UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A RESTRUCTURED SWEET POTATO FRENCH FRIES TYPE PRODUCT

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DEVELOPMENT OF A RESTRUCTURED

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By

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DEVELOPMENT OF A RESTRUCTURED SWEET POTATO FRENCH FRIES TYPE PRODUCT

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July 2009

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Faculty : Food Science and Technology

The 17 accessions from UPM collection and 4 commercial cultivars exhibited wide variation in physical and chemical characteristics. Results found that white flesh colour sweet potato showed the lowest hardness and followed by orange, yellow and purple cultivars. Starch content of 17 accessions varied significantly and amylose content of purple group was higher than the others. Yellow flesh group contains the highest fructose followed by orange, white and purple. Gelatinization temperatures for white, yellow, orange and purple were 78, 77, 73, and 72 °C, while the peak viscosity varied from 443 to 621, 510 to 725, 380 to 419 and 691 to 711 BU, respectively. The 17 accessions and 4 cultivars of sweet potato studied exhibit great variation in physical and chemical characteristics.

On the optimizing method for RSS processing, *White* cultivars was chosen as raw material, and processed using the combination of shapes, blanching methods and adding of sweet potato flour. Results showed that chips exhibited a proper shape for blanching compared with dice. Blanching in 1 % STP solution for 2 minutes significantly improved the quality of RSS such as firmness and dry matter content of dough, colour, fat and ash content, and texture. Mixing of 5 % sweet potato flour to the mashed sweet potato produced suitable conditions of the dough for further processing and generated RSS having uniform shape with an intermediate hardness, high lightness and low redness colouration and also the highest value of sensory preferences.

Sweet potato cultivars significantly affected the chemical, physical properties and organoleptic characteristics of RSS. Moisture content of *Orange* fresh tuber was lower than *White* and *Yellow* cultivars, and it generated the lowest moisture content of mashed sweet potato, prefried sticks and fried sticks. *White* cultivar generated the RSS having yellow bright colour, highest value of firmness and low fat content, while *Orange* cultivar produced RSS with bright orange colour, medium firmness but high fat content. RSS made of both varieties were evaluated as acceptable by a sensory panel with sensory score above the average. Recommendation from this study illustrates that *White and Orange* cultivars can be used to make a convenient restructured product.

On the final preparation of RSS, deep frying and heating in microwave oven was evaluated on the texture attributes and sensory preferences of the product. Results

showed that the most suitable condition of producing RSS was by using deep frying for final preparation on RSS made from *White* and *Orange* commercial cultivars as raw material. RSS made from *White* cultivar had hard texture, bright yellow colour and slightly below *like slightly,* while *Orange* RSS had softer texture, bright orange colour and slight above *like slightly*. Deep frying is the preferred method for the final preparation of RSS.

From these findings, one may recommend that RSS can be produced using *White* and *Orange* cultivars. The tubers are peeled, sliced into about 2.3 mm thickness and 25 mm width. Blanching was done by dipping the chip in 1 % (w/v) STP solution at about 100 °C for 2 minutes. The blanched materials were drained for about 3 minutes to remove excess water, and then mashed and CMC was added (0.3 %, w/w) as a binder. The mashed was mixed with 5 % sweet potato flour. Moulding could be done using simple extruder with 10 x 10 mm square holes. The sticks were then deep fried at 163 °C for 1 minute, packaged in plastic bags and frozen at -20 °C for storage purpose until final preparation. The RSS was prepared by deep frying in 175 °C for 2 minutes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN PRODUK KELEDEK "FRENCH FRIES" TERSTRUKTUR SEMULA

Oleh

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Sebanyak 17 jenis keledek koleksi daripada UPM dan 4 jenis keledek komersial mempunyai sifat fizikal dan kimia yang sangat pelbagi. Keledek putih memiliki kekerasan yang paling terendah dan diikuti dengan jingga, kuning dan ungu. "Chewiness" daripada keledek kukus mempunyai corak yang sama dengan kekerasan. Kandungan kanji daripada 17 varieti adalah berbeza, manakala kandungan amilosa pada keledek ungu adalah lebih tinggi daripada yang lain. Kumpulan keledek kuning mempunyai kandungan fruktosa yang paling tinggi dan diikuti oleh jingga, putih dan ungu. Walau bagaimana, kandungan gula iaitu glukosa, sukrosa dan maltosa tidak boleh dikumpulkan berdasarkan warna keledek. Suhu tergelatin bagi keledek putih, kuning, jingga dan ungu adalah masing-masing 78, 77, 73 dan 72 °C, manakala kelikatan puncak adalah dari 443 sampai 621, 510 sampai 725, 380 sampai

419 dan dari 691 sampai 711 BU. Dua puluh satu jenis keledek yang dikaji menunjukkan variasi yang sangat besar pada sifat fizikal dan kimianya.

Untuk mengoptimumkan cara pemprosesan RSS, keledek komersial warna putih (*Putih*) adalah digunakan sebagai bahan mentah, dan diolah menggunakan kombinasi bentuk hirisan keledek, cara mencelur dan penambahan tepung keledek. Hasil ujikaji menunjukkan bahawa "chip" adalah bentuk yang paling sesuai berbanding "dice". Mencelur di dalam larutan 1 % STP selama 2 minit boleh membaiki kualiti RSS, seumpama kekerasan dan jirim kering doh, warna, kandungan minyak dan abu, serta kekerasan daripada RSS. Pencampuran dengan 5 % tepung keledek menghasilkan doh yang mempunyai keadaan yang sesuai untuk pemprosesan seterusnya dan menghasilkan bentuk RSS yang berbentuk seragam dengan kekerasan yang sederhana, kecerahan yang tinggi dan kemerahan yang rendah, dan nilai kesukaan deria yang paling tinggi.

Pelbagi varieti keledek memberi kesan kepada sifat-sifat fisikal, kimia dan deria RSS. Kandungan air keledek *Oren* adalah lebih rendah daripada *Putih* dan *Kuning*, dan ianya menghasilkan kandungan air yang rendah pada doh, RSS beku dan RSS. Keledek *Putih* menghasilkan RSS dengan warna kuning cerah, nilai kekerasan yang tertinggi, dan kandungan minyak yang rendah, manakala keledek *Oren* menghasilkan warna RSS jingga yang cerah, kekerasan yang sederhana tetapi kandungan minyak yang tinggi. RSS daripada kedua-dua varieti diberi markah diatas purata oleh panel uji deria. Cadangan daripada ujikaji ini menunjukkan bahawa keledek *Putih* dan *Oren* boleh digunakan untuk membuat produk terstruktur semula (RSS) yang disukai.

Pada penyediaan akhir RSS, pemprosesan dilakukan dengan objektif untuk mengujikaji kesan menggoreng dengan minyak penuh dan dipanaskan dalam ketuhar gelombang mikro pada sifat-sifat tekstur dan kesukaan deria bagi produk. Keputusan menunjukkan yang keadaan paling sesuai bagi menyediakan RSS pada kajian ini adalah menggoreng dengan minuak penuh pada RSS yang dibuat dari keledek *Putih* dan *Oren.* RSS yang dibuat daripada keledek *Putih* mempunyai tekstur keras, warna kuning terang dan sedikit di bawah *like slightly*, manakala keledek *Oren* menghasilkan RSS yang mempunyai tekstur lebih lembut, warna jingga cerah dan sedikit di atas *like slightly*. Goreng minyak penuh adalah cara yang dipilih untuk penyediaan akhir RSS.

Daripada hasil yang diperolehi, adalah disyorkan yang RSS dapat dihasilkan menggunakan keledek *Putih* dan *Oren*. Pemprosesannya adalah ubi dikupas, dihiris dengan ketebalan sekitar 2.3 mm dan 25 mm lebar. Celur dilakukan dengan mencelupkan cip pada larutan 1 % (w/w) STP pada kira-kira 100 °C selama 2 minit. Cip yang telah dicelur ditus selama sekitar 3 minit bagi membuang lebihan air, dan kemudian dilumatkan dan dibubuh CMC (0.3 %, w/w) sebagai satu penambat. Keledek yang telah dilumatkan dicampur dengan tepung keledek sebanyak 5 %. Mencetak boleh dilakukan dengan penyemprit ringkas yang mempunyai lubang persegi bersize 10 x 10 mm. Stik kemudiannya digoreng pada 163 °C untuk 1 minit, dibungkus dalam beg plastik dan disejuk beku pada -20 °C untuk tujuan storan sehingga penyediaan terakhir. RSS disediakan dengan goreng minyak penuh pada 175 °C selama 2 minit.

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I certify that a Thesis Examination Committee has met on 14 July 2009 to conduct the final examination of Joko Susilo Utomo on his thesis entitle: "Development of a Restructured Sweet Potato French Fries Type Product" in accordance with the Universities and University colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I hereby declare that this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or any other institution.

JOKO SUSILO UTOMO

Date: 1 September 2009

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LIST OF ABBREVIATION

ANOVA	analysis of variance
BU	brabender unit
BV	brabender viscograph
CMC	carboxy methyl cellulose
fwb	fresh weight bases
HPLC	high performance liquid chromatography
IU	international unit
N	newton
NPN	non-protein nitrogen
Ns	newton-second
P	probability
RSS	restructured sweetpotato stick
sd	standard deviation
SP	sweet potato
STP	sodium trypolyphosphate
TPA	texture profile analysis
USRDA	United State Recommended Dietary Allowances
var	variant
v/v	volume per volume
w/v	weight per volume
w/w	weight per weight

CHAPTER 1

INTRODUCTION

Sweet potato, *Ipomoea batatas* Lam., is a dicotyledonous plant belonging to the *Convolvulaceae* family, in which there are approximately 50 genera and over 1,000 species (Woolfe, 1992). Its origin is probably from Central or Tropical America (Engel, 1970, O'Brien, 1972, Austin, 1977, Yen, 1982). Sweet potatoes are mostly grown in developing countries, which account for over 99 % of world output. Over 90 % of the production in developing countries is in Asia, especially in China producing about 86 % of the total world production. The rest was under 5 % in Africa; and about 5 % in all the rest of the world such as North, Central and South America; Oceania and Europe; and only about 2 % of the world's sweet potatoes are grown in industrial countries, mainly in United States and Japan. It has been estimated that sweet potato production in developing countries was about 130 million metric tonnes per annum, representing 34 % of all roots and tubers cultivated in these regions. The fluctuation of sweet potato production occurred significantly. World sweet potato production increased by 50 % from 1961 to 1973 and then decline to about 15 %. Over the last quarter of a century, production has fallen sharply in industrial country; however, in Latin America sweet potato production rose in the 1960s, but then fell to about 80 % of its initial level. The declining of sweet potato production followed a similar but less pronounced trend as occurred in Asia. The only world region that sweet potato production increased throughout the period is Africa (FAO, 1990).

The parts of the sweet potato used for food are roots and leaves or tips. Only these parts are relevant to the use of sweet potato as food, from the point of nutrition, quality or food processing. In common with other roots and tubers, sweet potato has high moisture content, resulting in relatively low dry matter content. The average of dry matter content is approximately 30 %, but varies very widely depending on factors cultivar, location, climate, day length, soil type, incidence of pest and diseases, and cultivation practices (Bradbury & Holloway, 1988b). Approximately 80 - 90 % of sweet potato dry matter (24 – 27 % fresh weight) is made of carbohydrates, which consist mainly of starch and sugars, with lesser amount of pectin, hemicelluloses and celluloses (Woolfe, 1992). The relative carbohydrate composition varies not only with cultivars and maturity of the tubers, but also with storage time and cooking or processing, and has considerable influence on quality factors such as texture, including firmness, dryness, mouthfeel, and taste. It is well known that sweet potato is not only a source of energy, but also an excellent source of vitamins, certain other minerals, dietary fiber and some protein (Edmond & Ammerman, 1978, Lanier & Sistrunk, 1979, Picha, 1985).

Despite these general nutritional excellences, the sweet potato is not a popular food item. Sweet potato can be boiled, steamed, baked, fried, chipped, candied, canned, frozen, made into flour and starch or processed into a number of products. However, it seems that presently sweet potato is underexploited as a direct human food. In some traditional sweet potato growing areas, production is decreasing as food consumption patterns change to imported cereal-based food. Attempts to expand the marketability of sweet potatoes have focus on processed products,

such as fries, chips and leathers (Hoover & Miller, 1973, Walter & Hoover, 1986, Collins & Washam-Hutsell, 1987, Schwartz *et al*, 1987). Hence, the increase of sweet potato consumption can be achieved by convincing people of its nutritional goodness, as well as palatability, so that they will prefer it to foods of lower nutritional value (Che Man, 1996).

One of the fried products from sweet potato is French fry-type product or strip or stick that is popular in United States, but is not well expanded in developing countries. Difficulty in controlling textural properties affecting the quality of sweet potato French fry-type product is the major reason for the scarcity of such product available in the market. Texture is mainly formed by the interaction between the raw material characteristics and the method of processing. From the raw material point of view, the difficulties arise due to the variation of sweet potato cultivars and its characteristics. To solve the inadequacy of sweet potato French fry-type to be produced from the regular roots, restructuring is an attempt to control the textural properties and to get the uniform quality of sweet potato stick. Method of processing is a critical stage which needs to be studied for producing desirable products. Many reports have described several pureed sweet potato products, however, no information of the use of blanching method for preparing restructured sweet potato French fry product. Blanching is a heating process subjected to control firmness of some agriculture commodity such as vegetables and fruits (Fuchigami *et al*., 1995, Stanley *et al*., 1995, Jackson *et al*., 1996, Howard *et al*., 1997). However, such information on sweet potato is limited. High temperature blanching disrupts cell integrity and cell adhesion, resulting in softening in sweet potato tissue. Beside that, browning which occurred when

sweet potato tissue subjected into the existing oxygen can be eliminated. Controlling the dry matter content of sweet potato puree was done by several methods; however using sweet potato flour to control the dry matter is hardly reported. Final preparation of French fry product is also an important step in process production to obtain high quality products. Generally French fry product can be prepared by deep frying and heating using microwave oven. As a new product type, the heating or baking using microwave oven for preparing of restructured sweet potato stick (RSS) has not been reported. Fabricating RSS from several sweet potato varieties which is available along the season is an important attempt to study the characteristics of RSS made from different characteristics of raw materials. For this purpose, production of RSS using several combinations of process such as blanching and adding of sweet potato flour; final preparation; and raw materials is expected to be able to improve other quality element such as colour and flavour of the finished product. Beside that, it is an effort to gain the utilization of sweet potato.

The general objective of this study was to characterize the variation of sweet potato cultivars and develop the RSS. Specific objectives were (1) to study the physical and chemical characteristics of the UPM sweet potato accessions and the commercials sweet potato cultivars. (2) to develop the preparation methods of RSS. 3. to study the characteristics of RSS made from commercial sweet potato cultivars.

CHAPTER 2

LITERATURE REVIEW

2.1 Production and consumption, and general characteristics of sweet potato

Sweet potato origin is probably Central or South America, which has spread to most of the world's tropical, sub-tropical and warmer temperature regions. The archaeological and historical studies on the origin of sweet potato were conducted by many researches. Yen (1982), Austin (1977), O'Brien (1972) and Engel (1970) summarized their finding that Central or South America was the origin of sweet potato. However, the exact centre of sweet potato is still in dispute and likely to remain so until further evidence is available. Whether it originated from Central or South America, the sweet potato was already widely in the New World by the time Europeans first arrived. Further spread of sweet potato in historic time was by two lines of transmission: (a) the *batatas* line, which followed on from the Spanish introduction to Europe, continuing by the transfer of European clones to Africa, India and the East Indies; and (b) the *kamote* line whereby Mexican clones were carried to the Philippines (Yen, 1982). Sweet potato was apparently brought to China from the Philippines; however, Ho (1955) observed that the earliest introduction was overland from India or Burma, while in Japan, sweet potato was introduced firstly by early English and then reintroduce by China.

The information of sweet potato on historical trends and the global status of production and utilization are very limited. The best statistics on global root crop

production and use is the Basic Data Unit of the FAO. However, available statistic is not reliable, particularly in developing countries where sweet potato are grown in isolated areas, irregularly or intercropped parcel lands. Despite this limitation, the FAO data statistics are useful for characterizing broad regional patterns and trends of sweet potato production. According to FAO, sweet potato is grown in 111 countries, of which 101 are classified as developing nations. Among the world's root crops the sweet potato ranks second only to the potato in economic importance (Horton, 1988a).

Sweet potatoes are mostly cultivated in developing countries, which account for over 99 % of world output. It has been estimated that sweet potato production in developing countries is about 130 million metric tonnes per annum, representing 34 % of all roots and tubers cultivated in this regions. Over 90 % of the production in developing countries is in Asia, just under 5 % in Africa and only 5 % in all the rest of the world such as North, Central and South America, Oceania and Europe. Only about 2 % of the world's sweet potatoes are grown in industrial countries mainly in United States and Japan. The statistic of production and food use is shown in Table 1 (FAO, 2006). World sweet potato production increased by 50 % from 1961 to 1973 and then decline to a level about 15 % higher than that of early 1960s. In term of fluctuation, sweet potato production has changed dramatically in Japan. These changes can be classified into four periods. (1) Period of postwar (1945 - 1960), sweet potato production reached the highest record of 7.18 million tons. (2) Period of high-growth (1961 - 1975), production was declined sharply from 6.33 to 1.42 million tons. (3) Period of stable growth (1976 - 1985), production was approximately 1.3 - 1.5 million metric tonnes. (4)

Period of internationalization (1986 - today) (JRT, 2000). The declining of sweet potato production followed a similar but less pronounced trend was occurred in Asia. China as the largest producer of sweet potato in the world, the area of sweet potato cultivation has declined significantly from a peak of 11 million hectares since 1970s, moreover by 1998, production area was down to about 6 million hectares although total production remained relatively constant at 20 - 23 metric tonnes/year (Huang-Jikun, *et al*, 2004). In spite of a decrease in harvested area, fluctuated only a little during the 1979 - 1999 periods due to higher yields, which registered the highest increase around 41.5 % in 21 years (CGPRT, 2006). The highest level of production was registered in 1999, at which time the harvested area was the smallest for the period. The declining of sweet potato production was continued until the last decade, and the lowest level was in 2003 (Table 1). Trend of the sweet potato production for other countries and regions have been more mixed. In Asia, sweet potato production has been characterized by four trends: (1) the continued overwhelming dominance of China with positive growth rate reversing the earlier decline; (2) shrinking area planted in sweet potatoes: (3) leveling off of yield as the rate of growth has slow in many countries, including China; (4) the possible shift in future prospects for regional sweet potato production due to recent changes in relative price for sweet potato versus traditional substitutes such as imported wheat flour, as a consequences of the economic crises in Southeast Asia.

For Latin America and the Caribbean, much of this region, production and area planted of sweet potato are most important in smaller, poorer countries such as Cuba, Haiti, and Paraguay. In Cuba, a sharp decline reflects the pressure on sweet

potato yields resulting from the shortage of chemical pesticides in the current transition to biological control of important pest. On the other hand in Peru, production and yields rose spectacularly over the last decade as agro-climatic conditions improved.

Table 1 Sweet potato production and use as food in the world and developing countries.

Year	Production (million mt)		Food (million mt)	
	World	Developing	World	Developing
1996	142.5	140.6	71.1	69.6
1997	121.8	119.9	63.4	61.8
1998	134.9	133.1	64.4	62.9
1999	146.0	144.3	68.6	67.2
2000	142.1	140.3	66.9	65.4
2001	143.1	141.3	67.1	65.5
2002	130.2	128.5	69.9	68.4
2003	125.4	123.6	65.8	64.2
2004	127.5	125.8	na	na
2005	129.4	127.5	na	na

Source: FAO, 2006; na = not available data, mt = metric tonnes

In Africa, growth rate of sweet potato production and area planted are the highest of any region. As area planted continued to expand, the annual average rate of improvement in yield turned negative in some cases (e.g. Uganda: -1.9 %), and offset what would have been faster rates of growth in production. In other words, as planting took place under more marginal conditions, and perhaps by farmer less acquainted with the most appropriate cultural practices, yields suffered in the process.

Though commonly categorized as strictly subsistence, *food security* or *famine relief* crop, sweet potato's uses have diversified considerably in developing countries over the last four decades. Hence, while these longstanding uses are still important in many countries, other uses have emerged, particularly in China and parts of Sub-Saharan Africa. Furthermore, some traditional uses have begun to attract the attention of crop and postharvest improvement specialists in recent years (FAO, 2004).

Consumption estimates are usually derived from food balance sheets published by the FAO. These equate domestic production plus imports minus export and net changes in year-end stocks to total domestic availability (Woolfe, 1992). The last is the sum of the quantities available for human consumption, industrial product, animal feed, seed and waste. Human consumption is estimated as total production minus the other four quantities. The balance is then divided by the estimated total national population to obtain per capita consumption. Although this figure is often presented as per capita consumption, it should actually be referred to as per capita availability for consumption.

Average annual per capita consumption of fresh roots for 1994-1996 is estimated by FAO (2001): Africa 9 kg, Asia 18 kg, Oceania 73 kg, Latin America 5 kg, Japan 7 kg, and USA 2 kg. In contrast to potato, per capita sweet potato consumption in Canada, Europe, and Australia is extremely limited and often confined to an immigrant population. The fluctuation of annual per capita consumption of fresh roots for the world, developing countries, and China from 1995 to1999 is illustrated on Figure 1. The world annual per capita consumption

is lower compared with developing countries and China. In Asia the largest producer of sweet potato, China also the highest per capita availability of sweet potato for food with ranged from 38.1 to 45.2 kg, however its slight decrease into 36 to 41 Kg in period of 1996 – 2004 (FAO, 2006). In Oceania, Papua New Guinea and the Solomon Island each have well over 100 kg of sweet potato per capita per year available for consumption and its stable until 2004. Within Africa, the group of neighbouring countries which includes Burundi and Rwanda has more than 100 kg, while Uganda has around 80 kg per capita available for consumption.

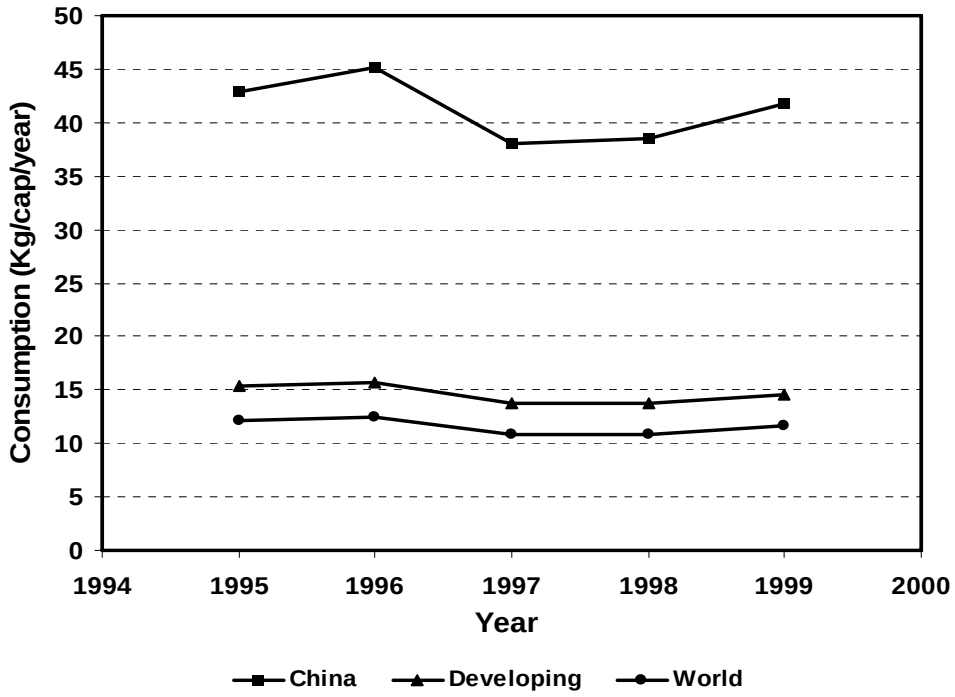


Figure 1 Evolution of annual per capita consumption of fresh sweet potato root in China, Asia, Developing countries and the World for 1995 – 1999. (Source: FAO, 2004).

The trend of consumption in China, as the highest producer of world sweet potato production, might reveal the situation of world sweet potato consumption. For 2003, China's total sweet potato production of almost 104 million tons, for a

population of slightly over 1.3 billion, averages out to 79 kilograms per capita (CIP, 2006). Consumption of sweet potato as a direct staple food crop has dramatically declined in recent decades, from an estimated 50 percent of total production in the 1970s to less than 15 percent by the end of the 1990s (Huang-Jikun, *et al,* 2003). Some studies have provided various estimation, but agree that a structural change has taken place, with strong regional variations. Generally, with rising incomes, demand has grown for wheat in northern China and rice in the south. Important utilization of China's sweet potato crop is the production of starch, used in a wide variety of products, including food (e.g. canned soups, desserts, processed meats) for many purposes, such as thickening, binding, taste and other culinary qualities, and conversion into sugar. Starch is also used for non-food applications such as textiles, paper, adhesives, and pharmaceuticals (Fuglie & Oates, 2004).

Japan is a highly developed country and one of the most economically successful nations in the world. Although it may seem to have relevance to the situation of many tropical developing nations, it is a case where the result of research into yield improvement and the development of specialized cultivars have enabled the sweet potato to demonstrate its flexibility and adaptation to changing economic circumstances. At a time of decreased direct use as human food, sweet potato was changed into a subsistence staple into a major industrial raw material and a component of livestock feeds. As an illustration, the decreased of annual per capita consumption is dramatically occurred from 27 kg in 1927 to only 4.3 kg in 1984 (Duell, 1989). However the per capita quantity of sweet potato consumption is very low, the high percentage of sweet potato production is used for industrial

purposes, particularly starch and alcohol manufacture. Only small percentage of total production is utilized for food processing, but within that sphere, a great diversity of products has arisen catering to increasing sophistication of consumer taste. In addition, about 12 % of the total production is used for animal feed purposes (Duell, 1985). As reported by CGPRT (2006) for Asia Pacific countries, the share of sweet potato used as food from domestic supply regularly decreased from 68 to 44 %, but it was increased significantly for animal feed from 26 to more than 50 %. The latest data reported by FAO (2006) that the annual per capita of sweet potato available for consumption is about 6.43 to 7.91 kg in the period of 1996 to 2004.

Africa is an important country in the changes of world sweet potato production and consumption. Rwanda and Uganda are among countries which have significantly increased sweet potato production in recent years due to an expansion of cultivated area (Horton, 1988a). According to the sweet potato balance sheet, over 80 % of total production is used as food, with the reminder being noted as waste. The average quantities of sweet potato available for consumption was 124 and 127 kg per capita per year in Rwanda and Uganda, respectively (Horton, 1988a). The latest data provided by FAO (2006) showed the decreasing of average consumption for the last decade in both countries, i.e. 122.40 and 79.84 kg/capita/year. According to Scott *et al*. (2000), sweet potato consumption decline as per capita income increase. Beside that, data on aggregate per capita food consumption can cover shift food uses, for example from fresh to processed food.

2.2 Chemical composition and physicochemical properties

Tuber crops are well known as source of carbohydrate composing of dry matter. Sweet potato contains approximately 30 % dry matter and about 80-90 % is made of carbohydrate. The chemical composition of 101 sweet potato varieties from Malaysia and 90 hybrid clones were determined by Saad (1996). The result showed the wide variation of chemical composition. Starch, protein, fiber and ash contents were 10.3 - 38.71 %, 0.18 - 5.53 %, 1.77 - 5.49 % and 2.46 - 5.69 %, respectively. Bradbury & Holloway (1988a) reported 20.1 % starch, 2.38 % sugar, 1.43 % protein, 1.64 % fiber, 0.74 % ash in 164 sweet potato samples from 5 South Pacific Countries. Different from other root crops, sweet potato contains carotene that is important compound as a precursor of Vitamin A (Wolfe, 1992, Bradbury & Holloway, 1988a, DA-EVIARC, 2006).

2.2.1 Carbohydrates

As a main component in dry weight of sweet potato, carbohydrate is dominantly composed of starch and sugar, with lesser amount of pectin, hemicellulose, and cellulose. The variation of carbohydrate composition is relatively not only with cultivars and maturity of the root, but also with storage time and cooking and processing, and has considerable influence on quality factors such as texture, firmness, *dryness*, mouthfeel and taste. It is important to consider that starch in sweet potato root undergoes ready to enzymatic hydrolysis into sugars. According to Garcia & Walter (1998), some physical characteristics were also

affected by location of production. Moreover, Noda *et al.* (1996) found that starch characteristics were influenced in cultivar rather than level of fertilizer. On the other hand, Sharfuddin & Voican (1984) determined that high doses of potassium fertilizer significantly increase the percentage of starch in dry mater due to increasing of leaf photosynthesis. The sugar composition of sweet potatoes is a fundamental component of their eating quality. Although generally considered sweet by definition, there is potentially a large range in perceived sweetness amongst cultivars, depending on sugar components and starch conversion at cooking (Takahata et al. 1992).

