{-1} amylase + 50 g kg^{-1} maltodextrin	0.66^{h}	13.76^{abc}	0.15^{a}	710.50^{i}
7 g kg^{-1} amylase	0.96^{a}	15.38^{a}	0.14^{ab}	741.9^{f}
7 g kg^{-1} amylase + 30 g kg^{-1} maltodextrin	0.94^{b}	14.53^{a}	0.13^{a}	757.70^{d}
7 g kg^{-1} amylase + 50 g kg^{-1} maltodextrin	0.89^{c}	15.69^{a}	0.15^{a}	743.40^{e}

[1] Flour prepared without treatment.

Means followed by different superscript alphabets in each column are significantly different ($p<0.05$).

Correlations

Table 6. 4 shows Pearson's correlation coefficients among all quality attributes of spray dried sweet potato flour. Mondy and Gosselin (2008) found phenols have been associated with the color changed particularly lightness. We found that L^* values were highly correlated with phenolic content. However, a^* and b^* value was positively and negatively correlated with antioxidant activity. On the other hand, ΔE values were highly correlated with phenolic content, L^*, a^* and b^* values and amylase. According to the correlation analysis, the WSI and WAI value was significantly ($p<0.001$) positively and negatively correlated with amylase treatment respectively. Huang *et al.* (2006) found that total antioxidant was highly correlated with total phenolic and anthocyanin content. However, Shih *et al.* (2009) reported that total antioxidant had no correlation with WSI, total phenolic and anthocyanin content. It was found that total phenolic and anthocyanin content were positively correlated with amylase, ΔE values and WSI and negatively correlated with WAI. However, in this study antioxidant capacity was negatively correlated with amylase, phenol, ΔE value, WSI and SWC and positively correlated with WAI. On the other hand, glass transition temperature was positively correlated with maltodextrin and negatively correlated with anthocyanin content

Table 6. 4. Pearson's correlation coefficients among all quality attributes of spray dried sweet potato flour

	Amylase	DPPH	Phenol	Anthocyanin	Vitamin C	L	a	b	WSI	WAI	SWC	ΔE	T_g
Maltodextrin		0.28	0.041	0.04	0.40	0.30	-0.16	0.02	0.07	-0.10	-0.68	0.32	0.55**
Amylase			-0.67***	0.81***	0.587***	-0.19	0.687***	-0.549**	0.43	0.68***	-0.75***	0.16	0.69***	-0.28
DPPH				-0.54*	-0.14	0.41	-0.61**	0.77***	-0.87***	-0.87**	0.82***	-0.61**	-0.54*	-0.14
Phenol					0.71***	-0.23	0.83***	-0.223	0.35	0.74***	-0.80***	0.216	0.83***	-0.22
Anthocyanin						-0.22	0.49**	-0.28	-0.75	0.35	-0.93***	-0.68	0.48**	-0.55**
Vitamin C							-0.49*	0.71***	-0.69***	-0.69***	0.67**	-0.522*	-0.46	-0.15
L								-0.88***	0.61***	0.84***	-0.87***	0.38	0.99***	0.24
a									-0.85***	-0.92***	0.98***	-0.56**	0.87***	-0.37
b										0.83***	-0.77***	0.68***	0.53**	0.44*
WSI											0.97***	0.98***	0.81***	0.223
WAI												-0.49*	-0.83***	-0.15
SWC													0.42	0.40
ΔE														0.19

*, **, *** = significant at $p<0.05$, $p<0.01$ and $p<0.001$ respectively.

Glass transition temperature

The thermograms of purple sweet potato flours different concentration of maltodextrin and amylase treatment are shown in Fig 6. 1-6. 2. To the best of our knowledge, this is the first report indicating the effect of different concentration of maltodextrin, amylase and combined with maltodextrin and amylase on glass transition temperature in purple sweet potato flour. Glass transition temperatures of treated and untreated flours were approximately 10.17 to 36.12°C. However, the values of glass transition temperature were lower than those reported by Grabowski *et al.*(2006) This may be due to the different operating conditions and variety of sweet potato used. The glass transition temperature of the flours increased with increase in maltodextrin concentration. This might be due to the increase in molecular weight of the component of the flours. On the other hand, amylase treated flours had lower glass transition temperature compared to the maltodextrin treated flours. This could be higher moisture content found in amylase treated flours. Goula *et al.*(2008) reported that the reduction of T_g caused by increasing moisture content due to the plasticizing effect of water.

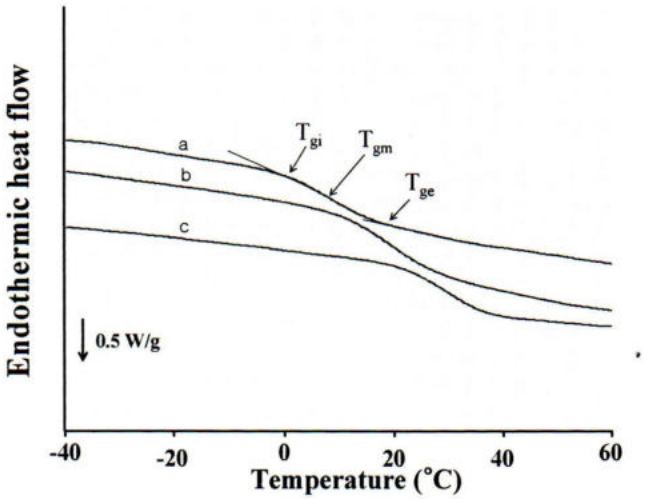

Figure 6. 1. Differential scanning calorimetry (DSC) thermographs showing the glass transition temperature of sweet potato flour with increasing levels of maltodextrin a) 0 g kg^{-1} b) 30 g kg^{-1} MD c) 50 g kg^{-1} MD.

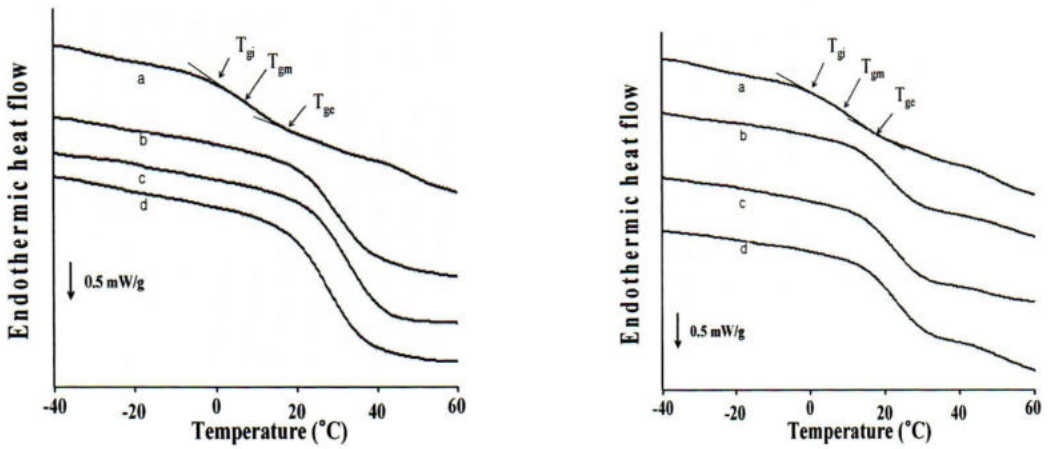

Figure 6. 2. Differential scanning calorimetry (DSC) thermographs showing the glass transition temperature of sweet potato flour. A) with and without 3 g kg^{-1}amylase and combined with amylase and maltodextrin: a) 0 g kg^{-1} b) 3 g kg^{-1} amylase c) 3 g kg^{-1} amylase with 30 g kg^{-1} MD d) 3 g kg^{-1} amylase with 50 g kg^{-1} MD. B) with and without 7 g kg^{-1}amylase and combined with amylase and maltodextrin: a) 0 g kg^{-1} b) 7 g kg^{-1} amylase c) 7 g kg^{-1} amylase with 30 g kg^{-1} MD d) 7 g kg^{-1} amylase with 50 g kg^{-1} MD.