2.2.1.1 Starch

Starch content in sweet potato varies very greatly. Starch content in fresh sweet potato root collected from five countries in Solomon Island varies from 17.7 % to 23.4 %, on average about 20.1 % (Bradbury & Holloway, 1988a), whereas Tian *et al* (1991) reported that sweet potato is rich in starch containing about 6.9 - 30.7% on wet basis. Research showed great variation in composition, for example 42.6 – 78 % (dwb) was exhibited among 18 cultivar growing a single in Brazilian location and 32.2 - 72.9 % (dwb) in Filipino and American cultivars (Truong *et al*. 1986a).

Starch occurs in plant tissue in the form of discreet granules whose characteristics of size, shape and form are unique to each botanical species. Sweet potato starch granules are oval, round, polygonal or bell with a central hylum and within

individual cultivar, vary greatly in size. In one cultivar, granule size ranged from 7 to 43 µm, moreover, between cultivars the mean granule size ranged from 12.3 to 21.5 µm (Woolfe, 1992). Sweet potato starch granules are reported as round, oval and polygonal shapes with sizes ranging between 2-42 µm (Tian *et al*, 1991, Hoover, 2001). According to Valetudie *et al*. (1999), Sweet potato VIII-18 light yellow flesh variety from West Indies has an average 15 µm diameter of granules. In medullar parenchyma cell, morphology of the native starch granules is much more heterogeneous, including polyhedric when smaller than 5 µm and spherical, hemispherical, ellipsoid or truncated when largest and up to 20 µm in diameter. Sweet potato starch granule commonly has an A-type structure crystalline organization as characterized by X-ray diffraction spectra. However, Gallant *et al* (1982), Zobel (1988), Lauzon *et al*. (1995) and McPherson and Jane (1999) argued that A types and C types of X-ray patterns have been found for sweet potato starches. Starch granules from the purple cultivars exhibited the Ca-type (C-type near A-type), and it's from orange cultivars exhibited C-type (Noda *et al.*, 1996).

Amylose and amylopectin are the two main polysaccharide component of sweet potato starch. Amylose molecule is a small, unbranched, straight-chained polymer with its glucose subunits being joined by α-1,4 links. The amylopectin is a larger, highly branched polymer of αα-1,4-linked glucose chains through α-1,6-glucosidic links. The amylose contents of sweet potato starch granules have variously been determined as ranging from 17.5 to 38 % in cultivar from United States, Philippines, Korea and Puerto Rico (Madamba *et al*., 1975, Shin & Ahn,

1983, Martin & Deshpande, 1985). While Noda *et al.* (1998) reported that amylose content of sweet potato from Japan was varied from 10 to 25%.

Gelatinization temperature of sweet potato has been variously reported by some researchers. It's take a place between 58 ºC and 80 ºC (Lii & Chang, 1978, Madamba *et al.*, 1975, Shin & Ahn, 1983). Moreover, gelatinization temperatures of sweet potato starches are reported in the range of 58 to 84 °C and the gelatinization enthalpy varied from 10.0 to 16.3 J/g (Takeda *et al.*, 1986, Zobel, 1988, Tian *et al*., 1991, Garcia & Walter 1998, Collado *et al.*, 1999). According to Zhang & Oates (1999), the content of amylopectin is a critical factor in governing the gelatinization temperature. Low gelatinization temperature sweet potato starches had less amylopectin and more amylose than high gelatinization temperature. In contrary, Noda *et al,* (1998) reported that the gelatinization properties of sweet potato starch were not affected by amylose-amylopectin ratio, but it was reflected by the molecular architecture of amylopectin.

The pasting behaviors of sweet potato starches exhibit a high peak viscosity and they become thinner rapidly with prolonged cooking before thickening on cooling (Tian *et al.*, 1991). However, for some sweet potato varieties no peak viscosities in the viscosity curves (Brabender Viscograph) were observed (Seog *et al.*, 1987). Despite amylose and amylopectin are responsible for viscosities character, it has been presumed that molecular weight and branched polymer density were affected in the intrinsic viscosities and reducing power. The degree of polymerization of sweet potato amylose has been reported in the range 3,025 to 4,100, while for amylopectin the average chain length of 21-29 was reported (Hizukuri, 1985,

Takeda *et al*., 1986, Ong *et al.*, 1994). The starch of sweet potato was found to have amylose containing lower degree of polymerization than legumes starch. Some cultivar have relatively low intrinsic starch viscosities and high starch reducing power, suggesting low molecular weights and highly branch polymer, however others appeared to have a high molecular weight and highly branch polymer (Martin & Deshpande, 1985).

When starch solution, paste or gel age they undergo physicochemical changes known as retrogradation, such changes include a reorientation of the starch solutions and subsequent hydrogen bonding to form crystalline structure. Sweet potato starches have been reported to retrograde more slowly than wheat and corn starches but similar to potato starch (Del Rosario & Pontiveros, 1983), while Takeda *et al.* (1986) found that sweet potato amylose appeared to retrograde at the same rate as tapioca amylose but it retrograded more slowly than potato amylose. Since there are many varieties of sweet potato grown in different field conditions, large variations in starch physicochemical properties are not really surprising.

In common with most other root and tuber crops, raw sweet potato starch is more resistant than the raw cereal starches to the action of digestive enzyme such as amylase. Sweet potato starch was only 2.4 % digested by bacterial α-amylases as compare to 9.2 % for maize and 17.6 % for wheat (Rasper, 1969). Other workers found that sweet potato starch was only 15 % degraded in 6 hours compared to 20 % for cassava. Susceptibility to amylase degradation was increased by rupture of starch granules by pelleting (animal feed use). Moreover, the susceptibility of sweet potato starch by α-amylase greatly increases on cooking. For example, it

reached 54 % after boiling sweet potato in water for 30 minutes (Rasper, 1969, Walter *et al.*, 1975, Truong *et al.*, 1986a)

The textural properties of starch are altered according to the large variation in the amylose-amylopectin ratio. The sweet potato starch amylopectin-amylose ratio is varied but generally about 3:1 to 4:1. The amylopectin-amylose ratio doesn't change in sweet potato during curing and storage according to some researchers (Bertoniere *et al*., 1966). Some researches found it increases on curing, remain stable during subsequent storage. It has been suggested that low amylose-high amylopectin content is responsible for the moist, sticky texture when baked, but other work found no correlation between *moistness* and amylopectin content (Woolfe, 1992).

2.2.1.2 Sugars

Free sugars are one of important constituent affecting the quality of fruits and vegetables, including sweet potato. The sugar composition of sweet potatoes is a fundamental component of their eating quality. Although generally considered sweet by definition, there is potentially a large range in perceived sweetness amongst cultivars, depending on sugar components and starch conversion at cooking (Takahata et al. 1992). The major sugars occurring in sweet potato roots are sucrose, glucose and fructose. Sucrose is generally the secondary sugar in the cultivars but became the primary sugar in certain cultivars such as Jewel, Jasper and Travis roots during certain period of storage (Picha, 1986a). In all cases of

cultivars analyzed the concentration of sucrose exceeded that of the other sugars (Truong *et al.* 1986a, Tamate & Bradbury, 1985, Martin & Deshpande, 1985, Picha, 1985b). In some cultivars the concentration of glucose is higher than that of fructose, in others they are present in approximately equal amount (Huang *et al.,* 1999a). Picha (1986a, 1986b) argued that glucose content after harvest of six cultivars grown in the USA was higher than fructose, while Takahata *et al.* (1996) reported that glucose and fructose were present at approximately equal concentration in six cultivars cultivated in Kyushu, Japan.

Variability in total sugar between sweet potato samples is ranging from 0.38 % to 5.64 % (fresh weight basis) among cultivar from various regions of the South Pacific (Bradbury & Holloway, 1988a) and from 2.9 % to 5.5 % (fwb) in American cultivar (Picha, 1985b). On a dry weight basis, total sugar varied from 5.6 % in Filipino cultivar to 38.3 % in a Louisiana sample (Truong *et al.* 1986a). Tamate & Bradbury (1985) stated that variability on sugar content exist even within different roots of the same cultivar. Picha (1986a) reported that total sugar concentration was changed during storage for different cultivars tested due to the altered activity of β-amylase as a result of curing. Moreover, Takahata *et al.* (1996) and Huang *et al.,* (1999a) found that there was significant relationship between acid invertase activities and hexose content affecting the varietal differences in sugars content in raw storage of sweet potato roots.

Regarding the moistness of sweet potato tubers, Walter *et al.* (1975) and Hammet & Barrentine (1961) reported that reducing sugars is one of important constituents to the quality of cooked sweet potato. Sopade & Filibus (1995) have measured a

reduction in the viscosity of gelatinized maize starch with an increasing level of sucrose, and they attributed this to the diluting effect of the disaccharide as a result of its much lower molecular weight than starch. Ahmad & Williams (1999), also, measured a reduction in storage modulus with increasing concentration of sugar, and glucose was more effective than fructose. Although both glucose and fructose are monosaccharides and hexose sugars, they are structurally different, and this could bear on their hydrogen binding strength. Whereas Reddy & Sistrunk (1980) argued that reducing sugar showed insignificant effect on texture of cooked tubers compared to starch, pectin, hemicellulose and cellulose content. Moreover, Ali & Jones (1967) and Swingle (1965) also found no relationships between moistness and carbohydrates component including reducing sugars.

The presence of reducing sugars was responsible to the flavour, aroma and dark coloured pigment. This phenomenon is called nonenzymatic browning that occurred during preparation and processing involving heat. When reducing sugars are heated with amines, amino acids or protein, a series of complex reaction, referred as the Maillard reactions occurs. The reducing sugars are essential in this initial step of the Maillard reaction which involves a reversible condensation between the carbonyl groups of reducing sugars and the α-amino-group of amino acids or proteins. The intermediate dicarbonyl compounds formed, such as aldehyd, furans, maltol, isomaltol, diacetyl, and the third route in the Maillard reaction involves oxidation of amino acid. The reaction called Strecker degradation, leads to formation of various aldehydes that responsible for the flavour of heated foods (Izydorczyk, 2005, Jouppila, 2006). Picha (1986c) reported that an association between reducing sugars and amino acids was found

between the levels of reducing sugars, glucose and fructose, in different cultivars or as a result of storage and degree of chip browning. The increase in maltose from trace level in the raw tubers to more than 2 % in the fried chips was also considered to be a factor in discoloration (Baba et al., 1981).

In raw tissue, sucrose, glucose, and fructose are present, whereas maltose is only produced during cooking (Picha, 1985). Maltose has also been found in low concentrations in raw roots (Bradbury & Holloway, 1988a, Truong *et al.*, 1986a, Tamate & Bradbury, 1985), but Picha (1985b) and Losh *et al*. (1981) found it was absent. Maltose is only produced when sweet potato roots are heated and may contribute substantially to product sweetness. During heating, much of the starch is converted into dextrins and maltose by α-amylase and β-amylase (Walter et al., 1975). However, there are cultivar differences in the degree of starch conversion (Babu, 1994). The general principles of maltose synthesis are known. Sweet potato starch is gelatinized at 68- 73 °C, and is then available for hydrolysis by enzymes (Walter *et al.,* 1976). From the onset of gelatinization, α-amylase rapidly degrades starch, whereas β-amylase hydrolyses the starch and starch fragments into maltose (Kiribuchi & Kubota 1976). The concentration of maltose increases significantly during cooking due to starch hydrolysis, which also produces polysaccharides of varying chain length known as dextrin.

Oligosaccharides, such as raffinose, stachyose and verbascose are interesting component to determine. These are important consideration to sweet potato consumer in connection to the poorly documented occurrence of flatulence among sweet potato consumers. It seems to be quite generally recognized that

consumption of sweet potato causes flatulence which can be severe (Palmer, 1982). It is well known in Asian consumer that flatulence is generated from sweet potato (Tsou & Yang, 1984). Raw and cooked Philippines sweet potato roots contained 0.23 - 0.4 % cellobiose, negligible raffinose, verbascose in only trace amount and no detectable stachyose (Truong *et al*., 1986a). Raffinose was reported at 0.5 % of the fresh weight in baked sweet potato (Palmer, 1982). Nine cultivars grown in Taiwan contained at levels ranging from no detectable to 1.08 % (dwb) and, whilst seven of the nine did not contain detectable amount of stachyose, two cultivars contain 0.2 and 0.9 % (dwb) (Tsou & Yang, 1984). The concurrence of flatulence has been suggested as a possible factor contributing to the low acceptability of sweet potato by consumers to increasing sweet potato intake (Tsou & Villareal, 1982).

2.2.2 Nitrogenous constituent

Nitrogenous compounds collectively referred to crude protein or total protein. Sweet potato contains a minor fraction of total protein content in dry matter compared to carbohydrates. It has been estimated by Walter *et al.* (1984) that sweet potato yields on average 184 kg protein/ha comparing to estimated on average yields of wheat (200 kg/ha) and rice (168 kg/ha). The concentration of protein as eaten is the first concern to consumer of cooked or processed sweet potato. The composition of most roots and tubers change a little on boiling, whereas that of cereals in preparation which absorb large quantitative of water changes significantly as nutrient are diluted (Wolfe, 1987).

Total protein in sweet potato usually is determined as Kjeldahl N x 6.25. The total protein content is on average about 5 % (dwb) or 1.5 % (fwb). This includes all nitrogenous compounds present in analysis. At harvest, these are made up of approximately 75 % true protein (coagulable) and 25 % non protein nitrogen (NPN) (Purcell & Walter, 1980). A range of total protein from 1.27 to 10.70 % was found among 300 lines grown in Taiwan under similar condition of cultivation, with the majority containing 4-5 % protein (Li, 1974). Dickey *et al.* (1984) reported that total protein of 100 seedlings from 7 parental clones grown in American location ranged from 4.38 to 8.98 % (dwb) with mean 6.29 %. On fresh weigh basis, the total of six American cultivars analyzed immediately after harvest ranged from 1.36 to 2.13 % (Picha, 1985a), while Bradbury *et al.* (1985b) reported that ten cultivars grown in Papua had 1.29 to 1.81 % (fwb).

A large percentage of true protein in the plant, in a storage capacity as it has been found in a high concentration in fresh root, but only low level in stem, petioles, leaves or sprouted roots (Maeshima *et al.*, 1985) and was almost absent in roots stored for one year (Lii & Oba, 1985). In general, sweet potato protein has more asparagine, but less of the sulphur-containing amino acid than maize or rice protein and less lysine and more S-containing amino acid than legumes protein (Purcell *et al*., 1972). Sweet potato protein has similar amino acid pattern to other roots and tubers. Wide range of all sweet potato essential amino acids have been found, due to varietals, environmental, cultural effect and post harvest treatment of roots (Bradbury *et al.* 1984, 1985b, Purcell & Walter 1982). They may also

reflect differences of analytical methods that are difficult to reproduce among laboratories even for a single sample (Woolfe, 1992).

Starch granules contain small quantities of other "minor" components, such as proteins, and known as starch granule associated proteins (SGAP). Typical root or tuber starch (e.g. sweet potato) contains 0.05% protein (Suurs & Raedts, 1993). Although on a quantitative scale this constituent is deemed minor, there is increasing awareness that it presence significantly affects both the properties of the granule as a whole and the properties of starch-derived products (Seguchi & Yamada, 1989, Hamaker & Griffin, 1993). At least ten major SGAPs can be extracted from most starches and have molecular weights in the range of approximately 5 to 149 kDa. A substantial number of these proteins are located at the starch granule surface, where their presence in association with that of other minor granule components such as lipids (Baldwin, 2001), while Malouf *et al.* (1992) suggested that the majority of starch granule-associated proteins (including the higher molecular weight proteins) are located at the surface of the granule, and that only a small amount of protein is located within the granules. The principle physical difference between hard and soft endosperm appears to lie in the adhesive strength between the starch granules and the surrounding protein matrix. Additionally, "friabilin" was responsible or at least a marker for endosperm texture, the "friabilin" protein(s) have also been known as "grain softness protein" (Jolly *et al*, 1993). In maize, the binding of protein oryzin to the starch components had a positive influence on the stickiness of cooked rice (Chrastil, 1990).

Non protein nitrogen (NPN) of sweet potato includes peptides to be precipitated by reagents which coagulated true protein, free amino acids, amides and other non-polymeric nitrogen compounds. Its main component after 107 days storage were asparagin (61 %), aspartic acid (11 %), glutamic acid (4 %), serine (4 %) and threonine (3 %) (Purcell & Walter, 1980). The remaining 5.5 % of NPN include of small amount of other amino acids and ammonia. A further 11.5 % N remained unrecovered and unidentified. The total nitrogen in NPN of 10 high protein seedlings out of 100 seedlings grown from seven parents ranged from 22.1 to 37.7 % (mean 29.6 %) (Dickey, *et al.,* 1984). NPN is undoubtedly part of a metabolically active pool containing large amount of amino acids as demanded by the roots (Purcell & Walter, 1980).

Part of protein present acts as an inhibitor of proteolytic digestive enzymes trypsin. The three different trypsin inhibitors were isolated from Japanese sweet potato roots by Sugiura *et al.* (1973). Inhibitors II and III were calculated to have molecular weight of 23,000 and 24,000 daltone respectively. They were acidic proteins, a finding confirmed by others (Lin *et al.* 1983), that also in Taiwan samples, found three to four different molecular species of inhibitors. Nigerian workers isolated 10 trypsin inhibitor from roots grown locally and the molecular weights of three most active inhibitors were estimated to be 12,000, 10,000 and 9,300 (Obidairo & Akpochafo, 1984).

2.2.3 Lipids

The lipid content of sweet potato is very low and nutritionally insignificant. Lipid concentration varies from 0.17 % to 1.0 % (fwb) in raw sweet potato tuber (Bradbury & Holloway, 1988a). Haytowitz & Matthews (1984) found that the lipid content of sweet potato tubers ranged from 0.1 to 0.8 % (fwb). Highly significant genetics differences were found among nine United States cultivars grown under uniform conditions, with values ranging from 1.21 % to 2.55 % on dry weight basis (Boggers *et al*. 1970). Walter *et al.* (1971) divided the lipid of Centennial cultivar into three classes: neutral lipid (42.1 %), containing neither sugar nor phosphorus in their molecules; glycolipids (30.8 %) and containing sugar; and phospholipids (27.1 %), which contain phosphorus. The analysis was not carried out to sweet potato after harvest but after curing for two weeks followed by storage at 16 ºC and 60 % relative humidity for 9 months. The lipid soluble carotenoid mainly found in neutral lipid fraction and in amount 2.3 % of total lipid.

Analysis of lipid fraction for their fatty acid composition showed that palmitic acid (16:0) and linoleic (18:2) acids are most abundant in all fractions, comprising 29.3 % and 44.7 % of the total lipid, respectively, (Walter *et al.,* 1971). This work gives similar result to other studies, approximately equal amounts of linoleic and oleic (18:1) acids which were found in Korea sweet potato lipids (Lee & Lee, 1972). The sum of linoleic and linolenic acids accounted for 59.1 % of the total fatty acids in a West African samples while the neutral lipid of Centennial contained 52.4 % unsaturated acids, and phospho- and glycolipid were more than 60 % unsaturated (Walter *et al*., 1971).

As mention in previous section, starch granules contain small quantities of other minor components, such as proteins, lipids, pentosans, and minerals (Zobel. 1988). The presence of minor component significantly affects the properties of the granule as a whole and the properties of starch-derived products. However, Blaszczak *et al.* (2003) postulated that the surface lipid constituents (i.e. , 0.05 % and 0.2 % in cereal and tuber starches, respectively) are susceptible to autoxidation, which is strongly related to their chemical character. Polar lipids (e.g., monoglycerides, fatty acid and similar compounds) form a helical inclusion complex with amylose molecule, between the hydrocarbon chain of the lipid and the helix of amylose (Eliasson & Gudmundsson, 2006). The amylose-lipid complex involves a coil helix transition (Eliasson & Kim, 1995). The lipids enter the helical cavities of starch molecules and modify the rheology of starch (Biliaderis & Juliano, 1993, Kaur & Singh, 2000, Krog, 1973).

During gelatinization, the starch granule swells to several times its initial size, ruptures and simultaneously amylose leaches out from inside the granule. Three-dimensional networks is formed by the leached out amylose (Eliasson, 1985 and Tester & Morrison, 1990), the lipids, either native or added, form complexes with exuded amylose, probably on the surface of the granules and retard their swelling; as a result the gelatinization temperature is somewhat increased (Larsson, 1980, Lorenz, 1976, Singh, *et al.*, 2002). Monoacyl lipids and surfactants found affect the rheological properties of the starches. Lipid or surfactant make the starch granules more rigid until certain temperature is reached, therefore, starch pastes should become more viscous when lipids or surfactant are added, and gels should

be firmer than starch pastes or gels without added lipid or surfactant (D'Appolonia & Moral, M.M, 1981). Although the lipid binding to amylose has been shown to be cooperative, the binding to amylopectin was found to be non cooperative interaction and negligible (Lundqvist *et al*., 2002a, Lundqvist *et al*., 2002b, Eliasson & Gudmundsson. 2006).

2.2.4 Vitamins

Sweet potatoes are substantial sources of ascorbic acid (vitamin C), and contain moderate amount of thiamin (B_1), riboflavin (B_2) and niacin as well as pyridoxine and its derivates (B_6), pantothenic acid (B_5) and folic acid. It has been reported to contain satisfactory quantities of vitamin E. Sweet potato lays in the ability to produce variable and sometime large quantities of the carotenoid which act as precursors of vitamin A.

2.2.4.1 Vitamin A

One of the major contributions which sweet potato could make to health and welfare of humankind is that of supplying carotenoid as vitamin A precursors. Dark orange-fleshed roots are rich sources of beta-carotene, the most active provitamin A carotenoid, and yellow or orange roots supply moderate amounts (Woolfe, 1992). Carotenoids are produced only in the plant and are converted to vitamin A in the intestinal mucosa of humans. Sweet potato contains high level of

total carotenoids, especially in the orange flesh cultivar, beta-carotene is the major carotenoid present. However, the fraction of the total beta-carotene decreases as the total carotenoid content decrease. Samples of sweet potato from Papua New Guinea and the Solomon Island contained respectively an average of 0.084 mg/100 g and 0.048 mg/100 g beta-carotene (Bradbury & Holloway, 1988a). Cream to pale yellow sweet potatoes collected in five major American cities during 3 months of a year period contained 0.184 mg/100 g to 0.368 mg/100 g beta-carotene determinate by HPLC. The principal carotenoid in seven lines of cream to yellow flesh sweet potato was beta-zeacarotene. However, the cultivars with deep orange flesh are rich sources of beta-carotene, American samples having been found to range from 3.36 mg/100 g to 19.60 mg/100 g (fwb) of beta-carotene (Woolfe, 1992). In Philippine, the average vitamin A content of yellow and white-fleshed colour approximately 1,255 and 60 µg/100g (fwb), respectively (DA-EVIARC, 2006). Vitamin A content of food is also expressed in IU (International Unit). Bangladesh Agriculture Research Institute (BARI) (2006) released four new sweet potato cultivars in 1994 and 2004 having creamy-flesh colour contained vitamin A ranged from 700 to 1050 IU/100 g edible portion (fwb). Moreover, USDA (2001) reported that raw and cooked sweet potato roots contained 20,063 and 17,054 IU/100 g (fwb), respectively.

2.2.4.2 Vitamin B

The range of vitamin B such as thiamin (B_1), riboflavin (B_2) and niacin (B_3) contents in some cultivars from South Pacific were 0.04 - 0.12, 0.02 - 0.06 and 0.26 - 0.89 mg/100 g (fwb), respectively (Bradbury & Singh, 1986). Total vitamin B_6 content of raw sweet potato was determined in Britain as 0.09 mg/100 g (fwb) (Kwiatkowska *et al.,* 1989), while New Zealand samples contained 0.15 mg/100 g (fwb) (Visser & Burrows, 1983). USDA (2001) reported that B_1, B_2, B_3 and B_6 content of raw sweet potato were 0.066, 0.147, 0.674 and 0.257 mg/ 100 g (fwb) respectively. There does not appear to be published information on the factors contributing to such variations in these or other vitamin B groups in sweet potato.

2.2.4.3 Vitamin C

Vitamin C is one of vitamin found in sweet potato fresh root that usually determined as only an ascorbic acid and not dehydroascorbic acid. However, most staples and vegetables contain vitamin C in both reduced and oxidized form. Both have full vitamin C activity, but post harvest oxidation of ascorbic acid to dehydroascorbic acid is reversible, may proceed irreversibly to produce inactive 2,3-diketogulonic acid with affect of loss vitamin C activity (Woolfe, 1992). The variability vitamin C content in sweet potato root can exist between cultivar. Samples from Papua New Guinea were reported to contain as much as 64 mg/100 g edible portion (Farnworth, 1973). Vitamin C content of samples from South Pacific countries was 30 mg/100 g. Total ascorbic acid in four samples from

Solomon Island varied from 19.8 to 32.9 mg/100 g (fwb) (Bradbury & Singh, 1986). Moreover, Bradbury & Holloway (1988a) calculated the amount of ascorbic acid and dehydroascorbic acid in sweet potato tubers from 9 countries was 24 mg/100 g. On average, vitamin C content of yellow-fleshed colour approximately 30 mg/100 g (fwb) of edible portion (DA-EVIARC, 2006). USDA (2001) reported the average vitamin C content of 12 samples was 22.7 mg/100 g (fwb) of edible portion. Lanier and Sistrunk (1979) found that variation was occurred on reduced ascorbic acid content of four cooked cultivars grown in one location in the same year ranged from 10.3 to 30.8 mg/100 g (fwb), while USDA (2001) reported the vitamin C content of cooked roots was 17.1 mg/100 g (fwb). Beside that, the cultivation method also affected the vitamin C content. Sharfuddin & Voican (1984) concluded that raising of fertilizer levels (K) from 62 to 186.7 kg/ha significantly lowered ascorbic acid content. Another study found an insignificant increase in ascorbic acid with later harvest date of three cultivars (Abubakar, 1982).

2.2.4.4 Vitamin E

Vitamin E in sweet potato determined in the form of tocopherol ranging from 0-10 mg/100 g (fwb) determined by several researchers (Hirahara & Koike, 1989). Raw New Zealand sweet potato roots were reported to contain 0.75 mg tocopherol/100 g (fwb) (Visser & Burrows, 1983), while Haytowitz & Matthews (1984) found that the white-fleshed colour sweet potato contained approximately 4.56 mg/100 g (fwb). There was no effect of cooking on tocopherol content was reported to

contain 0.28 mg/100 g (fwb) by USDA (2001). North American sweet potato baby food was found to contain alpha and beta-tocopherols (Davis, 1973). The analysis of the nutritionally most potent form α-tocopherol was the predominant component with other tocopherols undetected or present only in traces. α-tocopherol distribution within the root in one cultivar was in the order centre>upper part>lower part, but this difference was not significant. These differences were more attributable to effect of growth location than generic variation (Woolfe, 1992).

2.2.5 Minerals

The ash (non volatile inorganic residue) content of sweet potatoes averages approximately 1 % of the fresh root weight or about 3 – 4 % of the dry weight (Woolfe, 1992). Table 2 shows the mineral composition of sweet potato root. Ash contains trace minerals and trace elements, some of which have a function in the life of the plant. Others are absorbed in varying quantities depending on their concentration in the soil in which the roots are grown, or are derived from the fertilizer or spray employed during cultivation. The ash content of sweet potato peel is much higher than in that of in the flesh (Woolfe, 1992). Wolinski *et al.* (1988) indicated that peeling of sweet potatoes may significantly reduce level of nutritionally important mineral such as Ca and Fe. The extent of this reduction may depend on whether the root is peeled before or after cooking, and the percentage of peel which is removed.

Table 2 Mineral composition of raw sweet potato roots (mg/100 g, fwb)

Mineral	South Pacific SP. roots		General	
	Mean[a]	Ranges[a]	Mean[b]	Ranges[b]
Ca	29	7.5 - 74.5	24	17 - 34
P	51	41.0 - 70.0	41	28 - 54
Mg	26	18.4 - 35.7	20	14 - 23
Na	52	13.8 - 84.0	21	13 - 30
K	260	129 - 382	396	342 - 488
Fe	0.49	0.16 - 0.94	0.69	0.59 - 0.86

Notes: Adapted from: Bradbury & Holloway, 1988a.
[a] = Mean and ranges of 164 samples from 5 South Pacific countries (Bradbury & Holloway, 1988a)
[b] = Mean and range (Lopez, *et al.,* 1980, Monro, *et al*., 1986, Ohtsuka *et al*., 1984, Picha, 1985c).