Microstructure

Fig. 6. 3 shows the scanning electron micrographs of sweet potato flour prepared with different concentration of maltodextrin and amylase treatment. Maltodextrin treated flour granules were smoother than those of control sample. Similar morphology was observed in microcapsules of black carrot pigments with maltodextrin (10DE and 20-23DE, Ersus & Yurdagel, 2007).Amylase treatment flours had smaller granules and aggregated compared to the control and maltodextrin treated flours. This variation might be attributed to the amylase break down starch into lower molecular weight dextrin which is in agreement with Grabowski *et al.* (2006) findings.

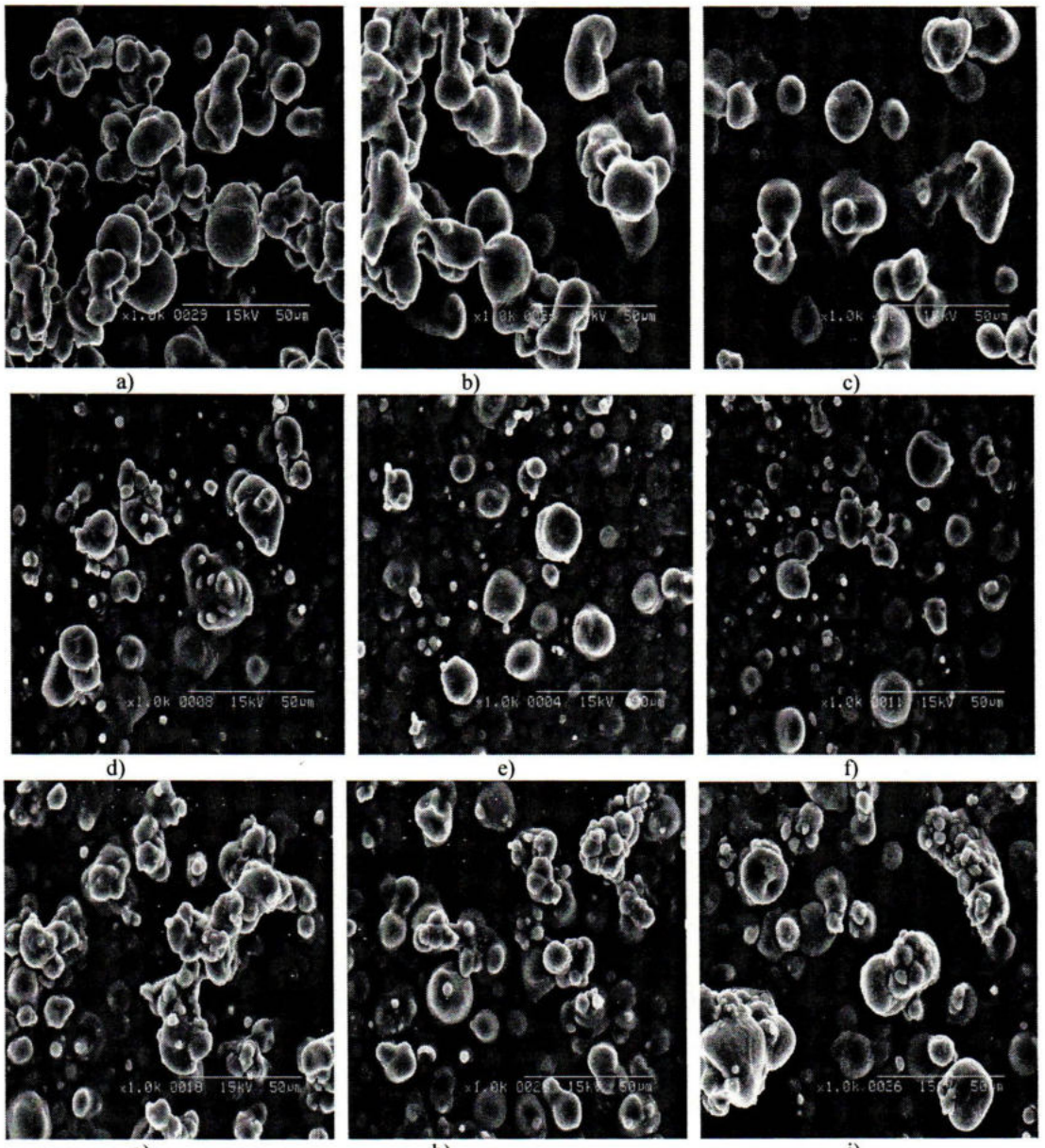

Figure 6. 3. Scanning electron microstructure of spray-dried sweet potato flour with various levels of maltodextrin, amylase and combined with amylase and maltodextrin. a) Control b) 30 g kg^{-1} maltodextrin c) 50 g kg^{-1} maltodextrin d) 3 g kg^{-1} amylase e) 3 g kg^{-1} amylase with 30 g kg^{-1} maltodextrin f) 3 g kg^{-1} amylase with 50 g kg^{-1} maltodextrin g) 7 g kg^{-1} amylase h) 7 g kg^{-1} amylase with 30 g kg^{-1} maltodextrin i) 7 g kg^{-1} amylase with 50 g kg^{-1} maltodextrin.

CONCLUSIONS

The addition of various levels of maltodextrin, amylase and combined with amylase and maltodextrin on the physicochemical, functional and antioxidant capacity of sweet potato flours were investigated in this study. The results showed that combined with maltodextrin and amylase treated flours had potential effect on quality characteristics as compared to the control and maltodextrin treated flours. Amylase and amylase with maltodextrin treated flours had higher color L*, ΔE values, anthocyanin and total phenolic content than control and maltodextrin treated flours. Therefore, the flour produced by combining with 30 g kg^{-1} maltodextrin and 7 g kg^{-1} amylase treatment could be used to make the higher quality product that would be more attractive to product developers and consumers.

CHAPTER VII

SUMMARY AND CONCLUSIONS

With high levels of nutritional values such as vitamins, minerals, and bioactive compounds, sweet potatoes have been used as a food ingredients and a source for natural food colorants. Most of the researcher focused on the development of new products adding with sweet potato flour. However, they didn't emphasis the flour quality. Therefore, the main purpose of this study was to prepare flour from two variety of sweet potato using different pretreatments and drying methods. In chapter III we have discussed to prepare flours from peeled and unpeeled yellow color sweet potatoes using hot air drying with sulfite treatment. The results of this study have shown peeled and unpeeled flour treated with sulfite had higher color values, swelling capacity, ascorbic acid and total phenolic contents than untreated peeled and unpeeled flour. However, flour from yellow color sweet potato treated with calcium chloride ($CaCl_2$) had higher amounts of ascorbic acid and β-carotene than that treated with sodium hydrogen sulfite ($NaHSO_3$) for both hot air drying and freeze drying (Chapter IV). On the other hand, maltodextrin-added flours from purple color sweet potato using hot air drying had higher L^* values, water soluble index, total phenolic and anthocyanin content than those of untreated flours (Chapter V). Moreover, purple color sweet potato flour prepared (Chapter VI) treated with amylase and amylase with maltodextrin. The results reveled that treated flours amylase and amylase with maltodextrin had higher anthocyanin and total phenolic than control and without amylase treated flours. On the other hand, maltodextrin increased whereas alpha-

amylase decreased the glass transition temperature. As a result, sweet potato flours could be produced using different pretreatments and drying methods that could be used to make a higher quality product and more attractive to product developers and consumers.

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