Sweet potato is not an outstanding source of calcium, a characteristics shared with most other plant staples, vegetables and fruits. However, sweet potato has a noticeable better Ca content than plantains, potatoes, yams, boiled rice, and cereal porridge or noodle dishes. One hundred grams of sweet potato can contributes 3 - 5 % of daily Ca requirement (Haytowitz & Matthews, 1984). Sweet potatoes are good source of phosphorus, being similar in this respect to other roots and tubers, vegetables and most cereals on a cooked basis. One hundred grams of boiled sweet potato supplies about 6 % of USRDA for P for both adult and children (National Research Council, 1989). Madamba *et al.* (1975) reported P content of sweet potato tubers was vary from 9 to 22 mg/100 g, and was 20 mg/100 g in two Taiwanese sweet potato tubers (Lii & Chang, 1978). The concentration of potassium, and the K:Na ratio, is higher in sweet potatoes, which could be used beneficially in diets designed to restrict Na intake. The iron content is comparable to some of other roots and tuber staples and to that of cereals cooked into

porridge, noodles or pasta. Although not an outstanding source of Fe, 100 g of boiled sweet potato roots can theoretically supply between 5 to 14 % of the estimated daily requirement for small children. Other elements are present as shown by various analysis are Fe, Cu, Mn, Zn, S and Cl. In addition, B, Cd, Ni and Pb, Hg, Se, and Si may be present. Within cultivars, minerals are not evenly distributed throughout the root. Other, less extensively investigated trace elements reported to have beneficial effects in human include copper, chromium, manganese, selenium and molybdenum (Passmore *et al*., 1974; National Research Council, 1980). The fluoride content of sweet potato has been measured as part of a study determines the contribution of foods to endemic fluorosis in South India (Venkateswara Rao & Mahajan, 1990). At approximately 0.5 mg/kg (fwb) the fluoride content of sweet potato roots was higher than that of other roots and tubers, but low compared with most other food analyses.

As a substantial mineral, phosphorus contents differed in different granular sizes. Jane & Shen (1993) reported the phosphorus content decreases with an increase in the granule size. Starch at the core had greater phosphorus content than that at the periphery. Both the remaining and the gelatinized starch had smaller contents of phosphorus than the original starch. Starch contains two type of phosphorous in small quantities: esterified phosphorous and phospholipids (Hizukuri *et al.*, 2006). The ester phosphate groups are found exclusively in amylopectin. Takeda *et al.* (1986) studied the structure of the phosphate ester and found that sweet potato amylopectin contained phosphate ester at C-3 or P3. Whereas, Lim et al. (1981) reported that larger amount of starch phosphate are on C-6 than C-3 in potato, sweet potato, lotus, arrowroot, green pea and mungbean. Phosphorous content of

sweet potato starch was 117 – 132 ppm, 82 – 99 ppm and 110 for P_0, P6 and Monoester-P, respectively (Hizukuri *et al.*, 2006).

Starch contains two type of hydroxyl, primary (6-OH) and secondary (2-OH and 3-OH). These hydroxyls are able to react with multifunctional reagent resulting in cross-linked starch (Xi et al. 2005). Cross-linking is done to restrict swelling of the starch granule under cooking conditions or to prevent gelatinization, however Mirmoghtadaie, *et al.* (2009) argued that cross-linking decreased the swelling factor whereas it increased syneresis but gelatinization temperature of starch was not significantly affected after cross-linking. Moreover, cross-linking alters not only the physical properties, but also the thermal transition characteristics of starch. Decrease in retrogradation rate and increases in gelatinization temperature have been observed with cross-linked starch, and these phenomena are related to the reduced mobility of amorphous chains in the starch granule as a result of intermolecular bridges (Singh, *et al.*, 2007). However, Jyothi *et al.* (2006) showed that cross-linked starch has more pronounced syneresis than has native starch because of ordered structure in the starch paste, thus resulting in a higher degree of retrogradation.

Starch granules can be interconnected by reactions with trace amounts of a multifunctional reagent (Seib, 1996). The reagents permitted by FDA for making cross-linking food grade starch are phosphoryl chloride, sodium trimetaphosphate, adipic acetic mixed anhydride, and mixtures of sodium trimetaphosphate and sodium trypolyphosphate.

There are two factors by which minerals can be lost during cooking of roots or tubers, which remove the outer skins and variables percentages of the underlying flesh, and through leaching of soluble minerals such as K and Na into surrounding cooking water. Whereas, an apparent slight increase in some mineral on roasting or baking can be accounted for by loss of moisture in the former, but not in the latter, which had the same moisture content as the raw roots (Ashida, 1982., Haytowitz & Matthews, 1984).

2.2.6 Non-starch polysaccharides

In addition to starch and sugar, root crops also contain some non-starch polysaccharides, including celluloses, pectins and hemicelluloses, as well as other associated structural proteins and lignins (FAO, 1990). The pectic substances, hemicelluloses and celluloses were the compound classified together as non-starch polysaccharides which are found in the middle lamella or plant cell wall. Pectic substances are polysaccharides found in plant intercellular or middle lamella region. They consist of water-insoluble protopectin, soluble pectic and pectinic acids and pectins, and also may contain small amount of the sugar D-galactose, L-arabinose and L-rhamnose (Woolfe, 1992). Hemicelluloses are cell wall polysaccharides classed according to the sugar present in their molecules, and known as mannans, xylans etc. Cellulose is a straight chain made up of glucose units held together by beta-1,4 linkages. It is a highly ordered a fibrillar structure occurring in the cell wall, and is water-insoluble and largely indigestible by human.

As a group, pectic substance, hemicellulose, and cellulose are classed as dietary fiber, and play a role in the nutritional value of sweet potato (Woolfe, 1992). The total dietary fibre (components unspecified) of raw sweet potato samples from Solomon and Papua New Guinea ranged from 1.20 % to 2.62 % (fwb) (Bradbury *et al.*, 1985a). Sweet potato is a significant source of dietary fibre as its pectin content can be as high as 5 % of the fresh weight or 20 % of the dry matter at harvest (Collins & Walter, 1982). The mean dietary fiber content (fwb) of four cooked American cultivars, calculated as the sum of pectin, hemicellulose and cellulose was 3.6 % (0.97 % + 0.93 % + 1.7 %) (Reddy & Sistrunk, 1980), while Bradbury & Holloway (1988a) reported that dietary fiber of sweet potato fresh root was 1.64 %. The total non-starch polysaccharide content of sweet potato flesh boiled for 5 minutes was 2.4 g/100 g (fwb) or 8.1 g/100 g (dwb) according to British researchers (Englyst *et al.*, 1988). These comprised of 40 % cellulosic and 60 % non-cellulosic polysaccharides.

Food textural properties, including firmness, are dependent on tissue organization (microstructure). In sweet potato, starch and cell walls exert a significant influence on textural properties and, whereas starch has been the object of a considerable amount of the research (Collins & Walter, 1992), only isolated reports of the composition of sweet potato cell wall exist. It has been suggested that pectic constituent contributes to textural attributes, such as firmness, *moistness* and *dryness* of baked roots (Shin & Ahn, 1983). Sistrunk (1971) reported that pectic substance played a key role in firmness of canned roots. Hardcore, a disorder induced in raw roots by chilling temperatures and manifested

in cooked roots as very hard areas of flesh, and had been correlated with content of protopectin and other pectin fractions (Daines *et al*, 1976, Buescher *et al*., 1976). Pectin content and pectin classes based on solubility have been determined for a number of cultivars at harvest and after storage (Ahmed and Scott, 1957). Decline in protopectin (Baumgardner and Scott, 1965) and hemicellulosic material (Sistrunk, 1971) has been correlated with decline in firmness of canned sweet potatoes. Shen & Sterling (1981) reported that baked, moist-type sweet potatoes exhibit large declines in hemicellulose, whereas the firmer, dry-type roots, when baked, show much lower declines in hemicellulose. Walter *et al.* (1990, 1993) reported that for sweet potato French fries, as firmness retention increased, water-soluble pectin content increased. They also showed that firmness retention increased as the pectin methyl ester content of the pectic substances decreased. Recently, Noda *et al*. (1994) fractionated and analyzed the cell wall material from Koganesingane cultivar sweet potato.

2.2.7 Carotenoid

Carotenoid is a pigment that is responsible for the cream, yellow, orange or deep orange flesh colour of sweet potato roots. The deep orange flesh colour is largely a function of concentration of beta-carotene. The amount of total carotenoid present as beta-carotene is high in yellow to deep orange flesh cultivars. Some cultivars with white flesh root contain no beta-carotene and others have small quantities (Bradbury & Holloway, 1988d). Those with creamy or light yellow

flesh may also contain traces only (Garcia *et al*., 1970), and the purple flesh sweet potato contain very low of beta-carotene (Wolfe, 1992).

The major factor influencing total carotenoid content is cultivar. The carotenoid content of 17 cultivars grown in Taiwan ranged from 0.40 mg/100 g (fwb) in local cultivar up to 24.80 mg/100 g (fwb) in cultivars introduced from the United States (Wang & Lin, 1969). While carotenoid content of 26 cultivars grown in Los Banos, Philippines, with flesh colour from white through cream and yellow to carrot-like, varied from traces only to 11.45 mg/100 g (fwb) (Garcia *et al*., 1970). Huang *et al.* (1999b) reported that orange fleshed varieties grown in Hawaii contained 6.7 – 13.7 mg/100 g (fwb), which was substantially lower than those reported by Bureau and Bushway (1986) for mainland USA varieties. However, variations occur in both total carotenoid and beta-carotene not only between but within cultivars. The stem end of a root has also been found to contain two or three times as much carotene as the root end. Variation in carotenoid content is much greater between cultivars than between production sites, but significant differences between locations for a particular cultivar occur. Differences between locations varied from as much as 62 % to 93 % in three American cultivars (Hammet, 1974). Variations in planting date within the usual season were not shown consistently to affect carotenoid levels at harvesting time. Time of harvest of roots from the same planting also showed no consistent effect on carotenoid content. Abubakar (1982) found that carotenoids were highest at first harvest (125 days after planting) for two of three cultivars, the third increasing in carotenoid concentration with prolonged harvest date.

Carotenoid content is affected by the management of tubers after harvesting including processing. Carotene content of Centennial, Travis, Jasper and Jewel were 9.5, 6.3, 5.4 and 5.0 mg/100 g of fresh root at harvesting time respectively, and increased slightly after curing and short time storage at either 7.0, 15.6 or 26.6 ºC (Picha, 1985a). Boiling unpeeled medium-size sweet potato roots for 30 min resulted in a 14 – 59 % reduction of the total carotenoid content of four sweet potato cultivars (K'osambo *et al.*, 1998), while Hagenimana *et al.* (1999) reported that a 20 % loss in total carotenoid content (dwb) after boiling for 30 min and mashing the roots of cultivar Zapallo. Van Jaarsveld *et al.* (2006) also reported that beta-carotene content of orange-fleshed sweet potato, variety Resito cultivated in South Africa, decreased after boiling. Retention of beta-carotene varied with the cooking condition, ranging from 82 to 92 % when the tubers was boiled from 20 to 30 min, but the retention was lower, ranging from 70 to 80 %, when sweet potato of different size were boiled which took 30 min.

Carotenoids other than beta-carotene identified in orange flesh roots include alpha- gamma- and zeta-carotenes, phyotene, phytofluene, beta-carotene-epoxide, hydroxyl-zeta-carotene, and beta-carotene-furanoxide (Purcell & Walter, 1968). Either beta-zeacarotene or neurosperene was the principal Carotenoid in several white or pale-flesh cultivars (Martin, 1983). Zeta-carotenes, phyotene, phytofluene, and nourosperene are intermediate substances in biosynthetic pathway leading to the production of biologically active carotenoids (Bauernfiend, 1972). The chief important in diet of beta-carotene and the other nutritionally active carotenoid lays in their provitamin A activity.

2.2.8 Anthocyanins

The acylated anthocyanin presenting in various parts of plants causes the pigmentation such as red, purple or blue. In some cultivars having colour of beetroot pronounce the present of anthocyanin. The purple-fleshed colour of sweet potatoes contains high level of anthocyanin, compared to white, yellow, and orange-fleshed ones, and the content differ depending on varieties (Suda *et al.* 2003). The major sweet potato anthocyanins are acylated glucosides of cynidrin and poenidin substituted in 3'- and 5'- carbon position on the flavilum nucleus: acyl groups of the pigment are caffeic, ferulic and p-hydroxybenzoic acid (Nozue *et al.* 1987). While Imbert *et al.* (1966) reported that the major anthocyanin in sweet potato was dicaffeoilpeonidin-3-sophoroside-5-glucoside. The concentration of anthocyanin is affected by the stage of development of the root. Large roots of 300-400 g contain about 200 mg/100 g total anthocyanin (dwb), whereas those of the same cultivar weighing only 80 - 150 g contain about 300 mg/100 g (dwb) anthocyanin (Woolfe, 1992). The cultivar Ayamurasaki from Japan is used as a natural food colourant and the anthocyanin content of this variety is about 0.6 mg/g (Yoshinaga, 1995).

The possibility exists of selecting cultivars especially for the purpose of extracting their very high level of anthocyanin. There is an increasing world-wide interest in the use food colourants from natural sources to replace those made by chemical synthesis. Sweet potato anthocyanins have been found to constitute a source of stable pigments, suitable for addition to beverages (Bassa & Francis, 1987). Anthocyanin of red sweet potato from Peru was found highly to moderately

resistant to the pH, temperature and light factors, and addition it maintained a red-violet hue for extended periods of time (Cevallos-Casals & Cisneros-Zevallos, 2004).

2.2.9 Polyphenolics

The sweet potato has a number of different compounds known collectively as polyphenolics, the oxidation of which by free oxygen is catalyzed by enzymes called polyphenol oxidases (Woolfe, 1992). The reaction known as enzymic browning, is part of the plants defense against invading parasites such as insect and fungi. It can happen also during harvest or transport or wounded such as cutting, peeling in the initial stages of processing. The potential for degree of darkening of root tissue varies between cultivars. Walter & McCollum (1979) reported the phenolics content of seven cultivars ranged from 14 to 51 mg/100 g (fwb). Darkening potential also varies year-to-year between cultivars (Walter & Purcell, 1980).

A green discolouration occurring in sweet potato has also been attributed to a chlorogenic acid-amino group reaction. Matsui (1981) studied the phenolic ester which formed green colour in sweet potato. It occurs under weakly alkaline condition when phenolic esters are oxidized and subsequently react with amino acids. This green discolouration occurs in sweet potato attributed to a chlorogenic acids-amino reaction.

Thompson (1981) studied the phenolic composition of 14 sweet potato cultivars directly after harvest and then curing and storage for 5 months at 15 °C and 80 - 85 % relative humidity. Chlorogenic and isochlorogenic acid were present in all cultivars at harvest and after storage, 4-*o*-caffeoylquinic acid in all two cultivars at harvest and in all after storage, and neochlorogenic acid in only one storage cultivar.

Some works have already been done due to comprehensively recognize the function of polyphenolics compound in sweet potato roots. Polyphenol found can act as both antibiotics and antioxidative agent. Chlorogenic and isochlorogenic acids were being slightly inhibitory to strain *C. fimbriata* attacking the sweet potato (Uritani, 1978). Phenolics of unspecified chemical composition were also reported to increase significantly in roots fed upon by adults or larvae of the sweet potato weevil (*Cylas formicarius* Fab.) (Padmaja & Rajamma, 1982). This rise, which took place for up to 14 days of feeding, coincided with the development of an unpleasant aroma and a bitter taste in the roots. The marked antioxidative activity displayed by a methanolic extract of sweet potato has been suggested due to synergistic effect of phenolic compounds and free amino acids (Hyase & Kato, 1984).

2.2.10 Enzymes

The sweet potato contains many enzymes systems, which catalyze individual synthetic and degradative processes within the tissue. The most important

enzymes from the point of quality in cooked and processed roots are amylases (Woolfe, 1992). These enzymes breakdown the starch into shorten chain molecules. Amylases in sweet potato root include α-amylase and β-amylase. α-amylase has unusual characteristics, which are high temperature activity (70 - 75 ºC), high thermal stability and low activity at ordinary temperature. Freshly harvested sweet potatoes contain relatively little α-amylase, but the level increase greatly during storage. On the other hand, β-amylase initially extents in higher concentration and changes erratically during storage (Walter *et al*. 1975).

Activity of both α-amylase and β-amylase varies with cultivar (Walter *et al*., 1975). α-amylase activity is distributed uniformly throughout the inner tissue of the roots, whereas β amylase is in the highest concentration in the innermost tissues. The outer cork layer and skin contain low concentration of both enzymes (Ikemiya & Deobald, 1966). α-amylase has an action to split α-1,4-links of amylose chain at random to form dextrins, after which these fragment are slowly hydrolyzed to maltose. In it actions, α-amylase is unable to split α-1,6 linkages, so amylopectin on breakdown gives maltose and polysaccharide fragment called *limit dextrin*. β-amylase attacks amylose chain through the α-1,4 linkages in a stepwise fashion, starting from non-reducing end, to give maltose. Amylopectin is similarly hydrolyzed, but as β-amylase is unable to hydrolyze or bypass α-1,6 links a high molecular weight limit dextrin remains unhydrolized. Both α and β-amylases appear to contribute to starch break down during cooking, and it is probable that by doing so they influence sweetness and the important quality attributes of mouthfeel in the cooked root. The degradation of starch by the amylases during cooking, particularly α-amylase, may influence mouthfeel by

lowering the water-binding capacity and viscosity of sweet potatoes that is being interpreted by mouth as increase *moistness*. Walter *et al*. (1975) suggested that mouthfeel in cooked sweet potatoes depends in the amount of starch remaining after hydrolysis, the amount and size of dextrins formed and the amount of sugar present, all of which are influenced by amylolitic activity.

Other enzyme with importance to the quality factors of colour and flavour, namely polyphenoloxidases. Substrate (polyphenolics) and enzymes (polyphenoloxidases) are separated in intact tissues, but if the tissues are disrupted in some way in the presence of oxygen the components mingle and oxidation rapidly occurs. This reaction produces quinines which either polymerize directly or combine with amino acids and amino group in proteins to form dark coloured (brown) compounds. This leads to unpleasant appearance and loss of quality of both the fresh root and final product. The majority of the phenolics are esters formed between quinic acid and caffeic acid. These phenolics esters are chlorogenic acid, isochlorogenic acid and related compounds, with isochlorogenic acid predominating in sweet potato (Woolfe, 1992). Darkening is inhibited by the presence in roots of ascorbic acid, which reduces the quinines, produced as a result of oxidation, back to phenolics before brown pigments can be form (Woolfe, 1992). Processing may therefore include a technique for inhibition of browning such as blanching, lowering pH, treatment with sulphite etc.

Sweet potato are relatively high in lipid-oxidizing activity (Rhee & Watts, 1966). The uptake of oxygen by stored dehydrate sweet potato flakes and consequent autoxidation of the highly unsaturated carotenoid and unsaturated fatty acids in a

portion of the total lipid, leading to loss of colour and production of off-odour and off-flavour by the activity of lipoxidase.

Sweet potato is the first non-leguminous plant reported to contain a trypsin inhibitor (Sohonie & Bhandarker, 1954). The isolated impure inhibitor was very thermolabile and it consists of more than one molecular species, but differing in the number of individual fractions found and in some cases the characteristics of these fractions. The inhibition effect of sweet potato has been demonstrated to occur in vitro with sweet potato trypsin inhibitor could indicate an interference with protein digestion in vivo thus having nutritional implication in humans. Level of trypsin inhibitor activity (TIA) in sweet potato liner or cultivars have been reported (Bradbury, *et al*. 1985b, Ravindran, *et al*. 1995, Zhang, *et al*. 1998). The measurement of the average TIA of sweet potato was 25.4 and 3.5 trypsin inhibitor unit per gram for sweet potato from Solomon Island and Papua New Guinea, respectively. The inhibitor activities of Japanese sample were quite stable on pH range 2 – 11, whereas Nigerian samples showed the maximum activity at 7.5 – 8.5. Beside that, a small amount of chymotrypsin inhibitor activity was detected in cultivars from the Solomon Islands (Bradbury *et al.* 1985a).

2.3 Sweet potato food products

Sweet potato is an important crop in the world. It is nutritious source of complex carbohydrate, dietary fiber, energy, vitamins, and minerals. Sweet potato root is consumed mainly in the home in tropical areas, although it may also be eaten in

restaurants as part of a meal or on the street as a snack. The basic method of cooking roots used in all areas are baking or roasting, boiling, steaming, and frying (Woolfe, 1992). Variations on these basic methods may be used to produce a variety of dishes to suit the taste of the consumer. Its low consumption may be increase with development of ready to serve product. Considerable research has been devoted of sweet potato cooked or product such as baked (Hammet & Berrentine, 1961, Walter *et al*., 1975, Sistrunk, 1977, Reddy & Sistrunk, 1980, Collins *et al*., 1995), French fried or strip or chips (Walter & Hoover, 1986, Schwartz *et al*., 1987, Walter *et al*., 1992, Walter *et al*., 1993), canned (Lanier & Sistrunk, 1979, Mason, 1982), patties (Hoover *et al*., 1983, Walter & Hoover, 1984), edible sheet or leather (Collins & Washam-Hutsell, 1987), and other cooked and frozen products (Damir, 1989, Wu *et al*., 1991, Valetudie *et al*, 1999).

The eating characteristics of sweet potatoes after cooking are often a result of changes in constituents due to combination of post harvest procedures. The quality of roots after cooking or processing is a complex character comprising a combination of aroma, taste, mouthfeel or texture colour and fiber content (Woolfe, 1992). The products, methods of preparing and its characteristic will be explained bellow.

2.3.1 Baked sweet potato

Baking is the simplest method of preparing food, which usually place the sweet potato roots in the baking instrument such as home-style oven or microwave oven

until the skin is charred. When oven is not available, the roots are roasted in the embers of fire which is conducted by people in East and Central Kenya (Jana, 1982) or Papua New Guinea (Kimber, 1972). In Japan, street vendors carry around a wood-burning stove which heats a bed of small smooth stones into which sweet potatoes are placed for roasting and sold as a snack during cold seasons (Duell, 1990). Sweet potatoes were baked together with other food items in stone-lined underground ovens on the island of Micronesia (Dayrit, 1987). Bake yellow-orange fleshed colour sweet potato are popular as a street snack in China (Sheng & Wang, 1988).

Carbohydrates are the one of the most important groups of constituent to the quality of baked sweet potato roots. These constituent affect not only firmness but also mouthfeel which includes smoothness, coarseness and consistency (Rao *et al.,* 1974, Hamann *et al.*, 1980). It is well known that much of the starch in sweet potato root is converted during baking into dextrins and maltose (Walter *et al*. 1975, Picha, 1985b, Picha, 1986a). Walter *et al*. (1975) found that dextrin in raw sweet potato root is 0.1 g/100 g (fwb) and in similar amount among the varieties studied (Centennial, Jewel, Porto Rico Mutant and Pelican Processor) and no increase was noted during storage. The relationship between α-amylase activity and dextrin formation appears to be complex and not in simple way. Although the cultivars have the different level of α-amylase activity, the dextrins produced were in the same percentage. α-amylase activity is also characterized by the range of dextrin molecular sizes produced. Increasing enzyme activity causes reduction in the average molecular size.

Maltose was most abundant sugar in bake root since it was not found in raw sweet potato root (Picha, 1985b), and about 99 % of the converted starch accumulated as maltose (Walter *et al*., 1975). The high percentage of maltose in baked root did not seem due to β-amylase activity levels. It was proved that Jewel variety has significantly less activity than any of other varieties and yet baking produced very similar amount of maltose. It seems there are any other factors controlling conversion of starch into maltose other than β-amylase. Reddy & Sistrunk (1980) found that roots cooked by baking were higher in total sugar than those cooked by other methods of cooking. Dextrin is also produced from starch during baking of the roots. The dextrin content was less than 0.1 g per 100 g fresh roots. However, the dextrin content appears to be affected by the length of storage. Walter *et al.*, (1975) found that dextrin produced by baking and raw α-amylase increased simultaneously with storage time of roots.

Beside dextrin and maltose, sugars include sucrose, fructose and glucose, are also important factor in baking process. There was an increase in the concentration of sugars during baking (Losh *et al*., 1981). Damir (1989) reported that baking was effective in the formation of reducing sugars. These sugars increased from 5.64 % in raw roots to 14.3 % in baked roots. These increases apparently represent the action of β-amylase on starch during baking.

From the organoleptic point of view, comprising *moistness*, *dryness*, and *coarseness*, the characteristics of baked root depend on the amount of starch remaining after baking, the amounts and molecular sizes of dextrin and possibility on the amount of sugar present. All of the properties are affected by amylolitic

enzymes (Walter *et al*., 1975, Wu *et al*., 1991, Woolfe, 1992). The relative *dryness* of freshly harvest cooked roots are no doubt partially attributable to the low levels of α-amylase with small production of dextrins and hence of low dextrin-pectin interaction. The amylases in moist cultivars may also be active over greater range of temperature than those dry cultivars (Walter *et al*., 1975). Again, the major change associated with baking is amylolitic hydrolysis of starch which produce maltose and dextrin. Losh *et al.* (1981) reported that softness increased with the increasing of temperature of baking from 150 or 180 °C to 200 or 230 °C. However, there are also changes associated with non-starch polysaccharides such as pectins, hemicellulose and cellulose

2.3.2 Cooked sweet potato (boiled and steamed)

Cooked products present a large diversity of structural, sensory, and functional properties according to the method and intensity of cooking-processing. Sweet potato was specifically studied for the sweet taste generated during cooking due to the actions of endogenous amylases. As a consequent of starch hydrolysis, the increase of reducing sugars is partially responsible for quality of products from sweet potato. Similar to baked sweet potato, boiled and steamed sweet potato have similar characteristics of the starch degradation term. However, boiled generally produces less sweet and moist than those which have been baked, as boiling rapidly raises the temperature of the flesh to that at which the enzyme are inactivated, and less starch is hydrolyzed (Walter & Hoover, 1984). Significant carbohydrate composition differences were found between baked and boiled roots,

including a lower percentage of starch, and higher percentages of hemicellulose and cellulose in the former than in the later (Sistrunk, 1977). Boiling and steaming have been found to increase the moisture content of sweet potato roots by about 4 % and 2 %, respectively (Bradbury *et al.*, 1988c).

There is an interesting difference characteristic between precooked roots (10 min, 75 °C boiling or steaming) and then boiled, or directly cooked root. Starch hydrolysis was much more advanced in precooked roots than the directly cooked roots whereby the hydrolyzed starch was 11.6 % and 41.4 %, respectively (Valetudie *et al*., 1999). Two methods of cooking explained above, induced significant differences of the percentage of damaged cells. It was always lower in precooked than directly cooked roots. However, precooking process caused shrinkage of the gelatinized starch from the cell walls creating large intra cellular spaces. In the puncture test, steamed roots showed both the lowest scores and the most damaged cell walls, on the other hands, the roots cooked after precooking stage showed the highest score and high cell walls strength. Shen & sterling (1981) found that degradation of cell walls contributes to the reduced strength of cooked roots.

Other products made using boiling method of sweet potato roots are candies, jam and *sweets*. The basic method of candies product: sweet potato is boiled with an equal weight of sugar, a little vanilla for flavours and either natural pectin content of sweet potato or added agar is used to produce a pasty or gelled mass. Sweet potato roots are also appropriate for jam making as it contains suitable content of water-soluble pectin with gelling properties similar to that of apple pectin

(Winarno, 1982). The Philippines sweet potato jam process consisted of cooking a mixture of 20.7 % sweet potato, 45 % sugar, 34 % water and 0.3 % citric acid until a solid content of 68 ^{o}Brix was obtained. The difference in consistency between sweet potato and fruit jam was due to the high starch content of sweet potato.

2.3.3 Fried sweet potato

One of the popular products of sweet potatoes is French fried-type product or strip and chip. Sweet potato French fried-type products and chips were judged as food quality and acceptability by consumer panel (Walter & Hoover, 1986, Hoover & Miller, 1973). The major quality problem in the development these products is discolouration, which arises from two different sources. The first of these is formation of grey discolouration caused by the oxidase reaction of polyphenol group's enzymes. The second type of discolouration is non-enzymatic browning, Maillard that result when reducing sugars condensed with amino groups. The rate of this reaction is increased at high temperatures such as that attained during frying. When untreated sweet potato chips containing more than 0.5 % reducing sugars are subjected to elevated temperatures such as that which occurs in normal deep-fat-frying, discolouration is often very pronounced.

Flavour and texture of French-fries are other quality factors whereas lack or loss of crispiness is the main problem in chips making. The latter which are affected by both post harvest handling and pre-frying process conditions. The increase of

desirable flavour is due to an increase in sugars and other undefined flavour component (Hamann *et al.*, 1980). Since some of the sugars must be removed to prevent browning, it is likely that when blanching or water extraction step is used some of flavour components will also be extracted. Textural properties are dependent on the way in which the structural components of food are arranged. Thus, texture is strongly affected by water extraction as is the sugar content. On the other hand, post harvest history of the roots is strongly related to textural properties. Hoover & Miller (1973) used sodium acid pyrophosphate blanch treatment to eliminate graying in the production of high quality chips. They used sodium acid pyrophosphate at levels between 0.5 and 1.0 % for 2 minutes in about 100 °C blanching. The blanched and drained chips were then partially dehydrated at 100 °C in forced air drier. Dried strips were then deep-fat-fried at optimum temperature (145 to 155 °C) for 2.5 to 3.5 minutes. The optimum chips dimension was $^{1}/_{2}$ in wide and $3^{2}/_{3}$ inch in thickness. The fried chips that were added with salt in the range of 2.5 to 3.5 lb per 100 lb of chips seemed to be preferred by taste panels. Walter & Hoover (1986) modified previous processing method for producing French fried type products. This method is as follow: The roots was washed, lye peeled and sliced into strips of 1.9 x 6.4 cm thickness. The strips were blanched in water 100 °C containing 1 % sodium acid pyrophosphate for 2.5 minutes, dried in forced air drier at 121 °C. The dehydrated strips were frozen and held in high-density polyethylene freeze bag at –34 °C until fried. The frozen strips were then deep-fried at 175 °C for 2.5 minutes. The good quality strips using this method could be prepared from moist and slight moist varieties sweet potato (Jewel and Centennial cultivars). Flavour and texture scores were 3.75 to good on a scale in which 3 was described as *fair* and 4 as *good*. Schwartz *et al.*

(1987) continued the work by using method developed previously by Walter & Hoover (1986) except that the additional stage of half drying of sweet potato strips was introduced after blanching. The strips were kept frozen until 1-year storage and fried at every 3 months interval. They found that few qualities were changed. Drying treatment significantly affected the magnitude of ascorbic acid loss. Sensory panels rated the fried product to be of good quality throughout storage. There was a small significant change in colour noted by panelists during frozen storage. Although a number of statistically significant interactions were affected by samples treatment, most were considered of minimal influenced on product quality.

Firmness is one of sweet potato frying product properties which is difficult to control. The difficulty of managing the firmness produces inconsistency textural properties of the products. Walter *et al*. (1992) and Walter *et al.* (1993) controlled the firmness through managing the pH of sweet potato tissue using acid and base media. The backgrounds of this method were: (1.a) Plant tissues of a parenchymatous nature were firmest when cooked in boiling water acidified to pH 4.0-5.0. (1.b) Alteration of normal tissue pH with buffered citric acid will partially inhibiting enzymatic starch hydrolysis (Sistrunk, 1971), and (2) The tissue softening of several vegetables was much more slowly when de-esterified with NaOH solution then cooked at neutral or slightly basic pH (Van Buren & Pitifer, 1992). Strips treated with acid were firmer than those untreated and treated with water. Strips treated with the higher acid concentration were firmer than those treated with lower levels. When strips were fried, they have an acidic flavour with intensity related to the strength and identity of acidulant used. On the other hand,

treatment of sweet potato tissue with either Na_2CO_3 or Na_3PO_4 prior to heat processing increased firmness retention. The firmness of the tissue was enhanced when the tissue was treated with *vacuum infiltration* in $CaCl_2$ base treated. Base mediated firmness retention was effective on strips and could be easily adapted to many types of products.

2.3.4 Dehydrated sweet potato products

Dehydration of sweet potato has been traditionally practiced in many developing countries. In traditional practice, the roots which may not be peeled, are sometime but are more often directly cut up into pieces and spread out in the sun to dry. The yield chips or slices can be stored or ground in mortar to flour which is then sieved. Drying yield a light, compact, relatively cheaply packaged, easily stored and transported material which can be used in a great variety of dishes and further food formulations (Woolfe, 1992). In Indonesia, fresh root are sometimes soaked in 8 – 10 % salt solution for about an hour before cutting and drying, a practice which is reported to inhibit microbial growth during drying (Winarno, 1982).

In China, several thousands metric tons of sweet potato were dried every year in the form of chips or slippers by traditional sun drying on the farm. The majority of this dried product is then sent to starch or alcohol factories for further processing. Methodologies for improvement of traditional drying to produce a higher quality product which can be stored without spoilage have been developed (Zhao & Jia, 1985). In the Philippines, a series of tools and equipment for use by small-scale

rural industries drying root crops, including sweet potato has been developed (Truong & Guarte, 1985). An excellent sample of sweet potato product which can be incorporated directly into a traditional dietary item has been produced. This is the small scale manufacture of sweet potato cubes. The process of cubes is as follow: sweet potato roots are peeled, washed and sliced to 1 cm thick. The slices are cut into cubes and then steamed and dried. The dried sweet potato is mixed with cubes of dried fruits and packaged in plastic bag. On reconstitution, the cubes are cooked with rice, coconut milk, brown sugar and vanilla to make a fruit soup called *quinata'an* which is traditional Philippines dish. This product has also been developed in India as quick-cooking convenient vegetable or in soup mixes (Truong, 1990). A product resembling dried fruit has been developed from orange-fleshed roots (Truong, 1987).

Another form of dried sweet potato snack is as edible *leather* which can be prepared by blending together vegetable materials and other ingredients and drying in thin sheets (Chan & Cavaletto, 1978, Przybyla, 1983). This product has also been explored in Malaysia (Che-Man & Raya, 1983) and United States (Collins & Washam-Hutsell, 1987) through presenting dehydrated orange flesh sweet potato as the main ingredient. The flesh of Malaysian cultivar was cooked, mashed and sieved, mixed with 0.5 % (w/w) carboxymethyl cellulose (a binder), 200 ppm sodium bisulphate and 7 % (w/w) sugar and formed into a sheet 1 mm thick which was oven dried to 10 - 17 % moisture and then packed in plastic film. Deep frying the leather increase its sweetness and improve the taste. A leather type product called *mushikiriboshi* is a Japanese traditional product produced in

someway similar to methods of the leather but is roasted or baked prior to consumption (Nakajima, 1970).

Sweet potato flake is the dehydrated product that was produced in large scale processor. The standard process of making flake using drum drying procedure has been investigated since sixties (Manlan *et al*., 1985). Flakes can be reconstituted into mashed sweet potato or incorporate into variety of other product such as pies, pasties, cakes etc. The production of high quality flake includes pre-process or pre-heating process to inactivate enzyme discolouration and to reduce of peeling time and dehydration process.

In the United States pre-process roots are pureed in a pulper where blades force the roots through a 0.8 mm screen, removing much fibrous materials. The puree is then dried to 2 - 3 % moisture on steam heated drum, flaked and immediately packaged in metal, glass or film containers which exclude moisture and oxygen. In addition, sodium acid pyrophosphate or citric acid may be added to the puree before drying (Manlan *et al*., 1985), to control non-enzymic browning which causes discolouration of the reconstituted flakes. Moreover, one important constraint to the widespread consumer acceptance of sweet potato flakes has been their limited self-life due to the development of strong hay-like off-odour. It is present when unsaturated fatty acids and carotenoids were oxidized with the consequent of production of compounds with off-flavour. When sweet potato flakes were stored in air at 31 °C, carotenoids and unsaturated fatty acids, especially linolenic acid, were destroyed by oxidation much more rapidly in the surface than in the bound lipid fraction (Walter & Purcell, 1974). The flakes were

found to develop a strong off-flavour after 29 days of storage. Sweet potato flakes canned in a reduced oxygen atmosphere and stored at 23 °C for 6 or 12 months, unsaturated linolenic decrease in all type of lipid, whereas the saturated palmitic and stearic increased slightly (Alexandridis & Lopez, 1979). An off odour characterized as hay-like, was detectable after 6 months storage.

Sweet potato flour is an intermediate product from dehydrated roots. The flour production was developed in several developing countries and the process including peeling, shredding, pressing to remove some of moisture, drying and then milling (Hamed *et al*., 1973a, Martin, 1984a, Guedes, 1986). The main problem in sweet potato flour production is undesirable changes due to non-enzymic Maillard as well as enzymic browning. Martin (1984b) developed methods to prevent the darkening by diffusion process. This entailed placing the cut of pieces of sweet potato in five times their weight of water for three consecutive 30 min intervals to remove soluble reactants such as polyphenolic compounds. Sweet potato flour is used usually as a partially substitution of wheat flour in bread making. The possibility of utilizing wheat-sweet potato composite flour in breads and other bake goods has been investigated in several countries includes Egypt (Hamed *et al*., 1973b), Ghana (Osei-Opare, 1987), India (Nair *et al*., 1987, Seralathan & Thirumaran, 1990), Korea, Philippines (Tapang & Rosario, 1977, Palomar *et al.* 1981), Taiwan (Lee, 1985), and the West Indies (Sammy, 1970). The level of wheat flour substitution with sweet potato flour found to produce a formulation resulting in acceptable bread with characteristics similar to those of bread made entirely with wheat differed between researches. This could have been due to variation of preparation and local taste preferences.

However, the maximum level of substitution was about 20 %, and when more than 20 %, the bread become unacceptable in terms of loaf volume, flavour and texture. It is not possible to use composite flour containing high percentage of sweet potato flour due to excessive dilution of wheat protein by sweet potato flour with a low protein content lacking the characteristic of gluten. Most researchers found 10-15 % substitution was the most acceptable in these terms. In large varieties of other bake good such as cakes, cookies, biscuits, doughnut etc, researchers have found it possible to utilized composite flours with high percentage of sweet potato flour than is that with breads. For example, Indian cakes and biscuits (Seralathan & Thirumaran, 1990) and Philippines butter cakes, cookies, brownies (Montemayor & Notario, 1982) and muffins (Anon, 1985) can be made of composite flour containing with acceptable quality by 50 % sweet potato-wheat flour composites. Furthermore, chiffon cakes has been successfully prepared from 100 % sweet potato flour in Philippines, and found no significant differences between the attributes of the product made with 100 % wheat flour (Kays, 1985, Woolfe, 1992).

2.3.5 Restructured products

A food product fabricated by combining sweet potato puree with other ingredient and moulding the resultant formulation into a patty-type has been developed. This product is typically called restructured product. This is because a major reason for the lack of sweet potato products in the marketplace those processors have not been able to develop products of consistence quality (Hoover *et al*., 1983, Walter

& Hoover, 1984, Bowkamp, 1985). Besides that, product preparation can also exert a significant effect on the chemical and physical attributes of the final products. The objective of restructuring process is to get consistent quality such as the taste, texture, and colour regardless of raw material.

Many reports on various aspects in production of sweet potato puree have been published (Collin & Walter, 1992), however a few accounts of restructured sweet potato products (Hoover *et al.*, 1983, Walter & Hoover, 1984). Truong & Walter (1994) developed the sweet potato puree restructured with cellulose derivates, and then Truong *et al.* (1995) developed a restructured baked sweet potato product in which sweet potato puree was texturized using an alginate-calcium gelling system. Previous attempts to control the textural properties of conventional sweet potato French fries have included partial dehydration (Walter & Hoover, 1986, Schwartz *et al.,* 1987) and temporary modification of tissue (Sylvia *et al.,* 1997). Patties preparation process was describe by Hoover *et al*. (1983). Briefly, the peeled, sliced roots were cooked for 5 minutes in steam, blended with other ingredients such as modified corn starch, sucrose and other minor ingredients, comminuted in hammer mill and once finish it was cooked in steam injector (steam at 160 °C) flow system. The cooked puree was then cooled (68 °C), moulded into patties and frozen at –20 °C. The frozen patties were fried in deep-fat-fryer in peanut oil at 171°C for 2 minutes prior to service. Walter & Hoover (1984) continued the previous study to evaluate the effect of processing step and history of the roots on the composition and acceptance of patties. Walter & Palma (1995) found that long term storage of the roots caused the change of cell wall component and affected texture of products. Walter *et. al*. (2002) reported that sweet potato french-fries

made of puree mixed with potato flakes (7 %, w/w), sucrose (4 %), tetrasodium pyrophosphate (0.18 %), alginate (0.35 %) and calcium sulfate (0.5 %) was the highest for appearance, texture, flavour and overall acceptability.

Baked sweet potato can be made through restructured process. Truong & Walter (1994) developed method of restructured baked sweet potato. The product was made by mixing sweet potato puree with sucrose and various concentration of cellulose derivatives gum, and then placed into sausage casing to form rolls. The rolls were then frozen and stored. Baking process was conducted for unthawed rolls at 204 °C for 15 min. They concluded that the food gum, methylcellulose, methylhidroxylcellulose at 0.25 % were excellent restructuring agent for sweet potato puree. Other method of producing sweet potato baked was studied by Collins *et al*. (1995). The process involved baking of sweet potato roots at 190 – 204 °C for 70-90 min. The baked roots then cut into irregular shape and stuffed into cellulose casings, and frozen until serving. Serving of baked product conducted by heated the frozen stuffed in microwave oven (750 watts) for 4 min at full power.

2.3.6 Other products

The natural sweetness of many sweet potato cultivars lends itself to the preservation of roots by the addition of further sugar to give a variety of candied products, candies, jam and *sweets*. Those products known as *doces* (Portuguese) or *dulces* (Spanish) are particularly popular in Latin America. In fact *dulce de*

batata is the national dessert of Argentina, consumption being in the order of 65,000 metric tons/year in that country alone (Horton, 1988b). In China, sweet potato candy has been developed for sale by the processing laboratory of the Sichuan Academy of Agriculture Science (Wiersema *et al.*, 1989). In this process, peeled sweet potato was cut, wash in basket to removed starch, boiled for 8 min in a sugar solution, flavouring added, steeped for 3 hours in a sugar solution, dried in traditional oven for 8 hour using moderate heat, weighed and packed by hand and machine sealed (Woolfe, 1992). The similar product was also prepared and sold in shop in Mexico called *camoterias* (Austin, 1973), while in Japan small individually wrapped candies were produced by traditional business (Woolfe, 1992). There is obviously a wide range of sweet candied products which can be produced from sweet potato. Recipes can be adapted to produce traditional candies for local taste in different areas of the world.

In Philippines, sweet potato jam has been prepared (Truong, 1987). Sweet potato is appropriate for jam making as it contains a suitable content of water-soluble pectin with gelling properties similar to that of apple pectin (Winarno, 1982). The Philippines process consisted of cooking a mixture of 20.7 % sweet potato, 45 % sugar, 34 % water and 0.3 % citric acid until solid content of 68° Brix was obtained. The different consistency between sweet potato and fruit jams was thought to be due to the high starch content of sweet potato. Jam with various natural colour, yellow, orange or pinkies could be prepared using cultivars with different flesh colour. Sweet potato jam was also prepared for sale on a small scale in some areas of China (Sheng & Wang, 1988).

Catsup (ketchup) is a popular condiment that usually prepared from tomatoes. However, sweet potato can be as a substitution material due to the highly price of tomatoes. Sweet potato-based catsup has been commercialized in Indonesia and Malaysia (Woolfe, 1992). The process of catsup making has been described in Philippines (Truong, 1987). Roots are washed, trimmed, cut into chunks and steamed. The cooked chunks are blended with water, vinegar, spices and food colouring agent and then boiled to the correct consistency before bottling. It has total soluble solid content 25 – 27 °Brix and pH of 2.7 - 2.8. Sensory evaluation indicates that some cultivars yield more acceptable catsup than others (Truong *et al.*, 1986b).

Non alcoholic beverages from high beta-carotene sweet potato cultivars, possessing a nutritional comparable with or superior to fruits drink have been formulated (Truong & Fementira, 1990). The colour of the beverages varied according to the colour of the roots, ranging from yellow to orange or pinkish-purple (Truong, 1987). The major anthocyanin of sweet potato was reported as a potential colourants in beverages production (Bassa & Francis, 1987). The process involves washing, peeling, trimming, steaming, juice extraction, addition of 0.2 % (w/v) citric acid, 232 mg/l ascorbic acid, and 12 % (w/v) sugar. Ascorbic acid can be replaced by lemon juice which improved flavour and enhanced acceptability, likewise the adding of juice or pulp of other fruits. The formulated beverages were bottled in glass containers, and pasteurizing at 90 – 95 °C. The sweet potato beverage has a pH of 3.2, total soluble solid as 13 °Brix and insoluble solid of 9.4 mg/100 ml. The natural colour of sweet potato beverage compared to that enhance artificially in most commercial fruit juice was thought to present a promotional

advantage for the sweet potato drink. Other traditional non-alcoholic sweet potato beverage *dolo* is also popular in Cameroon (Numfor & Lyonga, 1987).

Vinegar is a condiment made from sugar or starch-containing materials by an alcoholic fermentation followed by microbial oxidation of alcohol to acetic acid. Sweet potato can be used as a raw material; the starch requires initial hydrolysis to sugars before alcoholic fermentation by yeast can take place. The next step, oxidation of the alcohol to acetic acid is carried out by acetic acid bacteria. Vinegar processed from a high beta-carotene cultivar has been commercialized in Japan (Woolfe, 1992). A pickle made from sweet potato chips has been carried out in India (Nair *et al*., 1987). Various pickling media of 1, 2, or 5 % (w/v) brine and 50 % (w/v) sucrose syrups were used in trials.

CHAPTER 3

THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF 17 ACCESSIONS AND 4 SWEET POTATO CULTIVARS

3.1 Introduction

Tuber crops are important food crops serving either as subsidiary or subsistence food in different part of tropical countries. As is the case for most tuber crops, sweet potato is a staple food for many developing countries. Sweet potato is a nutritious crop with a good complement of energy, vitamins and minerals. The intervention of humans by domestication and artificial selection of the sweet potato has resulted in the existence of a large number of cultivars. Cultivars differ from one to another in the physical properties and chemical composition (Tian *et al*., 1991, Kitahara *et al*., 1996, Garcia & Walter, 1998).

Moisture as the major component in the sweet potato tubers is an important factor affecting the physical and chemical characteristics of sweet potato products. The change of moisture content occurred during cooking varies from 1 to 4 % affected the texture properties of sweet potato tubers (Bradbury & Holloway, 1988b). Shen & Sterling (1981) reported that varietal differences in carbohydrate degradation during cooking led to different textural properties among sweet potato cultivars. Noda *et al.* (1998) argued that the gelatinization properties of sweet potato starch were reflected by the molecular architecture of amylopectin. The typical changes

occurred in sweet potato during cooking include the starch conversion to sugar and dextrin by amylase enzymes, and the interaction of pectic compounds with sugars or dextrins which generate certain textural characteristics (Walter *et al*., 1975, Verlinden *et al*., 1995).

The physicochemical properties of sweet potato starch of various cultivars have been reported. Gelatinization temperature of sweet potato starch measured using brabender viscoamylograph varied from 63 to 90 °C (Suganuma & Kitahara, 1997 and Moorthy, 2002). Zhang & Oates (1999) argued that high gelatinization temperature was associated with high amylopectin content of sweet potato starch. Similar to gelatinization temperature, peak viscosity was also affected by amylose content. McPherson & Jane (1999) reported that the high amylose content on sweet potato starch contributed to its lower peak viscosity and resistance to shear thinning.

Sweet potatoes contain 52 – 85 % moisture, with carbohydrates making up 80 – 90 % of total dry matter. Starch is the major component of sweet potato, which comprise about 30 – 70 % of total dry matter (Bradbury & Holloway, 1988a). Den (1994) reported that varietal variation of starch content ranged from 11 to 25 % (fwb) or 33 to 73 % (db), moreover starch and dry matter content are highly correlated (r = 0.926). The linier component of sweet potato starch, viz. amylose, imparts definite characteristics to starch and varies considerably among different cultivars. Moorthy (2002) and Katayama *et al*., (2004) reported that amylose content of sweet potato tubers varied from 13.4 to 19.0 % and from 20 to 25 %, respectively.

Sugars composition of sweet potatoes is a fundamental component of their eating quality. Although generally considered sweet by definition, there is potentially a large range in perceived sweetness among cultivars, depending on sugar components and starch conversion at cooking (Takahata *et al.*, 1992). Sucrose, glucose and fructose are the principal sugars present in fresh sweet potato roots (Huang *et al.,* 1999a). Maltose presents is a result of starch conversion by alpha-amylase and beta-amylase during cooking (Picha, 1985b). During heating, much of the starch is converted into dextrins and maltose by alpha and beta amylase (Walter *et al.* 1975). However, there are cultivar differences in the degree of starch conversion (Babu, 1994). An examination of the sugar levels in raw tuber demonstrated some interrelationships between individual sugars that may be of use in screening germplasm destined for specific uses. The stability of the fructose to glucose ratio across clones, despite varying total raw sugars, was particularly striking (Lewthwaite *et al*., 1997). However, little information on texture of cooked sweet potato and starch characteristics were found. The purpose of this research was to establish the physical and chemical characteristics of sweet potato tubers and starch from 17 collection accessions and 4 commercial cultivars

3.2 Materials and methods

3.2.1 Materials

Seventeen accessions indicated by number were Universiti Putra Malaysia (UPM) collection cultivated on 8 March 2003 and harvested on 20 August 2003. They

consisted of 6 accessions of white flesh colour indicated by numbers 10116, 10168, 10166, 10217 and 11072, 7 accessions of yellow flesh colour numbers 10061, 10071, 10073, 10100, 10123 and 10200, 5 accessions of orange flesh colour numbers 10236, 11085, 11090 and 11092, and 3 accessions of purple flesh colour numbers 10120 and 11214. Four cultivars were purchased at a local market named as *White*, *Yellow*, *Orange* and *Purple*. Picture of sweet potato cultivation field is shown in Appendix 1 and a local market selling sweet potato is shown in Appendix 2.

3.2.2 Sample preparation

A middle portion of each raw sweet potato root was cut transversely to the long axis into 3.5 cm thick slab. Using cork borer with 1.35 cm diameter (No. 10, Cork borer, Ambala, India), cylindrical samples were taken from each slab and trimmed into cylinders of 2.2 cm thickness. Samples were taken at the inner tissue of the roots at an approximate distance of 1cm from the root skin. The cylindrical samples were washed with tap water to remove adhered starch and steamed in a steamer (CPC 61, Rational, Germany) at 100°C, atmospheric pressure for 20 minutes. Cooked samples were kept in a closed container to avoid moisture losses and subjected to moisture content determination, uniaxial compression test and texture profile analysis (TPA) on the day of preparation.

Sweet potato flour was prepared by oven-drying the sliced fresh roots at 55 °C for overnight and then a dried material was ground into flour. The flour is then

packaged, sealed tightly in plastic bag and stored at about -20 °C for further analysis.

Starch was isolated from fresh sweet potato tubers by the following procedure. The cleaned tubers were peeled, cut, and ground for 4 minutes at high speed in a Waring blender with 4 portions by weight of water. The slurry was filtered using double layer of muslin cloth. This grinding and screening process was repeated 3 more times. The resulting emulsion was settled for 2 hours, the mucilaginous layer was removed and the sediment was resuspended with water. This sedimentation and washing operation was repeated 3 times. Wet starch was dried in a cabinet drier at 45 °C for 8 hours, ground and sieve with 100-mesh sieve.

3.2.3 Moisture content

Moisture content of fresh and cooked sweet potato tubers were determined using the Oven method (AOAC, 1984). Approximately 5 g samples were dried at 105°C overnight or until constant weight was attained.

3.2.4 Texture Analysis

Peak force deformation was measured using uniaxial compression on cylinder of cooked tissue adopted from Walter *et al*. (2000). Uniaxial compression test was performed using a Texture Analyzer (TA.TX2i, Godalming, UK) fitted with a 25

kg load cell with a probe having 50 mm diameter compression plate. The compression was along the longitudinal axis of the steamed cylindrical specimen to about 75 % of its initial height at a constant crosshead speed of 1 mm/s. The data collected from the graph generated during the test. The peak force-deformation curves were obtained for 15 reading per samples.

Hardness, adhesiveness, springiness and chewiness were measured by Texture Profile Analysis (TPA) method as described by Bourne (1978). Texture Analyzer (TA.TX2i, Godalming, UK) was fitted with a 25 kg load cell with a probe having 50 mm diameter compression plate. The steamed cylindrical specimen was compressed longitudinally for two cycles. The test condition were: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, time between two cycles 5 s , trigger force 5 g and degree of compression 35 % of its initial height. The TPA curves were obtained for 15 replicates per samples. Data collection and analysis were accomplished by the EXTRAD Dimension Software that is supplied with of the Texture Analyzer.

3.2.5 Starch pasting properties

Starch pasting properties were investigated using Brabender Viscograph-E (C.W. Brabender Instruments, Inc., South Hackensack, New Jersey, USA) fitted with 700 cmg cartridge and stir at 75 rpm. Approximately 30 g starch (dry mater) was combined with 450 g distilled water, in a BV sample cup. The sample was heated from 45 °C to 92.5 °C with temperature rate increase 1.5 °C/min, held at 92.5 °C

for 20 min, cooled to 50 °C with temperature rate decrease -1.5 °C/min and held at that temperature for 20 min (ISI, 2000). The parameters studied were gelatinization temperature, peak viscosity, breakdown viscosity and setback, all of which were determined from the Brabender Viscograph (BV) plots.

3.2.6 Starch and amylose analysis

Starch and amylose content were determined on sweet potato flour and the results were expressed in fresh weight basis (fwb) or dry basis (db). Starch content was determined by acid-hydrolysis method and total sugars produced were calculated quantitatively by Nelson-Somogyi method (AOAC, 1984). Approximately 5 g sweet potato flour was homogenized with 50 ml of 85 % ethanol for about 1 hour. Sediment was removed quantitatively by filtering the suspension using no1 Whatman filter paper into an Erlenmeyer flask containing 200 ml distilled water and 20 ml of 25 % HCl. Hydrolysis was conducted by boiling the mixture for about 2.5 hours. The solution was cooled, neutralized using 45 % NaOH and made up to 500 ml in a volumetric flask. The solution was then filtered using Whatman filter paper and the filtrate was collected for the determination of glucose. Starch content was calculated by multiplying the glucose content by 0.9.

The apparent amylose content was determined using colourimetric iodine binding procedure according to the method of Juliano (1971). Amylose produced blue colour in iodine solution. The absorbance of solution then was read and compared to amylose standard curve. This method consist of two steps, firstly by preparing

the standard curve of amylose content versus absorbance of amylose standard and second was the determination of the amylose content of sweet potato starch. On preparing the standard curve, approximately 40 mg of amylose standard (Merck) was mixed with 1 ml of 95% Ethanol and 9 ml of 1 N NaOH, heated in boiling water for 10 min. The gel was formed, cooled to about 25 °C then made up to 100 ml in volumetric flask with distilled water. Six volumetric flasks were filled with 0, 1, 2, 3, 4 and 5 ml of amylose-standard solution and then 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of 1 N acetic acid were added, respectively. The mixtures were added with 2 ml iodine solution and the final mixture was made up to 100 ml with distilled water. The absorbance of standard solutions was read at 625 nm using spectrophotometer (Milton Roy, Genesys-5, Cambridge, UK). Curve standard was created by plotting the absorbance versus amylose content in standard solution.

Amylose content of sweet potato starch was determined using the same step of method above. Approximately 100 mg of sweet potato starch was mixed with 1 ml of 95 % Ethanol and 9 ml of 1 N NaOH, heated in boiling water for 10 min; cooled and made up to 100 ml. 5 ml sample was filled into volumetric flask, added 1 ml of 1 N Acetic acid and 2 ml of Iodine solution. The absorbance of the sample solution was read at 625 nm wave length. Absorbance results were plotted into standard curve to obtain the content of amylose in the samples.

3.2.7 Sugars analysis

Individual sugars in fresh sweet potato tuber consisted of glucose, fructose, maltose and sucrose were determined using HPLC method as describe by Picha

(1985b) and Rees *et al.* (2003). A Waters liquid chromatography unit (Waters Co., Milford, Massachusetts, USA) equipped with Waters 410 RI detector, Waters 501 injector and Pump and a Waters 600 controller. The column was a Merck prepacked stainless steel column 250 x 4.6 mm i.d. tube packed with 10 µm Lichrosper® 100 NH_2. The eluent was acetonitrile and water (80 : 20, v/v). Approximately 1 g of sweet potato flour was heated with 100 ml of 85 % methanol on a steam bath for 30 min. The mixture was filtered through Whatman No. 1 filter paper into a round bottom flask and the residue was re-extracted twice with 75 ml portions of methanol. The filtered filtrate was then evaporated to about 10 ml under vacuum at 50 °C in a rotary evaporator; then made up the volume to 10 ml in a volumetric flask. The extract (2.5 ml) was then passed through a cation-ion exchange (Sep Pak C_{18}) cartridge, eluted 1.25 ml to waste and collected the remainder for analysis. Finally, the extract was filtered through a 0.45 µm membrane filter (Whatman) using a syringe. Ten micro liters (µl) of sample extract was injected. Sugars in the samples are quantified by comparing peak areas of samples with those of the standard. The chromatographic standard containing fructose, glucose, maltose and sucrose was prepared by mixing these with acetonitrile in the portion of 80 : 20 (v/v). The concentration of standard was 1 % (w/v).

3.2.7 Statistical analysis

The experiment was arranged with a randomized complete block design with 3 replications. The data collected were analyzed by the analysis of variance

(ANOVA) and the significant differences among means were determined by Duncan's multiple range test (DMRT) with 5 % of the level of significance. Statistical analysis was done by using MSTAT-C statistical software.

3.3 Results and Discussion

Figures 2 to 5 show the photographs of materials used in this study. They were grouped based on the colour of flesh i.e. white, yellow, orange and purple fleshed-colour. The skin colour of the tubers varied from white to purple. The materials indicated by number are the collections of Faculty of Agriculture, Universiti Putra Malaysia, whereas those are indicated by the name of *White*, *Yellow*, *Orange* and *Purple* were the commercial cultivars cultivated by farmer and marketed in local market in Malaysia.

Evaluation on 17 accessions and 4 cultivars showed the presence of wide variability in physical and chemical characters. Colour of skin and flesh tuber is the simple character to determine visually. Based on flesh colour, the samples were classified into 4 major groups i.e. white, yellow, orange and purple. White group consist of 5 accessions and 1 commercial cultivar. Skin colour of 5 accession cultivars was light-red, whereas the commercial was white. Yellow group consist of 6 accessions and 1 commercial cultivar with the skin colour varied from light to dark red. The orange group consists of 4 accessions and 1 commercial cultivar. Skin colour of orange cultivars was orange with irregular red spot. In purple group that consist of 2 accessions and 1 commercial cultivar

exhibited the big variation in colour skin from white to purple. These findings showed the wide variation of skin and flesh colour determined visually.

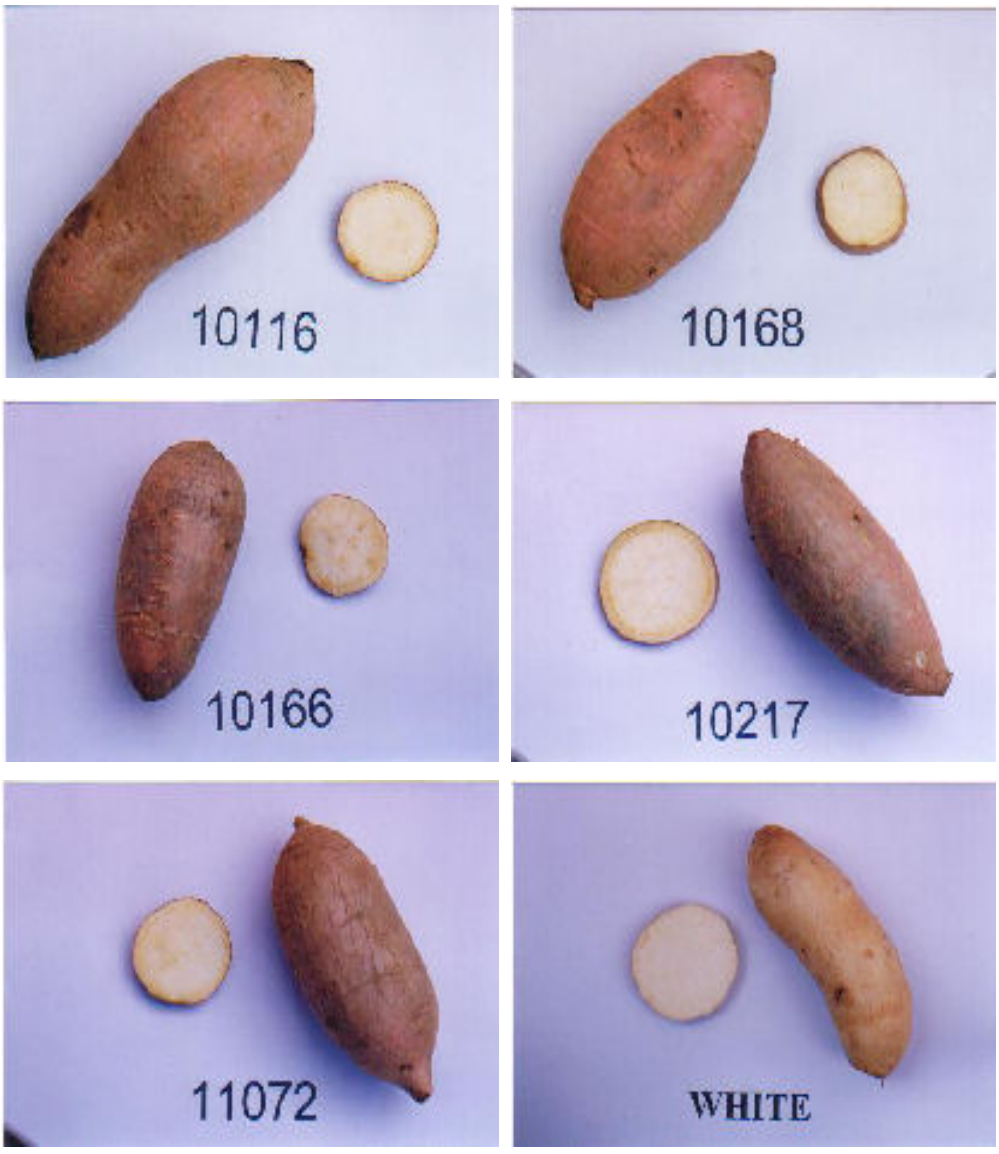


Figure 2 White flesh colour group of sweet potato tubers

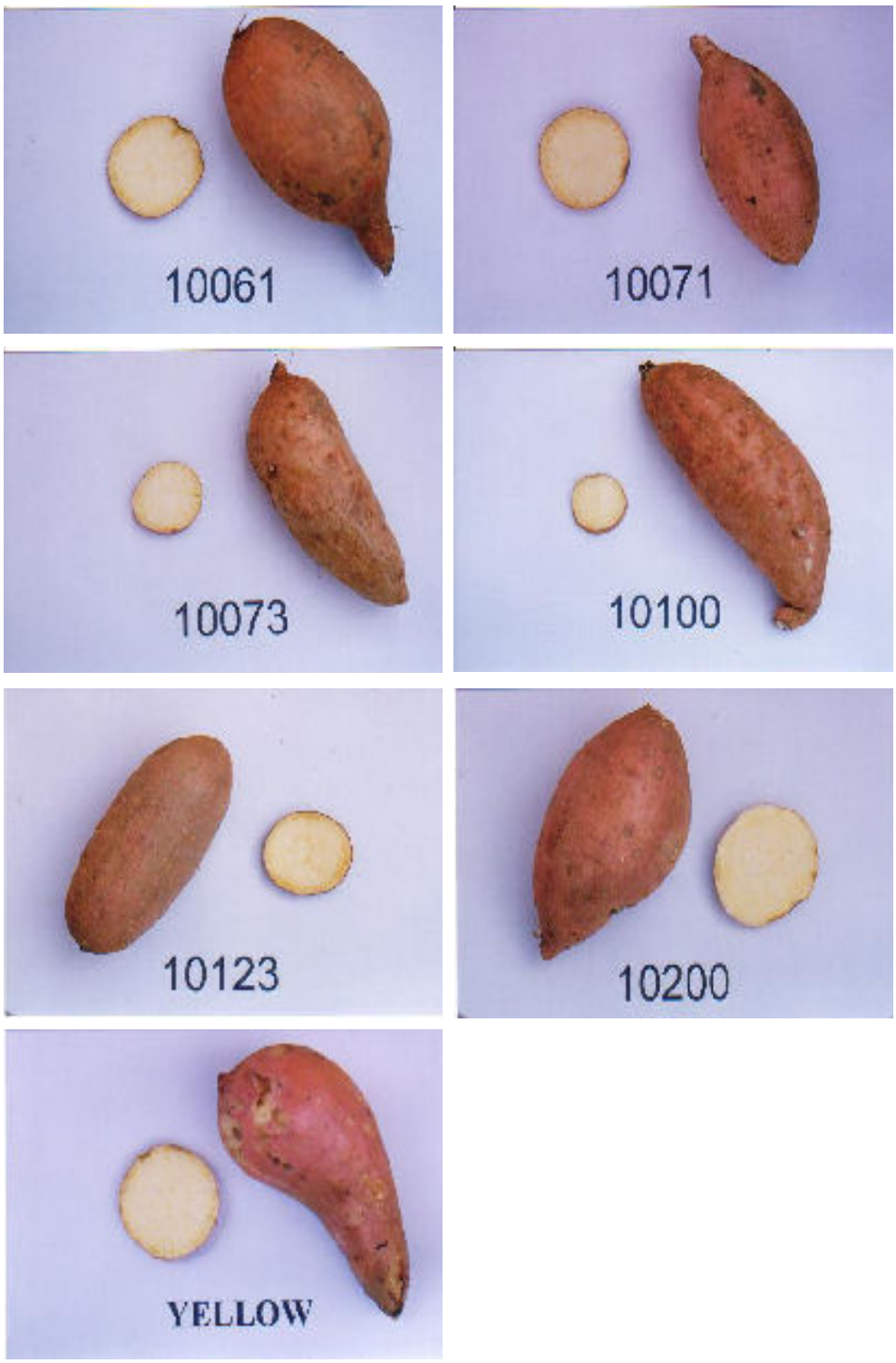


Figure 3 Yellow flesh colour group of sweet potato tubers

Figure 4 Orange flesh colour group of sweet potato tubers

Figure 5 Purple flesh colour group of sweet potato tubers

3.3.1 Moisture content

Table 3 shows that moisture content of fresh tubers after harvest ranged from 63.17 to 76.68 % with the average of 74.56 %. The mean of each groups were 76.27, 76.26, 74.23 and 67.70 % for white, yellow, orange and purple flesh colour, respectively. In white flesh group, 3 accessions had higher moisture content than mean value, while 3 other members were lower including *White* commercial cultivar. Mean value of yellow flesh group was similar to the white flesh group, however the variation of moisture content within this group was larger than white groups. The highest moisture content in yellow flesh group was

80.3 % whereas the lowest was 72.16 %. *Yellow* cultivar exhibits the highest moisture content compared to three other commercials cultivars. In orange flesh group, low variation occurred compared to other colour groups, however significant different ($P<0.05$) found within the member of this group. The high variant value in purple group indicated the wide variation of moisture content. The highest variation occurred in purple groups caused by *Purple* commercial cultivar which contained very high moisture content (76.78 %) compared to 2 UPM accessions.

The variation of moisture content does not depend only on the accession or cultivar, but also environmental factors such as location, climate, day length, soil type, incident of pest and cultivation practices (Bradbury & Holloway, 1988d). Earlier workers reported that soil moisture content significantly increased the moisture content (Constantine *et al.,* 1974, Ton & Hernandez, 1978, Hammet *et al*., 1982 and Bradbury & Holloway, 1988b). Four commercial cultivars were cultivated in different area with 17 accessions. *White* commercial cultivar was cultivated by farmer in sandy soil in Bidor, Perak, Malaysia, whereas the three other cultivars were planted in peat soil in Sepang, Selangor, Malaysia. Fertilizer also affected the moisture content of the tubers. The moisture content generally decreased on addition of increasing amounts of nitrogen fertilizer (Bradbury & Holloway, 1988b).

Table 3 Moisture content of sweet potato (fresh and steamed) tuber from 17 accessions and 4 cultivars

Accession/ Cultivar	Flesh Colour	Moisture Fresh (%, fwb)	Moisture Steamed (%, fwb)
10116	White	78.69 [b]	81.33 [a]
10168	White	79.67 [a]	81.08 [ab]
10166	White	73.18 [i]	72.46 [j]
10217	White	75.26 [ef]	79.31 [c]
11072	White	76.59 [de]	76.18 [ef]
White	White	73.82 [hi]	75.96 [e]
Mean		**76.27**	**77.63**
sd		**2.58**	**3.51**
Var		**6.68**	**12.35**
10061	Yellow	80.29 [a]	80.54 [abc]
10071	Yellow	77.93 [bc]	79.77 [bc]
10073	Yellow	73.62 [hi]	72.8 [ij]
10100	Yellow	72.16 [j]	70.47 [k]
10123	Yellow	77.15 [cd]	79.62 [bc]
10200	Yellow	74.16 [hi]	75.73 [ef]
Yellow	Yellow	78.53 [b]	80.54 [abc]
Mean		**76.26**	**77.06**
sd		**2.98**	**4.11**
Var		**8.87**	**16.91**
10236	Orange	70.80 [k]	74.05 [ghi]
11085	Orange	75.32 [fg]	73.73 [hij]
11090	Orange	73.89 [hi]	74.31 [fgh]
11092	Orange	74.67 [gh]	74.47 [efgh]
Orange	Orange	71.48 [de]	75.44 [efg]
Mean		**74.23**	**74.40**
sd		**2.14**	**0.65**
Var		**4.59**	**0.42**
10120	Purple	62.94 [l]	65.12 [l]
11214	Purple	63.39 [l]	63.53 [m]
Purple	Purple	76.78 [d]	77.78 [d]
Mean		**67.70**	**68.80**
sd		**7.87**	**7.79**
Var		**61.86**	**60.75**
Overall mean		**74.56**	**75.41**
sd		**4.52**	**4.85**
var		**20.41**	**23.57**

Note : Mean within column followed by different superscript letters are significantly different at $P<0.05$, n = 3
sd = standard deviation ; var = variant

Table 4 Correlation coefficient (r) of moisture, starch, amylose content and texture profile characteristics of 17 accessions and 4 sweet potato cultivar

Parameter	Moisture		Starch (fwb)	Amylose (fwb)	Peak Force	TPA Characteristics				
	Fresh	Steamed				Hardness	Adhesive-ness	Springi-ness	Cohesive-ness	Chewi-ness
Moisture-fresh	1									
Moisture-steamed	0.94**	1								
Starch	-0.917**	-0.85**	1							
Amylose	-0.54*	-0.52*	0.49*	1						
Peak force	-0.72**	-0.76**	0.47*	0.50**	1					
Hardness	-0.76**	-0.83**	0.60**	0.61**	0.90**	1				
Adhesiveness	0.41	0.54**	-0.24	-0.37**	-0.36	-0.43	1			
Springiness	0.33	0.30	-0.27	0.18	-0.30	-0.32	0.64**	1		
Cohesiveness	0.19	0.13	-0.37	-0.13	0.07	0.21	0.04	0.35	1	
Chewiness	-0.69**	-0.77**	0.49	0.10	0.51**	0.99**	-0.39	-0.22	0.36	1

* = significant at P<0.05 ** = significant at P<0.01

The changes of moisture content occurred after sweet potato tubers were steamed in 100 °C for 20 min. Positive correlation was found between fresh roots and after steaming ($r = 0.94$, $P<0.01$) (Table 4). The increase of moisture content happened in 11 accessions and 4 commercial cultivars which varied from 1 to 4 %. This is in agreement with the findings of Bradbury & Holloway (1988b). Moreover, Valitudie *et al*. (1999) reported that numerous intercellular spaces were noticed. It does seem that the amounts of intercellular spaces were filled by water. For 6 accessions, decreasing of moisture content occurred after 20 min steaming varying from 0.45 to 1.7 %. With the fact that no absorption of external water could take place during steaming, Biliaderis *et al*. (1986) argued whether cellular water was sufficient for the gelatinization process. The changes of moisture content might be related to the characteristics of certain cultivars. Table 4 also shows that negative correlation occurred between moisture content of steamed sweet potato tubers and both starch and amylose content. As explained by Wolfe (1992) that low amylose-high amylopectin content is responsible for the moist and sticky texture of cooked sweet potato.

3.3.2 Textural characteristics

Table 5 shows the textural characteristics of 17 accessions and 4 cultivars. Results of texture analysis shows wide variation of textural properties for the materials studied. Generally, the value of peak force deformation of UPM collection accessions were higher than *White, Orange* and *Purple,* except *Yellow* which showed higher than three other commercial cultivars. The two methods used for

determination of the texture of steamed samples, generated equal result on peak force deformation and hardness ($r = 0.90$, $P<0.01$) (Table 4). It provided evidence that both methods were appropriate to determine the hardness of the samples, although different settings of instrument were applied during testing.

All TPA curves of the steamed samples of the 17 accessions and 4 cultivars exhibited hardness which is similar to the TPA curves of baked sweet potato roots reported by Truong & Walter (1994), Truong *et al*. (1997) and Truong *et al*. (1998), however, no distinct fracturability appeared. Moisture content was an important factor affecting peak force deformation and hardness. Beside that, starch and amylose content were found as important factors affecting the textural properties (Table 4). Starch and amylose content affected the peak force deformation and hardness of cooked sweet potato which generated high positive correlation ($P<0.01$) as presented by Noda *et al.* (1998). Several studies reported that the amylose-amylopectin ratio was also responsible for the textural characteristics of sweet potato (Woolfe, 1992, Zhang & Oates, 1999), however, Noda *et al,* (1998) reported that it was reflected by the molecular architecture of amylopectin. Variation of peak force deformation and hardness could be explained by the varietal differences in the magnitude of degradation of starch and cell wall substances during cooking (Walter *et al*., 1975 and Shen & Sterling, 1981). Varietal differences in carbohydrate degradation during cooking which led to different textural properties among sweet potato cultivars have been reported (Shen & Sterling, 1981, Walter *et al*., 1975). It is supported by a wide cultivar variation in the concentration of maltose, a product of carbohydrate degradation during cooking (Truong *et al*., 1997). According to Verlinden *et al*. (1995), the

change in textural attributes during processing was caused by a decrease in cell stiffness as starch gelatinized and cell wall bonding was weakened.

Other results of TPA were adhesiveness, cohesiveness, springiness and chewiness. Adhesiveness was defined as the work necessary to overcome the attractive forces between the surface of the samples and the surface of other materials with which the sample comes in contact (Bourne, 2002). Wide variation occurred in adhesiveness, however, the 17 accessions had lower adhesiveness value than the 3 commercial cultivars (*White, Yellow* and *Purple*). Based on adhesiveness value, the samples could be grouped simply derived from the lowest to the highest values. *Low* adhesiveness referred cultivar having adhesiveness value in the range from 0.07 to 0.127 Ns, *medium* was from 0.128 to 0.184 Ns and *high* was from 0.185 to 0.24 Ns. The *Low* adhesiveness group was qualified by 10 UPM collection accessions that consist of 2 white, 2 yellow, 4 orange and 2 purple. *Medium* adhesiveness group consists of 3 white and 3 yellow accessions and also *Orange* commercial cultivar. *High* group adhesiveness was dominated by the commercial cultivars (*White, Yellow and Purple*), and yellow no. 10123. Adhesiveness was affected by moisture content and amylose content. Positive significant correlation ($P<0.01$) occurred between adhesiveness and moisture content of steamed samples. Negative correlation ($r = -0.37$, $P<0.01$) were found between amylose content and adhesiveness (Table 4). This means that high adhesiveness might be caused by the low amylose content of tubers. This is in agreement with the results reported by Hammett & Barrantine (1961), that low amylose content is responsible for the moist and sticky texture.

Table 5 Textural Characteristics of 17 accessions and 4 sweet potato cultivars

Accession/ Cultivar	Flesh Colour	Uniaxial Peak force Deformation (N)	TPA				
			Hardness (N)	Adhesive ness (Ns)	Cohesive ness ^{ns}	Springi-ness (%)	Chewi-ness (N)
10116	White	13.51 ^{bc}	9.80 ^{c}	0.17 ^{abc}	0.54	79.75 ^{def}	426.12 ^{b}
10168	White	7.80 ^{efg}	7.75 ^{de}	0.11 ^{cdefg}	0.53	76.08 ^{f}	316.84 ^{cd}
10166	White	6.98 ^{fgh}	6.76 ^{ef}	0.07 ^{g}	0.42	83.19 ^{cdef}	236.56 ^{defg}
10217	White	6.55 ^{gh}	4.52 ^{hi}	0.17 ^{abc}	0.44	85.96 ^{abcde}	170.00 ^{g}
11072	White	6.53 ^{gh}	6.20 ^{efg}	0.15 ^{bcdef}	0.49	82.86 ^{cdef}	253.38 ^{defg}
White	White	5.59 ^{h}	6.73 ^{ef}	0.24 ^{a}	0.44	92.57 ^{a}	273.07 ^{def}
Mean		**7.83**	**6.96**	**0.15**	**0.47**	**83.40**	**279.33**
sd		**2.88**	**1.75**	**0.06**	**0.05**	**5.62**	**86.54**
var		**8.27**	**3.059**	**0.003**	**0.003**	**31.555**	**7489.41**
10061	Yellow	5.56 ^{h}	5.74 ^{fgh}	0.15 ^{bcde}	0.50	79.74 ^{def}	231.66 ^{defg}
10071	Yellow	8.78 ^{e}	6.94 ^{ef}	0.16 ^{bcd}	0.52	79.53 ^{def}	288.91 ^{cde}
10073	Yellow	10.82 ^{d}	12.11 ^{b}	0.12 ^{cdefg}	0.52	81.80 ^{cdef}	517.50 ^{a}
10100	Yellow	12.28 ^{c}	13.23 ^{ab}	0.15 ^{bcde}	0.52	81.42 ^{def}	564.94 ^{a}
10123	Yellow	6.20 ^{gh}	5.76 ^{fgh}	0.22 ^{ab}	0.52	81.59 ^{def}	242.96 ^{defg}
10200	Yellow	6.68 ^{fgh}	6.79 ^{ef}	0.09 ^{defg}	0.47	79.27 ^{def}	258.13 ^{defg}
Yellow	Yellow	10.24 ^{d}	4.94 ^{ghi}	0.21 ^{ab}	0.46	84.81 ^{abcde}	193.28 ^{efg}
Mean		**8.65**	**7.93**	**0.16**	**0.50**	**81.17**	**328.20**
sd		**2.58**	**3.32**	**0.05**	**0.03**	**1.92**	**148.95**
var		**6.65**	**11.038**	**0.002**	**0.001**	**3.697**	**221.87**
10236	Orange	8.67 ^{e}	8.84 ^{cd}	0.11 ^{cdefg}	0.53	82.66 ^{cdef}	381.96 ^{bc}
11085	Orange	8.20 ^{ef}	7.28 ^{ef}	0.08 ^{efg}	0.51	91.38 ^{ab}	322.19 ^{cd}
11090	Orange	7.49 ^{efg}	6.33 ^{efg}	0.07 ^{g}	0.47	85.54 ^{abcde}	261.30 ^{defg}
11092	Orange	7.40 ^{efg}	7.18 ^{ef}	0.09 ^{defg}	0.49	83.88 ^{bcdef}	300.01 ^{cd}
Orange	Orange	5.59 ^{h}	5.94 ^{fgh}	0.17 ^{abc}	0.49	86.63 ^{abcd}	253.17 ^{defg}
Mean		**7.47**	**7.11**	**0.10**	**0.50**	**85.02**	**303.72**
sd		**1.17**	**1.12**	**0.04**	**0.02**	**1.70**	**52.03**
var		**1.38**	**1.245**	**0.002**	**0.000**	**2.895**	**27.08**
10120	Purple	16.40 ^{a}	14.25 ^{a}	0.10 ^{cdefg}	0.50	77.90 ^{ef}	576.86 ^{a}
11214	Purple	14.88 ^{b}	14.24 ^{a}	0.07 ^{g}	0.47	81.07 ^{def}	552.03 ^{a}
Purple	Purple	4.02 ^{i}	4.01 ^{i}	0.20 ^{ab}	0.52	90.04 ^{abc}	187.40 ^{fg}
Mean		**11.77**	**10.84**	**0.13**	**0.49**	**83.01**	**438.76**
sd		**6.75**	**5.91**	**0.07**	**0.03**	**6.30**	**218.04**
var		**45.583**	**34.952**	**0.005**	**0.001**	**39.651**	**475.41**
Overall Mean		**8.58**	**7.87**	**0.14**	**0.49**	**82.98**	**324.20**
sd		**3.30**	**3.09**	**0.05**	**0.03**	**3.97**	**128.48**
var		**10.898**	**9.532**	**0.003**	**0.001**	**15.785**	**165.07**

$^{a - i}$ Mean within column followed by different superscript letters are significantly different at $P<0.05$, n = 3 with 15 reading for each n

^{ns} = not significant

sd = standard deviation, var = variant, N = Newton, Ns = Newton second

Cohesiveness is one of the characteristics of the product exhibiting the rate at which the material disintegrates under mechanical action. Insignificant value of cohesiveness occurred indicating that all the samples had similar characteristics after cooking, including gelatinization of starch filling the cells, with the cell walls themselves remain intact (Sterling & Aldridge, 1977). In this study, cohesiveness was not correlated with other attributes (Table 2), and this is in agreement with the results reported by Truong *et al*. (1997).

Springiness is originally named *elasticity* (Szczesniak, 1963) and defined as the rate at which a deformed material goes back to its undeformed condition after the deforming force is removed (Pons & Fiszman, 1996). Table 5 shows the springiness value which varied from 76.08 to 92.57%. The wide variation was found for 17 accessions and 4 cultivars studied, additionally it occurred also within the flesh colour groups. Orange groups had the highest mean value and followed by white, purple and orange groups. When springiness value was separated into three major ranks, 17 accessions and 4 cultivars studied showed low and medium springiness. TPA springiness was not correlated with starch and amylose content. It seems that not only starch and amylose content affected the springiness of the cooked tubers, but more in the cooking process itself.

Chewiness is measured in terms of the energy required to masticate a solid food which mathematically as the product of hardness, cohesiveness and springiness (Friedman *et al.* 1963). Table 5 shows wide variation of chewiness value occurred which ranged from 170.00 to 576.86 N. The overall mean of the data was 324.20 N, whereas based on flesh colour groups the mean value was 279.33, 328.20,

303.72, and 438.76 N for white, yellow, orange and purple, respectively. By definition, chewiness was expressed mathematically as the product of hardness, cohesiveness and elasticity or springiness, however in this study the chewiness value was only highly affected by hardness ($r = 0.99$, $P<0.01$). Other factor affecting chewiness was moisture content of steamed samples, where negative correlation ($r = -0.77$, $P<0.01$) was found between these parameters (Table 4). From this data, the chewiness value appeared to be affected by the combination of moisture content and hardness. The low moisture content with high hardness generates the high chewiness, and vice versa.

The variation of textural characteristics might be affected by moisture content of steamed sweet potato tubers (Table 4). It was proven by the highly negative correlation between the moisture content and peak force deformation, hardness, adhesiveness and chewiness. The effect of moisture content on peak force deformation and hardness generated $r = -0.76$ ($P<0.01$) and $r = -0.83$ ($P<0.01$), respectively. Positive significant correlation ($r = 0.54$, $P<0.01$) also occurred between moisture content and adhesiveness, but negative correlation occurred in chewiness ($r = -0.77$, $P<0.01$). According to Verlinden *et al*. (1995), the changes in textural attributes during processing were caused by a decrease in cell stiffness as starch gelatinized and cell wall bonding was weakened. The typical textural changes in sweet potato cooking include starch conversion to sugar and dextrin by amylase enzymes. The degradation of starch by the amylases during cooking, particularly α-amylase, may influence mouthfeel by lowering the water-binding capacity and viscosity of sweet potatoes that is being interpreted by mouth as increase *moistness*. Walter *et al*. (1975) also suggested that mouthfeel in cooked

sweet potatoes depends in the amount of starch remaining after hydrolysis, the amount and size of dextrins formed and the amount of sugar present, all of which are influenced by amylolitic activity. Beside that, the interaction of pectic compounds with sugars or dextrins generated certain textural characteristics (Verlinden *et al*. 1995). Other minor component such as proteins in lipids and proteins that associated with starch granules found affects the properties of the granule as a whole and the properties of starch-derived products (Seguchi & Yamada, 1989, Hamaker & Griffin, 1993). Starch granule associated proteins (SGAP) in tuber crops including sweet potato present in a minor amount, for about 0.05 % (Suurs & Raedts, 1993). The principle physical difference between hard and soft appears to lie in the adhesive strength between the starch granules and the surrounding protein matrix. The "friabilin" protein(s) have also been known as "grain softness protein" that responsible for the softness texture. Monoacyl lipids found affect the rheological properties of the starches. Lipid makes the starch granules more rigid until certain gelatinization temperature is reached. Lipids, either native or added, form complexes with exuded amylose, probably on the surface of the granules and retard their swelling.

3.3.3 Starch pasting properties

In the presence of water and heat, starch granules swell by absorbing water and the starch granule begin to break down resulting in a paste which then form a gel on cooling. The consistency of the paste, the properties of the gel and the latter's viscosity during the pasting cycle are important for many purposes. Different

sweet potato starches exhibit considerable variation in their viscosity characteristics. The starch pasting properties of 17 accessions and 4 cultivars as measured by Brabender Viscograph are given in Table 6**.** Variation of gelatinization temperature was from 71.5 to 80.00 °C which was in agreement with the results reported by other researchers. As reported by several studies, gelatinization temperature of sweet potato starch measured using Brabender Viscoamylograph varied from 63 to 90 °C (Shin & Ahn, 1983, Zobel, 1988, de Melo et al., 1994., Suganuma & Kitahara, 1997., Moorthy, 2002), however they were higher than that reported by Takeda *et al*. (1986) and Garcia & Walter (1998) especially for commercial cultivars. Gelatinization temperature of white flesh group was higher than three other groups and varied from 75.5 to 79 °C. Yellow group exhibited large differences that varied from 75.5 to 79.3 °C, whereas orange and purple groups considered lower having variation from 71.5 to 75.4 °C. *Yellow* commercial cultivar had the highest gelatinization temperature and followed by *White*, *Orange* and *Purple* i.e. 80, 78.8, 75.4 and 72.9 °C, respectively.

Many parameters affect the gelatinization temperature, perhaps the most fundamental influence is the influence of water. During heating, the material leached in the temperature interval of 50 - 70 °C is mainly composed of amylose. The material solubilized increases in molecular weight, and is becoming more branched with increasing temperature (Ellis & Ring, 1985, Doublier, 1987, Prentice & Stark, 1992). According to Zhang & Oates (1999), the amylopectin content is a critical factor in governing the gelatinization temperature. Low gelatinization temperature sweet potato starches had less amylopectin and more

amylose than high gelatinization temperature. In this study, gelatinization temperature seems to be affected by amylose content. From 21 starch samples evaluated, negative correlation occurred between gelatinization temperature and amylose content of the starch ($r = -0.70$, $P<0.01$). The lower the amylose content, the higher the gelatinize temperature. Other components having effect of gelatinization temperature are lipid and the presence of minerals, especially phosphate. During gelatinization, the starch granule swells to several times its initial size, ruptures and simultaneously amylose leaches out from inside the granule. Three-dimensional networks is formed by the leached out amylose (Eliasson, 1985 and Tester & Morrison, 1990), the lipids, either native or added, form complexes with exuded amylose, probably on the surface of the granules and retard their swelling; as a result the gelatinization temperature is somewhat increased (Larsson, 1980, Lorenz, 1976, Singh, *et al.*, 2002). Starch contains two type of phosphorous in small quantities: esterified phosphorous and phospholipids (Hizukuri *et al.*, 2006). The ester phosphate groups are found exclusively in amylopectin. Cross-linking is done to restrict swelling of the starch granule under cooking conditions or to prevent gelatinization (Xi et al. 2005).

Peak viscosity is the value which indicates how readily the starch granules arc disintegrated, cohesive forces within the granules having the higher values arc stronger than those having the lower values (Garcia & Walter, 1998). The consistency of paste after holding at 93 °C for 20 min (breakdown viscosity) provides an estimate of the resistance of the paste to disintegration in response to heating and stirring. The wide variation of peak viscosity occurred from 380 to 711 BU for 20 samples studied, except for *Purple* which had >1000 BU. Peak

viscosity of white collection accessions was 443 to 621 BU with breakdown viscosity ranged from -31 to 35 BU. Yellow cultivar groups had the higher peak and breakdown viscosity that ranged from 510 to 725 BU and 41 to 144 BU, respectively. Orange accessions are considered to have lower peak viscosity with high breakdown viscosity compared with white and yellow groups except certain accessions which shown to have very high breakdown viscosity. Purple group had significant peak and breakdown viscosity compared with three other groups. As shown in Table 6, white, yellow and orange accessions had the common peak viscosity and agree with the results of previous literatures. Furthermore, purple accessions exhibited the highest peak viscosity value. Similar with gelatinization temperature, peak viscosity was also affected by amylose content. McPherson & Jane (1999) reported that the high amylose content on sweet potato starch might contribute to its lower peak viscosity and resistance to shear thinning. *Orange* commercial cultivar contained high amylose content in average, thus it generated the low peak viscosity. On the contrary, *Purple* contained the highest amylose content, but did not generate peak viscosity. It is in agreement with the result of (Chen, 2003) reported that one sweet potato cultivar from China (Sushu 8) didn't show peak viscosity. Amylose content found to be responsible for gelatinization and peak viscosity of the starch as argued by Zhang & Oates (1999) and McPherson & Jane (1999). It was proven by negative correlation between amylose content and gelatinization temperature ($r = -0.70$, $P<0.01$) and peak viscosity ($r = -0.41$, $P<0.05$).

The pasting behaviors of sweet potato starches exhibit a high peak viscosity and they become thinner rapidly with prolonged cooking before thickening on cooling

(Tian *et al.*, 1991). However, for some sweet potato varieties no peak viscosities in the viscosity curves (Brabender Viscograph) were observed (Seog *et al.*, 1987).

Table 6 Starch pasting properties of 17 accessions and 4 sweet potato cultivars

Accession/ Cultivar	Flesh colour	Gelatinization Temperature (°C)	Peak viscosity (BU)	Breakdown viscosity (BU)	Setback (BU)
10116	White	79	526	-24	161
10168	White	78.8	621	-31	273
10166	White	75.5	443	35	237
10217	White	79	541	4	193
11072	White	78.7	534	-1	148
White	White	78.8	598	142	178
10061	Yellow	78.6	725	144	179
10071	Yellow	78.6	630	55	172
10073	Yellow	76.2	569	41	262
10100	Yellow	75.5	510	79	195
10123	Yellow	79.3	647	83	160
10200	Yellow	75.5	516	70	177
Yellow	Yellow	80	545	10	215
10236	Orange	73.5	411	95	202
11085	Orange	73.2	409	94	145
11090	Orange	72.9	419	98	116
11092	Orange	73.1	380	87	94
Orange	Orange	75.4	527	41	304
10120	Purple	72.3	711	108	233
11214	Purple	71.5	691	120	256
Purple	Purple	72.9	nd (>1000)	>317	619

Note : BU = Brabender Unit; nd = not detected

Despite amylose and amylopectin are responsible for viscosities character, it has been presumed that molecular weight and branched polymer density were affected in the intrinsic viscosities and reducing power. The degree of polymerization of

sweet potato amylose has been reported in the range 3,025 to 4,100, while for amylopectin the average chain length of 21-29 was reported (Hizukuri, 1985, Takeda *et al*., 1986, Ong *et al.*, 1994). The starch of sweet potato was found to have amylose containing lower degree of polymerization than legumes starch. Some cultivar have relatively low intrinsic starch viscosities and high starch reducing power, suggesting low molecular weights and highly branch polymer, however others appeared to have a high molecular weight and highly branch polymer (Martin & Deshpande, 1985).

Setback defined as the degree of re-association between the starch molecules involving amylose, has been directly related to the amount of amylose leached from granule (Greenwood, 1979, Charles *et al.*, 2004), beside the amylose content, degree of polymerization and chain length distribution of amylopectin also have an effect positively on the pasting properties (Garcia, 1998, Seetharaman *et al.*, 2001, Noda, 2005, Sandhu & Singh, 2007). Setback varied greatly, which is common for sweet potato starch, especially for the 17 UPM accessions which ranged from 94 to 273 BU. In practical terms, upon cooling, the cultivar having higher setback viscosity would tend to have stiffer paste than those that have lower setback. *Purple* showed different setback value compared to other cultivars which had very high peak viscosity (>1000 BU), but, no breakdown viscosity, indicating that it had a strong paste and rigid granular structure. It might be *Purple* cultivar contained highest amylose content of the starch (28.79 %, db), compared to other commercial cultivars. Other factors affecting the high setback were larger starch granule size, low amount of phosphorous, calcium and magnesium, and high level of sodium and potassium (Zaidul *et al.*, 2007).

The four commercial cultivars were found to have different characteristics compared to UPM's accessions. Gelatinization temperature of commercial cultivars was higher than collection cultivars. *White*, *Yellow* and *Orange* had medium peak viscosity with *Yellow* was the most resistant to disintegration followed and by *Orange* and *White.*

3.3.4 Starch and amylose content

The carbohydrates in sweet potato roots play an important part not only in the degree of sweetness of cooked roots, but also in their texture. Starch is the major carbohydrate dominating the dry matter content of sweet potato tubers, can comprise from 30 to 70 % of sweet potato dry matter compound (Garcia & Walter, 1998, Woolfe, 1992). Starch content of the 17 accessions and 4 cultivars varies widely, especially for white and purple flesh colour groups (Table 7). Starch content is shown in fresh weight basis (fwb) and dry basis (db). Starch content in fwb is used to indicate the amount of starch in fresh roots, whereas in db is used to show the amount of starch in dry matter fraction of the root. Starch content of 17 accessions and 4 cultivars in this study varied from 10 to 25 % (fwb), with the average were 14.33, 13.14, 14.30 and 20.80% (fwb) or 53.31, 53.20, 53.20 and 52.20 % (db) for white, yellow, orange and purple groups, respectively. The result is in agreement with the results reported by earlier workers. This study is in agreement also with Den (1994) which showed positive correlation (r = 0.927) occurred between starch (fwb) and dry matter content.

Table 7 Starch and amylose content of 17 accessions and 4 sweet potato cultivars

Accession/ Cultivar	Flesh Colour	Starch (%, fwb)	Starch (%, db)	Amylose (%, db)
10116	White	11.02 ^{hij}	53.47 ^{b}	23.95 ^{bc}
10168	White	10.67 ^{ij}	52.98 ^{fgh}	23.76 ^{bc}
10166	White	16.59 ^{d}	52.93 ^{ghi}	25.61 ^{abc}
10217	White	14.86 ^{de}	53.75 ^{a}	24.64 ^{abc}
11072	White	13.53 ^{efg}	53.53 ^{b}	24.96 ^{abc}
White	White	19.30 ^{c}	53.21 ^{de}	25.53 ^{abc}
Mean		**14.33**	**53.31**	**24.74**
sd		**3.32**	**0.32**	**0.78**
Var		**11.01**	**0.10**	**0.60**
10061	Yellow	9.87 ^{j}	53.71 ^{a}	23.11 ^{c}
10071	Yellow	11.72 ^{ghij}	53.52 ^{b}	19.15 ^{d}
10073	Yellow	15.51 ^{de}	52.90 ^{hi}	24.67 ^{abc}
10100	Yellow	15.08 ^{de}	52.98 ^{fgh}	25.06 ^{abc}
10123	Yellow	13.27 ^{efgh}	53.05 ^{f}	23.57 ^{bc}
10200	Yellow	14.16 ^{def}	52.85 ^{ij}	24.67 ^{abc}
Yellow	Yellow	12.34 ^{fghi}	53.37 ^{c}	24.83 ^{abc}
Mean		**13.14**	**53.20**	**23.58**
sd		**1.99**	**0.33**	**2.08**
Var		**3.96**	**0.11**	**4.33**
10236	Orange	16.23 ^{d}	52.95 ^{fghi}	27.93 ^{ab}
11085	Orange	11.51 ^{ghij}	53.29 ^{cd}	26.52 ^{abc}
11090	Orange	15.01 ^{de}	53.22 ^{de}	26.35 ^{abc}
11092	Orange	14.34 ^{def}	53.51 ^{b}	26.33 ^{abc}
Orange	Orange	14.43 ^{def}	53.01 ^{fg}	27.15 ^{abc}
Mean		**14.30**	**53.20**	**26.86**
sd		**1.73**	**0.23**	**0.69**
Var		**3.00**	**0.05**	**0.47**
10120	Purple	22.53 ^{b}	52.79 ^{j}	26.94 ^{abc}
11214	Purple	25.40 ^{a}	53.15 ^{e}	26.69 ^{abc}
Purple	Purple	14.47 ^{def}	53.03 ^{fg}	28.79 ^{a}
Mean		**20.80**	**52.99**	**27.48**
sd		**5.67**	**0.19**	**1.15**
Var		**32.10**	**0.03**	**1.32**
Overall Mean		**14.85**	**53.20**	**25.25**
sd		**3.77**	**0.29**	**2.03**
Var		**14.25**	**0.08**	**4.11**

Note : Mean within column followed by different superscript letters are significantly different at $P<0.05$, n = 3
sd = standard deviation, var = variant

The linear component of starch, viz., amylose, imparts definite characteristics to starch. Amylose content varies considerably among the different of the 17 accessions and 4 cultivars. Based on the mean in each group of colour, the amylose content varies from 19.15 to 28.80 % (db). Purple accessions contained the highest amylose content (27.48 %) and followed by orange (26.86 %), white (24.74 %) and yellow (23.58 %). Four commercial cultivars showed similar pattern for the amylose content as 17 collection accessions.

Starch and amylose content of the samples in this study was in agreement with the results reported by other researchers (Madamba *et al.,* 1975, Suganuma & Kitahara, 1997, Moorthy, 2002, Katayama *et al*., 2004). Dissimilarly with starch content, the variation of amylose content in sweet potato starch was found to be affected by the cultivar (Garcia & Walter, 1998, Moorthy, 2002).

Starch content of 4 commercial cultivars was around the average of all sweet potato studied, 15.14 % (fwb) or 53.20 % (db), with amylose content was above the average for each groups. Starch content of commercial cultivars was 19.30, 12.34, 14.43 and 14.47 % (fwb) or 53.21, 53.37, 53.01 and 53.03 % (dwb) for *White, Yellow, Orange* and *Purple,* respectively, whereas, the amylose content was 25.53, 24.83, 27.15 and 28.79 for *White, Yellow, Orange* and *Purple,* respectively.

3.3.5 Sugars content

Figure 6 illustrates a typical chromatogram of sugar separation in fresh sweet potato tubers using an NH_2 column. A large Acetonitrile-water solvent peak elutes before the monosaccharide, fructose and glucose, followed by the disaccharides, sucrose and maltose, respectively. The previous literature on sweet potato carbohydrate components is mostly based on total sugar or total reducing sugar with limited information on the individual sugar. Sucrose, glucose and fructose are the principal sugars present in fresh sweet potato roots (Picha, 1986b, Huang *et al.,* 1999a). The changes of composition and concentration of free sugars is important factors of eating quality (Picha, 1986b, Truong *et al*., 1986a, Ajlouni & Hamdy, 1988, Takahata *et al*., 1996, Lewthwaite *et al*., 1997).

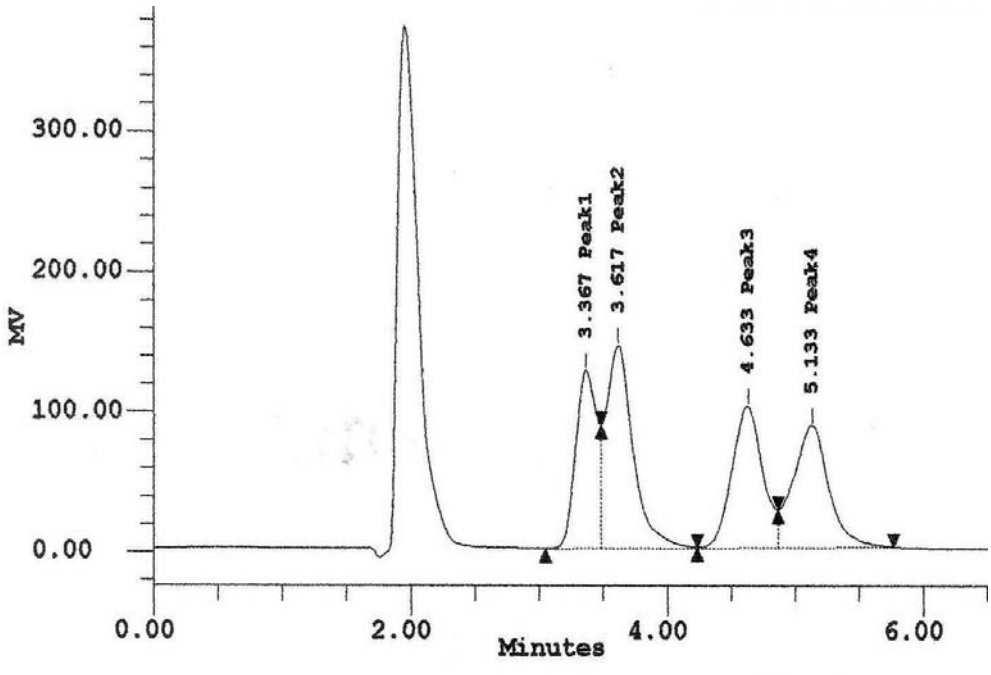


Figure 6 Typical chromatogram of sugar separation in fresh sweet potato tubers. Very first Peak = Acetonitrile-water solvent, Peak 1=Fructose, Peak 2=Glucose, Peak 3=Sucrose and Peak 4=Maltose. MV = milivolt

Sugar concentration in fresh tubers of 17 collection accessions and 4 commercial cultivars is shown in Table 8. Sucrose was the most abundant sugar in fresh tubers and followed by glucose, fructose and maltose. Glucose was the second most abundant sugar in 16 out of 17 accessions. The amount varies from 1.1 to 2.37% with the other 1 accession (no. 11214) having less than 1%. White flesh colour group contained the highest glucose content and followed by yellow, orange and purple. Orange and purple groups had the lower glucose content than two other groups. Four commercial cultivars contained very low glucose and below the average within each groups, that varied from 0.07 to 0.89 %.

Fructose presented in a lower content than glucose in sweet potato tubers which varied from 0.05 to 1.87 %. The average of fructose content was 1.09, 1.47, 1.06 and 0.75 % for white, yellow, orange and purple group, respectively, with the mean value of 1.16 %. Generally, insignificant difference was found in fructose content among the members of white, yellow and orange-flesh colour groups for collection accessions. Fructose content within yellow groups showed insignificant different, except *Yellow* commercial cultivar that contained lower fructose content than the collection accessions. Orange collection accessions generated insignificant difference within the group, whereas *Orange* commercial cultivar containing lower fructose content. Significant difference ($P<0.05$) occurred in purple group. Commercial cultivars contained very low fructose in the range 0.05 to 0.8 % and showed below the average of each group, compared to 17 collection accessions.

Table 8 Sugar content of fresh sweet potato tubers from 17 accessions and 4 cultivars

Cultivar	Flesh colour	Glucose (%, db)	Fructose (%, db)	Sucrose (%, db)	Maltose (%, db)
10116	White	1.59 ^{bcdef}	1. 40 ^{abcd}	1.80 ^{fg}	0.88 ^{abcd}
10168	White	1.90 ^{abcd}	1. 54 ^{abc}	2.55 ^{cdef}	0.58 ^{cde}
10166	White	1.73 ^{abcde}	0.89 ^{defg}	1.79 ^{fg}	1.23 ^{abc}
10217	White	1.99 ^{abc}	1.07 ^{cdef}	1.72 ^{fg}	0.73 ^{bcd}
11072	White	2.37 ^{a}	1.22 ^{bcdef}	1.94 ^{efg}	1.20 ^{abc}
White	White	0.63 ^{hij}	0.45 ^{ghi}	1.70 ^{fg}	0 ^{e}
Mean		**1.70**	**1.09**	**1.91**	**0.77**
sd		**0.59**	**0.39**	**0.33**	**0.46**
Var		**0.35**	**0.15**	**0.11**	**0.21**
10061	Yellow	1.42 ^{cdefg}	1.61 ^{abc}	1.22 ^{g}	0.80 ^{abcd}
10071	Yellow	1.53 ^{cdefg}	1.35 ^{abcd}	1.29 ^{g}	0.92 ^{abcd}
10073	Yellow	1.10 ^{efgh}	1.53 ^{abc}	1.24 ^{g}	1.39 ^{ab}
10100	Yellow	2.34 ^{a}	1.77 ^{ab}	2.09 ^{defg}	1.51 ^{a}
10123	Yellow	2.28 ^{ab}	1.87 ^{a}	1.45 ^{g}	1.41 ^{ab}
10200	Yellow	1.39 ^{cdefg}	1.41 ^{abcd}	1.87 ^{efg}	1.52 ^{a}
Yellow	Yellow	0.89 ^{fghi}	0.80 ^{efg}	2.84 ^{bcd}	0.91 ^{abcd}
Mean		**1.56**	**1.47**	**1.71**	**1.13**
sd		**0.56**	**0.35**	**0.60**	**0.32**
Var		**0.31**	**0.12**	**0.36**	**0.10**
10236	Orange	1.44 ^{cdefg}	1.29 ^{bcde}	3.79 ^{a}	1.40 ^{ab}
11085	Orange	1.51 ^{cdefg}	1.36 ^{abcd}	3.49 ^{ab}	1.31 ^{abc}
11090	Orange	1.19 ^{defgh}	1.16 ^{cdef}	2.73 ^{bcde}	0.94 ^{abcd}
11092	Orange	1.33 ^{cdefg}	1.20 ^{cdef}	1.82 ^{fg}	1.13 ^{abc}
Orange	Orange	0.35 ^{ij}	0.27 ^{hi}	2.92 ^{bcd}	0 ^{e}
Mean		**1.16**	**1.06**	**2.95**	**0.95**
sd		**0.47**	**0.45**	**0.76**	**0.56**
Var		**0.22**	**0.21**	**0.58**	**0.32**
10120	Purple	1.63 ^{bcde}	1.50 ^{abc}	2.06 ^{defg}	0.72 ^{bcd}
11214	Purple	0.82 ^{ghi}	0.70 ^{fgh}	3.34 ^{abc}	0.42 ^{de}
Purple	Purple	0.07 ^{j}	0.05 ^{i}	2.41 ^{def}	1.07 ^{abcd}
Mean		**0.84**	**0.75**	**2.60**	**0.74**
sd		**0.78**	**0.73**	**0.66**	**0.32**
Var		**0.60**	**0.53**	**0.43**	**0.10**
Overall Mean		**1.40**	**1.16**	**2.19**	**0.93**
sd		**0.62**	**0.48**	**0.75**	**0.43**
Var		**0.38**	**0.23**	**0.57**	**0.18**

Note : Mean within column followed by different superscript letters are significantly different at $P<0.05$, n = 5 with 5 reading for each n
sd = standard deviation
var = variant

Sucrose was the most abundant sugar in fresh tubers, especially for orange and purple cultivars, including 4 commercial cultivars. Sucrose content of 17 accessions and 4 cultivars studied varied from 1.22 to 3.79 %. The means of sucrose content were 1.91, 1.71, 2.95 and 2.60 % (db) for white, yellow, orange and purple, respectively. Based on the average, orange and purple contain higher sucrose content than white and yellow. Orange no. 10236 contained the highest sucrose content (3.79 %) and followed by purple no 11214 that contained 3.34 %. For four commercial cultivars, *Orange* contained 2.92 % and followed by *Yellow* 2.84 %, *Purple* 2.41 %, and *White* 1.70 %.

Dissimilar to sucrose, maltose is disaccharide which generally presents in a very low amount in fresh sweet potato tubers. Picha (1985b) reported that maltose is only produced during cooking. During heating, much of the starch is converted into dextrin and maltose by alpha-amylase and beta-amylase (Walter *et al.*, 1975). However, there are cultivar differences in the degree of starch conversion (Babu, 1994). From the 17 collection accessions and 4 commercial cultivars showed the variation of maltose content was widespread from 0 to 1.53 %. The mean values of the four groups are as follow: white 0.77 %, yellow 1.13 %, orange 0.95 %, and purple 0.74 %, whereas means of 17 collection accessions and 4 commercial cultivars studied was 0.93 %. From the 17 accessions and 4 cultivars, 19 showed insignificant difference ($P>0.05$), including 2 commercial cultivars (*Yellow* and *Purple*). Two commercial cultivars (*White* and *Orange*) did not contain any maltose. The sequence of sugar content in fresh tubers obtained in this study is in agreement with the results of Picha (1985b), Takahata *et al.,* (1996) and Huang *et al*., (1999a) that found in several cultivars from different sources.

3.4 Conclusions

The difference of skin and flesh colour in sweet potato generated very wide variation of individual characteristic. A simple way to classify sweet potato roots was based on flesh colour. Twenty one cultivars were evaluated, consisted of 17 accessions provided by UPM and 4 commercial cultivars. Based on flesh colour, it could be classified into 4 groups; i.e. white, yellow, orange and purple, disregard of skin colour.

Seventeen accessions and 4 commercial cultivars of sweet potato studied exhibit wide variation in physical and chemical characteristics. Commercial cultivars showed different characteristics compare to the collection cultivars. Textural characteristics were influenced by moisture, starch and amylose content of SP tubers. The variation of moisture content of tubers after steaming revealed the characteristic of the cultivars. The higher moisture content generated the lower peak force deformation and hardness. Starch and amylose content in 17 accessions and 4 cultivars varied widely. Starch and amylose were components which responsible in physical characteristics of sweet potato tubers. Sweet potato which contain high starch and amylose content showed high peak force deformation and hardness, but low adhesiveness. The difference of amylose content resulted in the variation of pasting characteristics. The lower the amylose content, the higher the gelatinize temperature and the higher peak viscosity. The sequence of sugar content in fresh tubers obtained in this study is sucrose, glucose, fructose and maltose.

CHAPTER 4

THE EFFECT OF STEAMING TIME ON THE TEXTURAL CHARACTERISTICS OF 2 SWEET POTATO CULTIVARS

4.1 Introduction

Cooking is a generic term for all hydrothermal treatments. Cooked products present a large diversity of structural, sensory and functional properties according to the methods and intensity of cooking. Such effects were reported on sweet potato tubers (Sarhan, 1975, Walter *et al*., 1975, Bradbury *et al*., 1988b, Reddy & Sistrunk, 1980, Shen & Sterling, 1981), because of the very wide variation characteristics of the cultivars. On baking, Wu *et al*. (1991) reported that texture profile parameter was influenced by storage of tubers, whereas Losh *et al*. (1981) reported that roots baked at 180, 200 and 230 °C were significantly less resistant to compression than at 150 °C. Controlling the pH of sweet potato strips prior to frying using acid and base treatments were reported by Walter *et al*. (1992) and Walter *et al*. (1993) in attempt to increase the firmness of cooked sweet potato stick.

Cooked sweet potatoes have been arbitrarily classified into two major textural types. The moist or yam type has a soft, syrupy texture. At the other extreme is the firm, mealy texture, the dry type. This property describes the mouthfeel characteristics and is independent of water content (Rao *et al.,* 1974). Histological studies (Sterling & Aldridge, 1977) indicated that mealiness in baked roots of dry

sweet potatoes was due to whole cell separation similar to that reported for white potato. These workers found that sogginess of baked roots of moist sweet potatoes had a different cause in that the cells did not separate but both starch and cell wall tended to break down. Walter *et al.* (1975) reported that the moistness of baked sweet potatoes was influenced by the extent of starch degradation by a-amylase. Many researches on sweet potato have been conducted to explain the causes of textural differences among varieties and processed product (Hamann *et al*., 1980, Truong *et al*., 1997, Truong *et al*., 1998). Truong *et al*. (1997) employed a uniaxial test and Texture Profile Analysis (TPA) to determine textural properties of commercial and experimental cultivars/selections and to establish a correlation between instrumental and sensory measurements.

The objective of this study is to determine the texture profile characteristics of *Yellow* and *White* cultivars cooked at different steaming times in attempt to choose the suitable raw material for further research on restructured sweet potato product.

4.2 Materials and methods

4.2.1 Materials

Sweet potato roots were *White* and *Yellow* flesh colour commercial cultivars purchased from Pasar Borong Selangor, Selangor, Malaysia which was available all along the year.

4.2.2 Sample preparation

A middle portion of each raw sweet potato root was cut transversely to the long axis into 3.5 cm thick slab. Using cork borer with 1.35 cm diameter (No. 10, Cork borer, Ambala, India), cylindrical samples were taken from each slab and trimmed into cylinders of 2.2 cm thickness. Samples were taken at the inner tissue of the roots at an approximate distance of 1 cm from the root skin. The preparation of cylindrical samples was done as explained in section 3.2.2.

The cylindrical samples were washed with tap water to remove adhered starch and steamed in a steamer (CPC 61, Rational, Germany) at 100 °C, atmospheric pressure for 5, 10, 15 and 20 minutes. Cooked samples were kept in a closed container to avoid moisture losses and subjected to moisture content determination, uniaxial compression test and texture profile analysis (TPA) on the day of preparation.

4.2.3 Moisture content

Moisture content of both raw and cooked samples was determined using the Oven method (AOAC, 1984). Approximately 4 gram samples were dried at 105 °C in aluminum cup overnight or until constant weight was attained. The percentage of weight lost was calculated as moisture content. The determination was repeated three times for each individual samples.

4.2.4 Texture Analysis

Peak force deformation was measured using uniaxial compression on cylinder of fresh and steamed tissue adopted from Walter *et al*. (2000). Uniaxial compression test was performed using a Texture Analyzer (TA.TX2i, Godalming, UK) fitted with a 25 Kg load cell with a TA-50 probe having 50 mm diameter compression plate. The test condition was conducted as explained in section 3.2.4. The peak force-deformation curves were obtained from 15 reading for every replication of sample.

Hardness, adhesiveness, springiness and chewiness were measured by Texture Profile Analysis (TPA) method as described by Bourne (1978). Texture Analyzer (TA.TX2i, Godalming, UK) was fitted with a 25 Kg load cell with a probe having 50 mm diameter compression plate. The steamed cylindrical specimen was compressed longitudinal for two cycles. The test condition was conducted as explained in section 3.2.4. The TPA curves were obtained from 15 reading for every replication of sample.

Data collection and analysis were accomplished by the EXTRAD Dimension Software that is supplied with of the Texture Analyzer. For Uniaxial compression test, the data from the force-deformation curves was peak force or firmness. Hardness, adhesiveness, springiness and chewiness were measured by Texture Profile Analysis (TPA) method (Bourne, 1978).

4.2.5 Statistical analysis

The experiment was arranged with a randomized complete block design with 3 replications. The data collected were analyzed using analysis of variance (ANOVA) and significant differences among means were determined by Duncan's multiple range test (DMRT) with 5 % of the level of significance, using MSTAT-C statistical software.

4.3 Results and discussion

4.3.1 Moisture content

Based on statistical calculation, the average of moisture content between *White* and *Yellow* showed significant difference ($P<0.05$), but there was no significant difference occurred on the specimens during step of steaming for b cultivars. Moisture content of *White* was lower for fresh tuber until the final process of steaming than *Yellow* cultivar. However, the fluctuation of moisture content occurred during steaming and followed similar tendency between *White* and *Yellow*. As explained in previous chapter, the difference of moisture content does not depend only on the character of cultivar, but also environmental factors such as location, soil type and cultivation practices. *White* commercial cultivar was cultivated sandy soil in Bidor, Perak, Malaysia, whereas *Yellow* was planted in peat soil in Sepang, Selangor, Malaysia.

Figure 7 shows the changes of moisture content during steaming at 100 °C. Similar pattern of moisture content during steaming occurred in both cultivars, except after 15 minutes steaming. Slight decrease in moisture content occurred during first five minutes steaming and this may be caused by evaporation. It is in agreement with Truong *et al.* (1997) reporting that water evaporation occurred during steaming resulting in a slight increase in dry matter content of cooked sweet potato. The increase in moisture content after 5 to 10 minutes of cooking indicated that hydration and gelatinization was going on although no significant difference occurred.

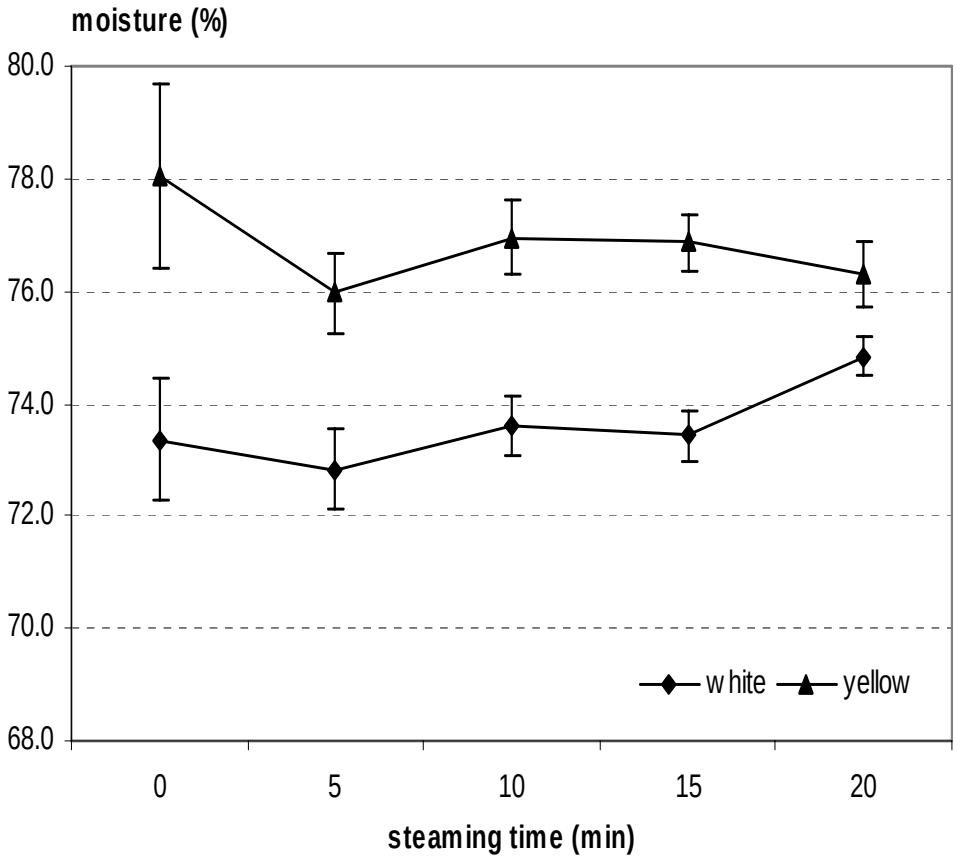


Figure 7 Changes of moisture content of *White* and *Yellow* cultivars during steaming at 100 °C, atmospheric pressure for 0, 5, 10, 15 and 20 minutes.

White cultivar always shows lower moisture content compared with *Yellow* for fresh tubers, that was about 73 and 78 % for *White* and *Yellow*, respectively. Moisture is an important parameter on heat treatment such as boiling, steaming or baking, especially for products containing high moisture content and carbohydrates. The alteration of moisture content occurs due to the gelatinization process starting with absorption of water by carbohydrate molecules until complete gelatinization. In this study, decreasing of moisture content during first step of steaming might be due to water evaporation, especially in the surface of specimen that took place immediately when it was subjected to the temperature of steaming. *White* cultivar containing lower moisture content than *Yellow*, decreased from 73.35 % to 72.82 % and it happened at the first five minutes of steaming, whereas for *Yellow*, the decreasing of moisture content occurred from 78.04 % to 75.97 %. At that time, increasing of temperature stimulated the swelling of starch granules by absorbing internal water. Biliaderis *et al*. (1986) reported that during steaming no absorption of external water could take place, whether the cellular water was sufficient for the gelatinization process. On the second five minutes of steaming, moisture content slightly increased which indicated that the starch molecules continued to swell by absorbing water and possibly the gelatinization process was initialized. Rising of moisture content for *White* and *Yellow* was 0.77 and 0.99 %, respectively. Steaming the sweet potato specimens for additional 5 min might result in continued swelling and gelatinization of the starch granules. At the end of 15 minutes steaming, moisture content was found slightly decreased for all cultivar; however at the end of steaming (20 min) *White* cultivar showed significantly ($P<0.05$) changes of moisture content. This condition might be due to the different of starch or amylose content, in which *White* cultivar contained

higher starch and amylose content than *Yellow* as explained in previous chapter (Table 7, Chapter III). Consequently, *White* required more external water throughout gelatinization process.

4.3.2 Peak force deformation of fresh sweet potato tubers

Force deformation curve generated from uniaxial compression test for fresh tubers of *White* and *Yellow* cultivars is shown in Figure 8. Fresh sweet potato generated curves with a steep slope and a sharp peak force at fracture. The peak force deformation of *White* was found to be higher than the *Yellow* cultivar. The maximum force needed to deform the specimen of *White* cultivar was 349.36 N, whereas for *Yellow* was 298.15 N. The different value of peak force deformation might be affected by the internal cell structure of the sweet potato flesh-tissue.

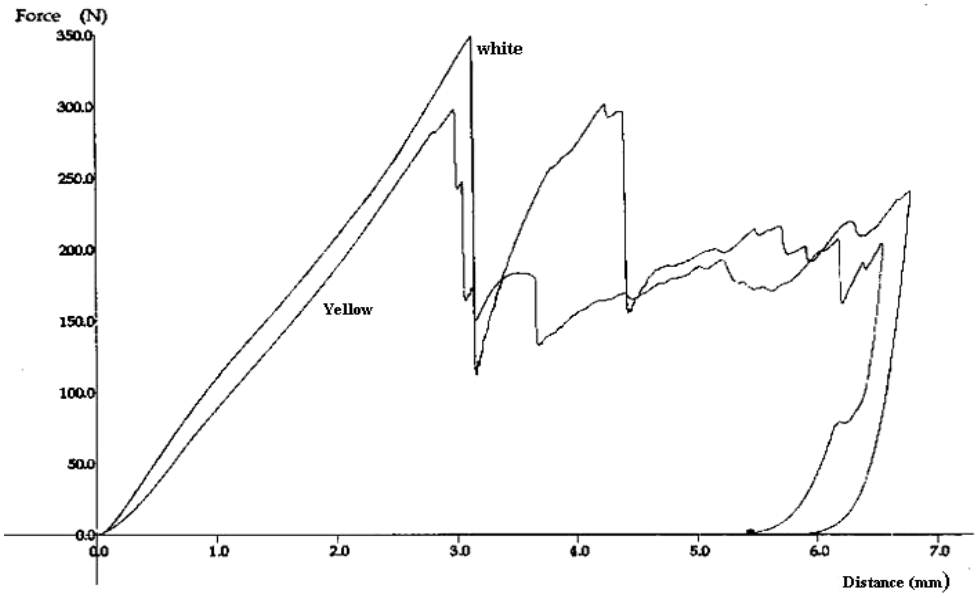


Figure 8 Force deformation curve of uniaxial compression test for fresh tubers of *White* and *Yellow* cultivars.

Figure 8 exhibits a typical deformation pattern of rigid plant materials under loading. The fracture was the shear type along 45 ° rupture plane, as reported by Truong *et al*. (1997). It has been recognized that in raw plant tissue, cell turgor pressure and cell wall strength account for tissue stiffness and the mode of failure (Lin & Pit, 1986). Similar force deformation curves and fracture type under uniaxial compression have been reported in fresh apples and potatoes (Khan & Vincent, 1993). In raw sweet potato, thickness of cell walls is an average 2.5 µm and is two times that of potato cell walls (Hadziyev & Stele, 1982). The cell walls show extensive folding, the primary cell wall consist of fibrous substructure, probably cellulose fibrils, which are loosely woven together in a pattern and embedded in an amorphous matrix (Sterling, 1963). Numerous intercellular spaces were noticed (Sterling & Aldridge, 1977, Valitudie *et al*., 1999). It does seem that the lower the amount of intercellular spaces, the lower the water filling the space, and the firmer the tissue. This fact probably supported the consequence that *White* generated a higher peak force deformation than *Yellow* cultivar, since *White* contained lower moisture content than *Yellow*

4.3.3 Peak force deformation of steamed sweet potato tubers

The decreasing of peak force deformation occurred during heating process, however prolonging steaming time after 10 minutes insignificantly affected peak force deformation for both cultivars (Table 9). Based on the cultivar, *White* generated higher peak force deformation value in first 5 minutes steaming time compared to *Yellow*. For the *White* cultivar, peak force deformation of samples

steamed for 10, 15, and 20 minutes (6.98, 6.28 and 5.07 N respectively) were 3 fold lower than steaming for 5 minutes (19.81 N), whereas for *Yellow* cultivar, peak force deformation of samples steamed for 10, 15 and 20 minutes were 5.09, 5.03 and 4.71 N respectively which was 2.5 fold lower than steaming for 5 minutes (12.94 N). However, the difference of peak force deformation between 5 minutes and three other duration of steaming might be caused by the incomplete of gelatinization of the starch granules during 5 minute of cooking.

Table 9 Texture profile characteristics of 2 commercial sweet potato cultivars

Culti-var	Steaming time (minute)	peak force deforma-tion (N)	TPA			
			Hardness (N)	Adhesive-ness (Ns)	Springi-ness (%)	Chewi-ness (N)
White	5	19.81^{a} ± 7.68	18.17 ^{a} ± 4.69	0.07 ^{d} ± 0.01	91 ^{a} ± 11.0	294.01 ^{b} ± 127.00
	10	6.98^{c} ± 1.32	11.55 ^{b} ± 3.07	0.10 ^{d} ± 0.01	83 ^{cd} ± 9.5	201.65 ^{c} ± 24.74
	15	6.28 ^{c} ± 1.40	7.18 ^{c} ± 1.77	0.14 ^{cd} ± 0.01	82 ^{cd} ± 12.3	120.47 ^{cd} ± 31.03
	20	5.07 ^{c} ± 2.24	4.96 ^{c} ± 1.25	0.13 ^{cd} ± 0.01	80 ^{d} ± 9.7	69.22 ^{d} ± 24.87
Yellow	5	12.94^{b} ± 3.87	16.78 ^{a} ± 6.16	0.13 ^{cd} ± 0.06	86 ^{a} ± 8.4	321.30 ^{a} ± 118.88
	10	5.09 ^{c} ± 0.25	6.35 ^{c} ± 1.35	0.20 ^{bc} ± 0.04	90 ^{a} ± 9.4	155.91 ^{c} ± 59.52
	15	5.08 ^{c} ± 0.52	4.48 ^{c} ± 0.87	0.26 ^{ab} ± 0.08	88 ^{a} ± 13.3	114.25 ^{cd} ± 27.42
	20	4.71 ^{c} ± 0.66	4.48 ^{c} ± 0.88	0.29 ^{a} ± 0.07	86 ^{ab} ± 12.7	115.38 ^{cd} ± 17.06

Note : Mean within column followed by different superscript letters are significantly different at P<0.05, n = 3 with 15 reading for each n
N = Newton, Ns = Newton second

The graph of steam-cooked samples as shown in Figures 9 and 10 that exhibit peak force-deformation of samples steamed in 5, 10, 15, and 20 minutes. Force deformation curve of cooked samples was found dissimilar to curve of fresh samples as shown in Figure. Unsharp peak force deformation indicated no fracture

was found, and modification of cell and tissue occurred. The subjection of heat on the specimens disrupted cell integrity and cell adhesion resulting in decrease in tissue rigidity. Steaming for 5 minutes radically decrease the peak force deformation indicating that physical changes occurred. Furthermore, the declining of peak force deformation continued until 10 min of steaming, indicating major changes in texture for both cultivars.

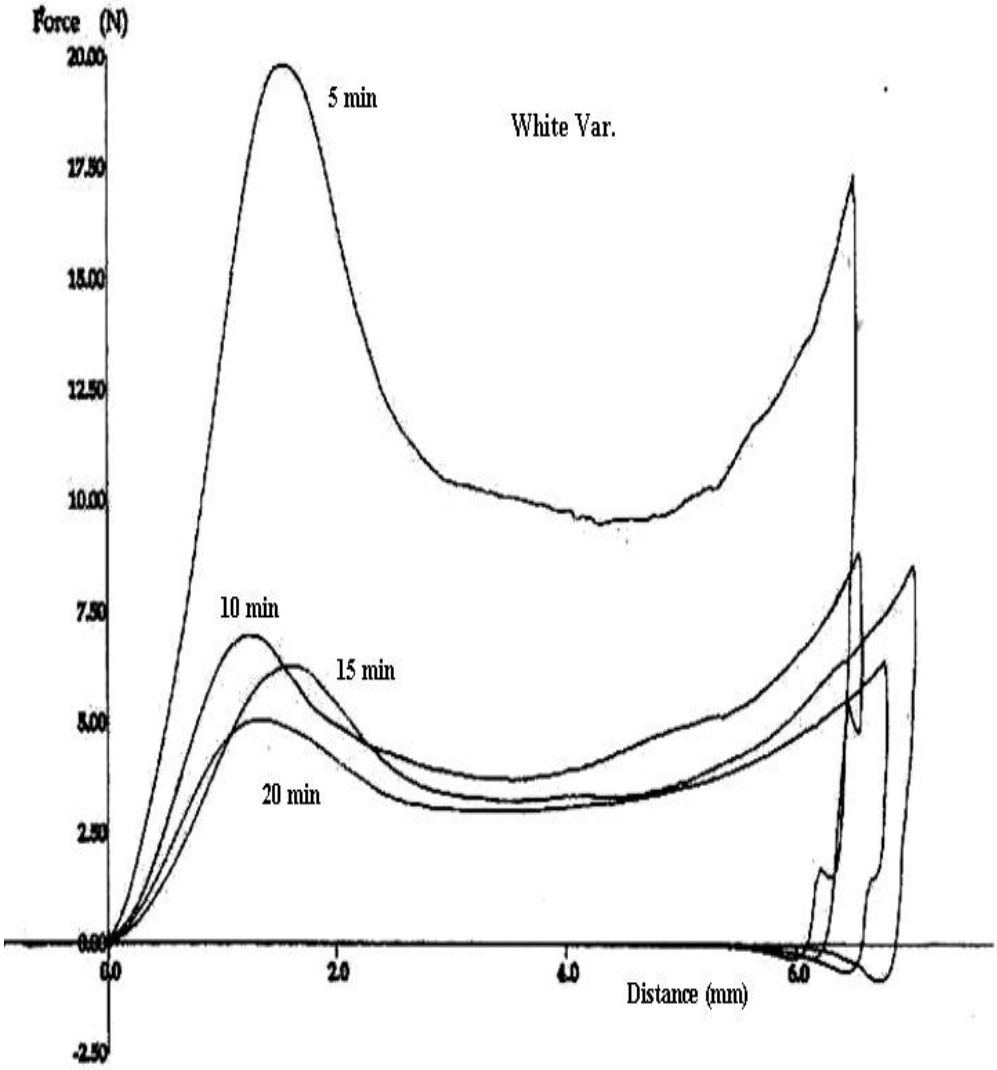


Figure 9 Force deformation curves of uniaxial compression test of *White* cultivar for 4 duration steaming time.

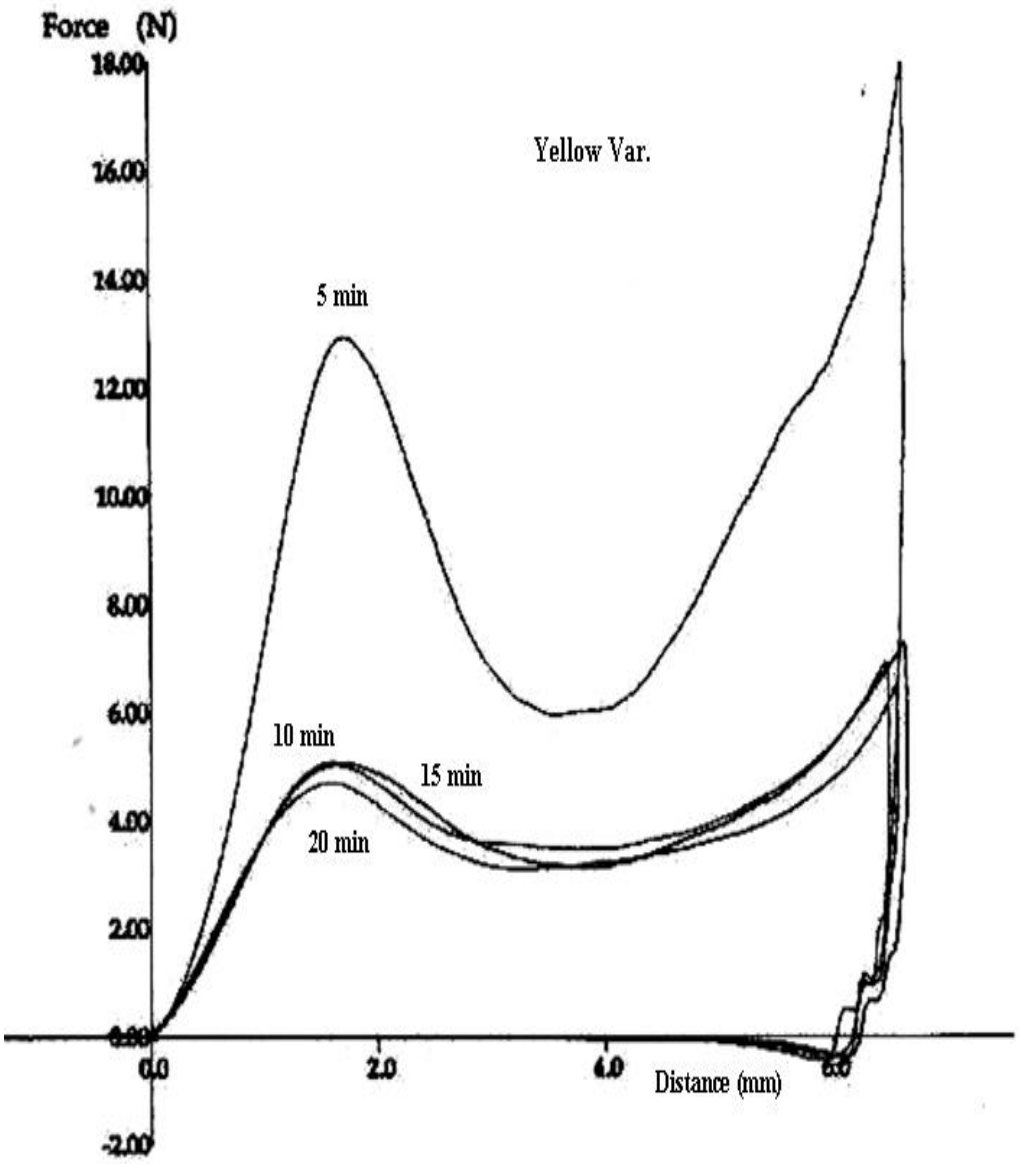


Figure 10 Force deformation curves of uniaxial compression test of *Yellow* cultivar for 4 duration steaming time.

The decline in textural attributes is composed of two first order mechanisms, a quick and a slow softening as shown by Huang & Bourne (1983) and Alvarez & Canet (2002). According to Verlinden *et al*. (1995), the decrease in textural attributes during processing was caused by a decrease in cell stiffness as starch gelatinized and cell wall bonding was weakened. Complete deformation of cell

structure accompanied by considerable cellular collapse and disorganization at cell-cell interfaces was occurred.

4.3.4 Texture profile characteristics

The mean values of TPA values including hardness, adhesiveness, springiness and chewiness at 5 minutes duration of steaming were compared. For four TPA attributes, not only *White* and *Yellow* cultivars exhibited significant difference, but also duration of steaming statistically. Table 9 shows the mean value of TPA attributes for two commercial cultivars.

The declining of hardness of 2 sweet potato cultivars during steaming is shown in Figure 11. Hardness of *White* cultivars was found to be significantly ($P<0.05$) higher than *Yellow* during steaming process. Steaming for 5 minutes generated significant difference ($P<0.05$) hardness with three other duration of two cultivars, moreover steaming at 10 min was also found significant difference ($P<0.05$) with other period of steaming. Continuing steaming for 15 or 20 min caused no difference of hardness. The decrease of hardness was parallel with the increase of moisture content; the lower the moisture content, the higher was the hardness. There was high correlation ($r = 0.92$, $P<0.05$) between hardness and peak force deformation that exhibited identical textural changes during steaming process.

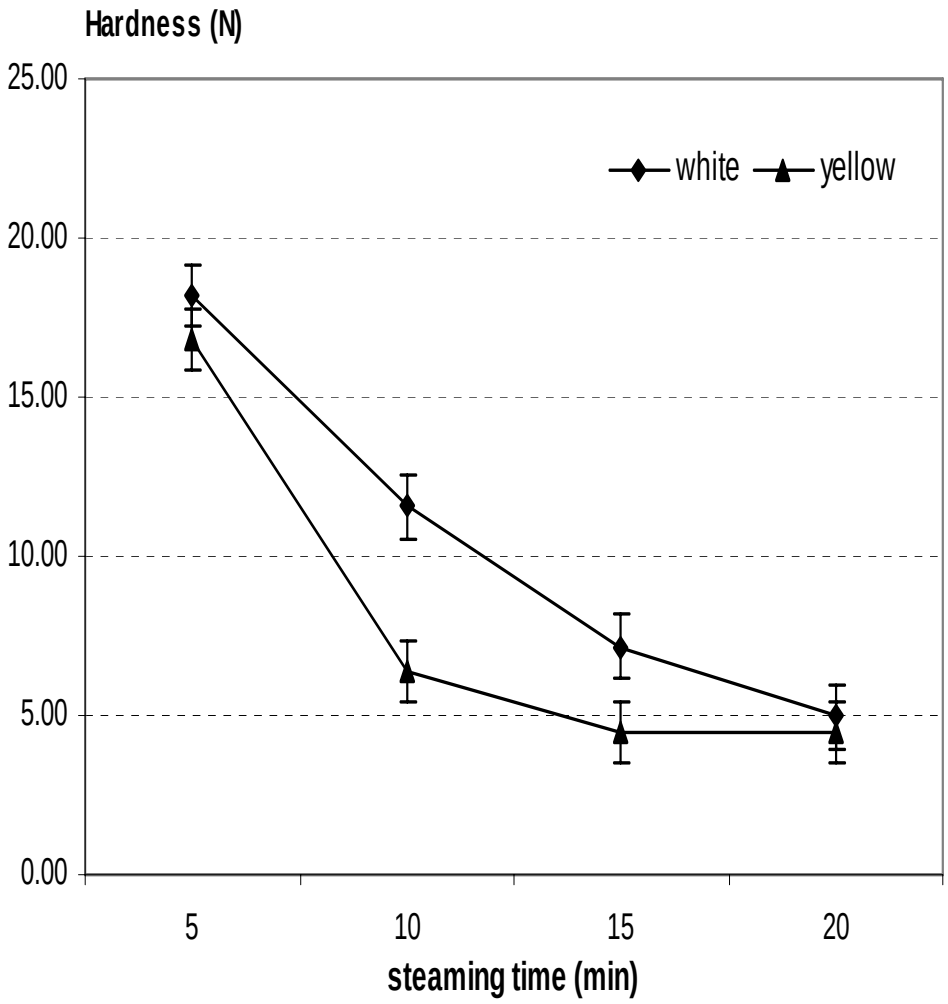


Figure 11 Changes of hardness of *White* and *Yellow* cultivars during steaming at 100 °C, atmospheric pressure for 0, 5, 10, 15 and 20 minutes.

Figure 12 shows the adhesiveness changes affected by different steaming time for two sweet potato cultivars. Adhesiveness of the two sweet potato cultivars was significant different ($P<0.05$) where *White* was less adhesive than *Yellow* cultivar for all duration of steaming. Adhesiveness of *Yellow* increased significantly ($P<0.05$) during steaming, whereas *White* cultivar did not significantly increase ($P>0.05$), instead decreased after 15 min of steaming.

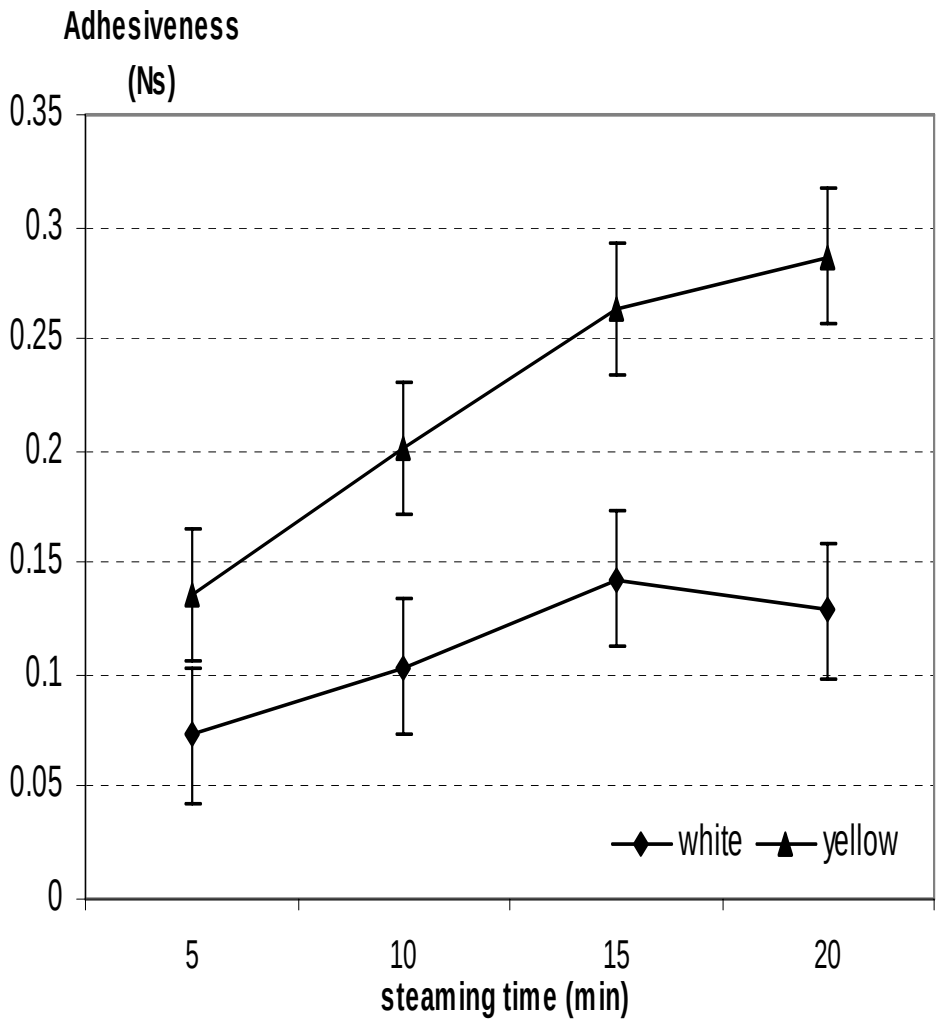


Figure 12 Changes of adhesiveness of *White* and *Yellow* cultivars during steaming at 100 °C, atmospheric pressure for 0, 5, 10, 15 and 20 minutes.

Adhesiveness was defined as the work necessary to overcome the attractive forces between the surface of the samples and the surface of other materials with which the sample comes in contact (Bourne, 2002). From the definition and Figure 10, it could be explained that sweet potato had sticky surface after cooking. It might be due to the sticky gel produced from the gelatinization of amylose and amylopectin, while the level of adhesiveness might be affected by the amylose or amylopectin content. The increasing adhesiveness value was in line with the

length of steaming in which, it showed the step of gelatinization during steaming. The adhesiveness of *White* cultivars decreased after 15 min steaming, most probably the gelatinization happened completely, and gel covered the surface was leached in condensed steam.

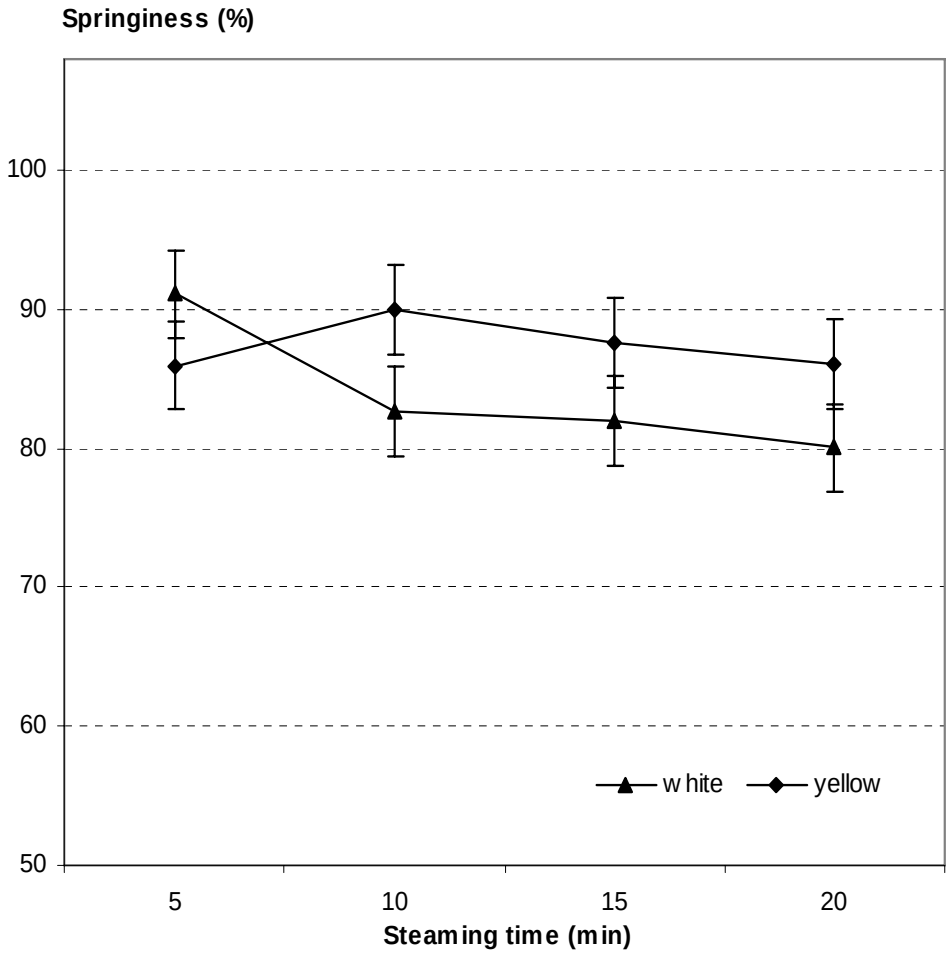


Figure 13 Changes of Springiness of *White* and *Yellow* cultivars during steaming at 100 °C, atmospheric pressure for 0, 5, 10, 15 and 20 minutes.

Steaming subjected into sample obviously had no effect on springiness, it was proven by Table 9 and Figure 13, that springiness slightly decreased and exhibit no significant difference (P>0.05). Springiness value of *White* cultivar decreased

sharply during steaming, particularly in the period of 10 minute steaming, and continued declining until the end of steaming. In *Yellow* cultivar, springiness increased slightly after 10 min steaming, and then decreased until 20 min of steaming. Though springiness value fluctuated, the different steaming time did not effect on the springiness of the 2 commercial cultivars.

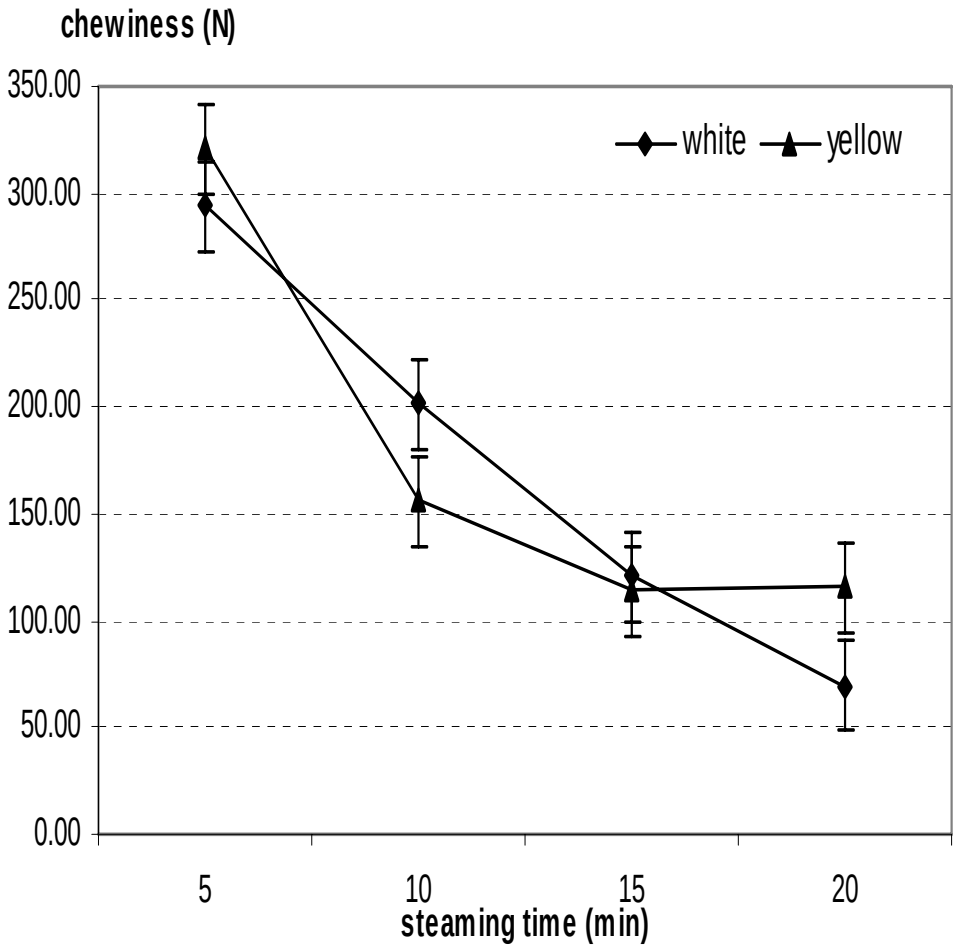


Figure 14 Chewiness Changes of chewiness of *White* and *Yellow* cultivars during steaming at 100 °C, atmospheric pressure for 0, 5, 10, 15 and 20 minutes.

Chewiness was measured in term of the energy to masticate a solid food involving compressing, shearing, piercing, grinding, tearing and cutting. Based on Table 9 and Figure 14 , chewiness of *White* decreased almost linear during steaming, on

the other hand, for *Yellow* cultivar the decrease was sharp in the first 10 minutes and then only slightly there after. Chewiness of 2 sweet potato cultivars was significantly ($P<0.05$) affected by time of steaming. The declining of chewiness was found sharply in *White* cultivar from beginning until the end of steaming; whereas in *Yellow* cultivar, the curve decreased sharply for 10 minutes and slightly plain after that. Generally, chewiness is a mathematical calculation of hardness, cohesiveness and springiness. In this study, chewiness was highly affected by hardness ($r = 0.84$, $P<0.05$). Beside, it might be caused by the increase of moisture content that was found fluctuating during steaming.

4.4 Conclusions

Two commercial cultivars, *White* and *Yellow* exhibited different physical characteristics. Moisture content of *White* was lower than *Yellow* which could be declared as typical moisture content for both cultivars. Steaming sweet potato for 5 minutes performed the “raw” properties tissue, whereas steaming for more than 10 minutes would generate “cooked” tissue that significantly affected the textural characteristics. As the time of steaming was increased, there was less hardness value for both sweet potato cultivars. *White* cultivar was less adhesive and less elastic than *Yellow* cultivar; moreover *White* had less chewiness value than *Yellow* cultivar. Thus the use of *White* cultivar as a raw material of mashed products would have several advantages, such as easier to mash, less tendency to stick to the cooking tools and of low elasticity.

CHAPTER 5

THE EFFECT OF SHAPE, BLANCHING METHODS AND ADDITION OF FLOUR ON CHARACTERISTICS OF A RESTRUCTURED SWEET POTATO STICK

5.1 Introduction

Sweet potato is an important food crop in the world, especially in developing countries of the tropics and sub-tropics. It is well known that sweet potato not only provide energy, but also an excellent source of provitamin A and vitamin C, minerals, dietary fibre and protein (Edmond & Ammerman, 1971, Lanier & Sistrunk, 1979, Picha, 1985a). Despite to these properties, SP is not a well developed food item. Traditionally, sweet potato is processed using basic conventional method of cooking, such as baking, boiling, steaming and frying.

The popular frying products of sweet potato are French fried-type products or sticks and chips. Sweet potato French fries and chips were judged to be of a good quality and acceptability, normally by a consumer panel (Hoover & Miller, 1973, Walter & Hoover, 1986, Schwartz *et al.* 1987). Texture is one of the important attribute of the product. Walter *et al.* (1992, 1993) controlled the firmness of fries through managing the pH of SP tissue using acid and base media.

Many published reports have described pureed sweet potato products, however there are few accounts of restructured products (Collins & Walter, 1992). Hoover *et al*. (1983) and Walter & Hoover (1984) developed patties SP processed from SP puree. Collins & Washam-Hutsell (1987) introduced *vegetable leather* prepared from sweet potato puree. Che Man (1996) developed sweet potato rounds made from SP patties. Development of texturized sweet potato puree was reported by Truong & Walter (1994) and Truong *et al*. (1995). Restructured French fries were also developed by Sylvia *et al*. (1997) and Walter *et al*. (2002).

The preparation of sweet potato foods has several drawbacks. Further difficulties arise due to chemical and physical characteristics of the SP such as size, shape, sugar content, solid content, etc. All these variations affect the colour, texture and flavour of the finished products. Discolouration is a major problem to the quality of those products which arises from two different sources. The first is the formation of grey discolouration caused by the oxidase reaction of polyphenol group of enzymes and the second is non-enzymatic browning, that results when reducing sugars condensed with amino groups. Several methods have been developed to eliminate discolouration. Hoover & Miller (1973) used sodium acid pyrophosphate blanch treatment to eliminate graying. Olorunda & Kitson (1977) eliminated discolouration in chips prepared from white flesh varieties by dipping in sodium sulfite (SO_2). Langdon (1987) reported that phenolase enzymes could be eliminated by lowering the pH of the media and maintaining it below 3.0. Hannigan (1979) and Truong *et al*. (1998) eliminated non-enzymatic browning by water extraction and blanching treatment in attempt to reduce reducing sugars content.

To solve the difficulties controlling the inadequate qualities, an attempt can be made to prepare *fabricated* French fries or sticks from restructured sweet potato roots. The essential ingredients of extrudable French fries potato dough are dehydrated mashed potatoes and a sufficient amount of water to afford a malleable consistency. To prevent browning process on sweet potato, dehydration cannot be carried out, SP flour may be added to increase dry matter content. Blanching and flour addition are the treatments which control the colour and solid content of the mashed roots, affecting the appearance and textural properties of the products. In this manner, the chemical and physical characteristics of final products can be carefully controlled.

The objectives of the study were (1) to study the effect of shape of trimmed tubers, blanching methods and the addition of sweet potato flour into mashed sweet potato on the physical properties of dough, and chemical and physical properties of restructured sweet potato sticks (RSS), and (2) generate the method of RSS production.

5.2 Materials and methods

5.2.1 Materials

White cultivar sweet potato roots were purchased from a local market, Pasar Borong, Selangor, Malaysia. Refined bleached and deodorized (RBD) palm olein

was obtained from a local refinery. Carboxymethylcellulose (CMC) and sodium tripolyphosphate (STP) were of food grade. All chemicals and solvents used were of analytical grade unless otherwise specified.

Sweet potato-flour (SP flour) was prepared in Food Engineering laboratory, Faculty of Food Science and Technology, UPM. Sweet potato tubers were peeled and shredded manually. Drying was conducted using a cabinet drier at 55 °C for overnight. Dried material was then milled and sifted through a 70 mesh sieve. The flour was packaged in plastic bag and stored at -20 ^{o}C for further use.

5.2.2 Preparation of restructured sweet potato sticks (RSS)

Preparation of RSS was arranged by factorial of Randomized Complete Block Design, 2 x 2 x 5 x 3 (shape of trimmed tubers x blanching methods x percentage of SP flour added x replication). The tubers were peeled, (1) sliced into about 2.3 mm thickness and 25 mm width (Hoover & Miller, 1973) or (2) diced into cubes of approximately 10 x 10 x 10 mm, washed and blanched. Blanching was done by dipping SP cut in (1) water for 2 min at about 100 °C or (2) 1 % (w/v) STP solution for 2 min at 100 °C (Hoover & Miller, 1973). Volume to weight ratio of the solutions to the SP cut was approximately 5:1 (v/w). The blanched materials were drained about to 3 minutes to remove excess water, and then mashed and CMC was added (0.3 %, w/w) as a binder (Grover, 1982, Dziezak, 1991). The mashed was mixed using universal mixer (Aikosha-AM-20, Saitama, Japan) with (1) 0 %, (2) 5 % (3) 10 %, (4) 15 % or (5) 20 % SP flour. Moulding of RSS was

conducted using Texture Analyzer (TA.TX2i, Godalming, UK) attached with a stainless steel tube (75 mm inner diameter) having three of 10 x 10 mm square holes at the bottom and compression platen (SMS/P75), 50 kg load cell with 2 mm/s speed for 90 % distance to produce sticks having dimension 10 x 10 mm and then cut into 50 mm length. The sticks were then deep fried at 163 °C for 1 min, packaged in plastic bags and frozen using fast freezing method and the stored at -20 °C until final preparation and evaluation. The RSS were prepared by deep frying at 175 °C for 2 minutes (Walter & Hoover, 1986).

5.2.3 Physical characteristics

Textural properties of dough and fried sticks were evaluated using a texture analyzer (TA.TX2i, Godalming, UK) fitted with the appropriate test accessories. Firmness of dough was recorded as a force needed during extruding the dough using a stainless steel tube (75 mm inner diameter) having three of 10 x 10 mm square holes at the bottom and compression platen (SMS/P75), with 50 kg load cell fitted in the instrument. The test condition was: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, trigger force 5 g and degree of compression 90 % of its initial height. The average of force needed to extrude the dough was calculated as firmness of the dough.

Hardness of fried sticks was expressed as force required for shearing and cutting the samples by a single downward action of the shear blade. The slotted insert (HDP/BS) was secured on the heavy duty platform. The Guillotine Blade knife

was attached to the load cell carrier and lowered into the slotted insert. A sample was placed onto the heavy duty platform, positioned centrally under the blade, and the test was commenced. The test speed was 1 mm/s until it reached 110 % distance. Peak force was expressed as Hardness (N). Data collection and analysis were accomplished by the EXTRAD Dimension Software that is supplied with of the Texture Analyzer.

The colour of fried sticks was determined by the Hunter Color Instrument (Hunter Lab, Reston, USA) and values (*L*, *a*, *b*) were collected. *L* describes Lightness (0 = black, 100 = white), *a* intensity in red (a > 0) and *b* intensity in Yellow (b > 0). Ten replication of reading per sample were done.

5.2.4 Proximate analysis

Dry matter content of root and dough before extrusion was determined by the different of moisture content (dry matter = 100 % - moisture content). Moisture content of both root and dough samples were determined using the Oven method (AOAC, 1984). Approximately 4 gram samples were dried at 105 °C overnight or until constant weight was attained. The percentage of weight lost was calculated as moisture content.

Protein content was determined by the Kjeldahl method (AOAC, 1975). Approximately 0.1 g sample was destructed by 2.0 ± 0.1 ml H_2SO_4 and 1.9 g K_2SO_4, 10 mg HgO (as catalyst) at about 360 °C until clear. The tube containing

solution was added with 40 % NaOH then attached into distilling unit and distilled producing about 15 ml of distillate. Distillated solution containing nitrogen was caught by 5 ml H_2BO_3 and 10 ml NaOH-$Na_2S_2O_3$. The final solution then titrated with 0.02 N HCl. Blank test was conducted without any sample using same method above. Total nitrogen was calculated using formula:

$$\% N = \frac{(\text{ml HCl sample} - \text{ml HCl blank}) \times N\ HCl \times 14.007 \times 100}{\text{mg sample}}$$

$$\% \text{ Protein} = \% N \times 6.25$$

Fat content was determined by Soxhlet method using Soctec apparatus (Tecator, Sweden) with Petroleum ether as solvent. About 3 g sample was put into the thimble (Wathman) and covered with cotton and metal ring. Thimbles were then attached on the samples holder of extraction unit. Temperature of solvent during extraction was maintained approximately 80 °C. Fat extraction was conducted by boiling the timble containing the samples in solvent cup for 30 minutes followed by rinsing, and then flushed the thimble with the solvent for 45 minutes. Solvent containing fat in the cup was then evaporated and dried at 100 °C or until constant weight was attained. The percentage of fat was calculated:

$$\% \text{ Fat} = \frac{(g\ cup_{\text{after extraction}} - g\ cup_{\text{empty}}) \times 100}{g\ sample}$$

Ash content of the RSS was determined using the Oven furnace method (AOAC, 1984). Approximately 5 gram samples were put into porcelain cup and heated at

400 °C for about 4 hours. Porcelain cups were cooled and weighed, until constant weight was attained. The percentage of ash was calculated as the weight of ash divided by weight of sample. Carbohydrate was expressed as the difference from moisture, protein, fat and ash.

% Carbohydrate = 100 - % moisture - % protein - % fat - % ash

5.2.5 Sensory analysis

Sensory evaluations were performed on all fried samples including color, texture, and overall acceptability. Twenty four untrained panelists evaluated the products consist of students and staff of Faculty of Food Science and Technology, UPM, Malaysia. A nine point hedonic scale was used for scoring the samples (1 = *dislike extremely*, 2 = *dislike moderately*, 3 = *dislike*, 4 = *dislike slightly*, 5 = *neither like nor dislike*, 6 = *like slightly*, 7 = *like*, 8 = *like moderately* and 9 = *like extremely*). Samples were coded with 3 digits in a randomized arrangement to equalize the effect of samples sequence food preference. Sensory evaluation sheet on this study is shown in Appendix 3.

5.2.6 Statistical analysis

The experiment was arranged by factorial of Randomized Complete Block Design, 2 x 2 x 5 x 3 (shape of trimmed tubers x blanching methods x percentage of SP flour added x replication). The data collected were analyzed by the analysis

of variance (ANOVA) and significant differences among means were determined by Duncan's multiple range test (DMRT) with 5 % of the level of significance. Statistical analysis was conducted using MSTAT-C statistical software.

5.3 Results and discussion

5.3.1 Physical characteristics of dough

Table 10 shows the effect of shape of trimmed sweet potato, blanching medium, and the amount of SP flour added in mashed sweet potato on firmness of dough and dry matter content. Based on the ANOVA, there was no effect of combination among the three factors, shape of materials, blanching methods and amount of SP flour added on firmness and dry matter content of dough. Moreover, shape of materials did not have an affect on the firmness and dry matter content of dough, individually. Regarding the two shapes before blanching, chips with 2.3 mm thickness and dices or cubes with dimension 10 x 10 x 10 mm seemed to receive equal effect of heating during blanching. Whereas, blanching methods significantly ($P<0.05$) influenced both parameters. Blanching in 1 % (w/v) STP for 2 min produced firmer dough (186.17 N) than in water (160.59 N) and higher dry matter content (32.80 %) compared with 32.25 %. Gelatinization of carbohydrate is the major changes during blanching process. The morphological changes occur when starch is heated in excess water. The granule absorbs the water and swells to a larger size. During heating, at the same time as the absorption of water, material is leached out from the starch granules. This material

is largely amylose although amylopectin might also be leached. The material solubilized during gelatinization increases in molecular weight and is becoming more branched forming a network structure. When blanching in water, the network structure formed will trap the water inside the structure. Nevertheless, when blanching in 1 % STP, the hydroxyls-end of amylose or amylopectin chain will be replaced by phosphate compounds generating less network structure and decrease water binding capacity, furthermore, it produced the firmer dough after mashing.

Table 10 Effect of experimental factors on firmness and dry matter of dough

Treatment		Firmness (N)	Dry-matter (%, w/w)
Shape	Sliced	178.60 $^{a\ ns}$ ± 85.89	32.43 $^{a\ ns}$ ± 7.91
	Diced	168.15 ^{a} ± 78.06	32.62 ^{a} ± 4.57
Blanching	Water	160.59 ^{b} ± 78.35	32.25 ^{b} ± 4.67
	1% STP	186.17 ^{a} ± 83.96	32.80 ^{a} ± 4.81
% SP flour	0	95.83 ^{d} ± 25.07	25.98 ^{e} ± 1.15
	5	124.68 ^{cd} ± 33.47	29.46 ^{d} ± 1.23
	10	153.60 ^{c} ± 39.43	32.60 ^{c} ± 1.09
	15	202.55 ^{b} ± 51.47	35.75 ^{b} ± 1.18
	20	290.23 ^{a} ± 65.69	38.83 ^{a} ± 1.31

$^{a-e}$ Means within columns for each treatments (Shape; Blanching or % SP flour), followed by different superscripts letters are significantly different at $P < 0.05$, $n = 3$

^{ns} not significant

N Newton

The percentage of SP flour added into mashed sweet potato significantly ($P<0.05$) influenced firmness and dry matter, the higher the percentage of SP flour, the higher the firmness and dry matter. On firmness, mashed sweet potato without any addition of SP flour (0 % SP flour) showed no significant difference with the dough added of 5 % SP flour, whereas dough that was added with 5 % SP flour had no significant difference with further addition of 5 % SP flour, but it exhibited significant difference by increasing more 5 % SP flour. The range of dry matter content of dough was 25.98 % to 38.83 %, from the 0 % to 20 % SP flour added. The increase of dry matter was around 3 % for every 5 % of SP flour added. Without any addition, the dry matter content of dough was 25.98 %, and it was considered too soft to extrude so that the shape of stick was not formed. Adding of 5 and 10% SP flour generated dough with similar firmness (124.68 and 153.60 N) statistically.

Dry matter or moisture content is an important factor in controlling the firmness of dough. According to Gutcho (1973), restructured products containing more than 73 % by weight of water tend to puff undesirably during frying. The dough itself is too soft to handle and it tends to disintegrate prior to completion of frying. There are two general ways of controlling dry matter content of dough i.e. mixing with flour containing low moisture content and drying in attempt to reduce the water content. Addition of SP flour into mashed sweet potato is a method to control the dry matter content of the dough. Beside that, using the SP flour is aimed to produce RSS made of 100 % sweet potato. This dry matter content was the suitable condition to extrude in producing the sticks. This shows that 5 % SP

flour is the lowest amount of SP flour needed to be added into mashed sweet potato to produce dough suitable for further processing.

The problem facing the dough preparation was discoloration. Blanching was chosen in attempt to prevent the browning process. Blanching in STP solution found as a better way to eliminate browning than in water, by inactivation of polyphenol oxidases in the presence of phosphate, as explain by several researchers (Hoover & Miller, 1973, Manlan *et al*., 1985, Woolfe, 1992). Beside that, water extraction and blanching was effective in removal of the sugar from raw sweet potato slices as reported by Hannigan (1979).

5.3.2 Physical characteristics of RSS

Table 11 shows the effect of experimental factors on hardness, Hunter *L*, *a* and *b* values of fried RSS. Hardness of RSS was affected only by the amount of SP flour which added into mashed sweet potato, whereas shape and methods of blanching showed no significance effect on hardness. Increasing the amount of SP flour added into mashed sweet potato was gained the hardness of RSS, however the addition of 5 and 10 % of SP flour generated insignificant in hardness of RSS. This hardness of RSS followed tendency the firmness of dough consistently.

Shape of raw materials prepared before blanching did not affect the hardness and colour value of RSS. Blanching methods significantly ($P<0.05$) generated

different colour value of the product. Higher value of *L*, *a* and *b* values were produced by blanching the raw materials in 1 % STP solution.

Table 11 Effect of experimental factors on Hardness, Hunter *L*, *a* and *b* value of fried RSS

Treatment		Hardness (N)	*L*	*a*	*b*
Shape	Sliced	19.29 $^{a\ ns}$ ±7.76	8.18 $^{a\ ns}$ ±3.54	5.84 $^{a\ ns}$ ±1.01	13.17 $^{a\ ns}$ ±2.45
	Diced	21.24 ^{a} ± 8.54	8.26 ^{a} ± 4.29	6.02 ^{a} ± 0.89	13.16 ^{a} ± 2.69
Blanching	Water	21.44 $^{a\ ns}$ ±9.30	6.72 ^{b} ± 4.08	5.45 ^{b} ± 0.77	12.17 ^{b} ± 2.54
	1% STP	19.09 ^{a} ± 6.76	9.72 ^{a} ± 3.11	6.41 ^{a} ± 0.88	14.16 ^{a} ± 2.17
% SP flour	0	13.12 ^{d} ± 5.35	2.03 ^{a} ± 5.74	6.04 ^{ab} ±1.09	16.29 ^{a} ± 3.35
	5	16.85 ^{c} ± 7.35	7.09 ^{b} ± 2.89	5.36 ^{b} ± 0.60	12.34 ^{b} ± 1.53
	10	19.78 ^{c} ± 6.43	7.14 ^{b} ± 2.47	5.75 ^{b} ± 0.89	12.30 ^{b} ± 1.57
	15	23.28 ^{b} ± 5.94	7.43 ^{b} ± 3.37	5.99 ^{ab} ±0.93	12.41 ^{b} ± 1.85
	20	28.42 ^{a} ± 6.75	7.44 ^{b} ± 1.83	6.51 ^{a} ± 0.93	12.49 ^{b} ± 1.44

$^{a-c}$ Means within columns for each treatments (Shape, Blanching or % SP flour), followed by different superscripts letters are significantly different at $P < 0.05$, n = 3 with 15 reading for each n

^{ns} not significant
N Newton

For the colour attributes, the two shapes of raw materials produced no significantly effect, however, the different colour was distinguished visually (Figure 14). Blanching methods significantly ($P<0.05$) affected Hunter *L*, *a* and *b* colour values of RSS. Blanching in 1 % STP solution produced fried sticks with higher *L* value (49.72) than blanching in water (46.72). This result was in agreement with several publications that sodium-phosphate salt able to prevent

discoloration in sweet potato product (Hoover, 1963, Hoover & Miller, 1973). Based on *a* and *b* values of fried sticks, red and yellow colouration increase when materials were blanched in STP solution. This shows that blanching in 1 % STP improves the colour of fried RSS compared with blanching in water. The colour of chip and cube before mashed displayed in Figure 14. It shows that the material blanched in 1 % STP solution has a brighter colour and no browning was occurred than blanching in water. The amount of SP flour significantly affected ($P<0.05$) the colour of RSS. The addition SP flour significantly affected *L* and *b* values. RSS produced without SP flour had a higher *L* and *b* value than any other percentage of SP flour, however there was no significant different value among the amount of SP flour added. Redness or *a* value was not influenced by a percentage of SP flour mixed. Regarding the mean of colour value, the browning process might be occurred during producing of RSS. Browning might be caused by the activity of polyphenol oxidase enzymes in the presence of tannin or tannin-like compounds that exists in SP flour and also non enzymatic browning, such as Maillard, and also caramelization, occurred during frying due to the high content of sugar in sweet potato. It is possible that SP flour contains high sugar leading to browning during frying.

Figure 15 shows raw and blanched sweet potato chips and dices. Visually, raw chip and dice were white, and changed into pale yellow after blanched in hot water, whereas bright yellow occurred when it was blanched in STP solution.

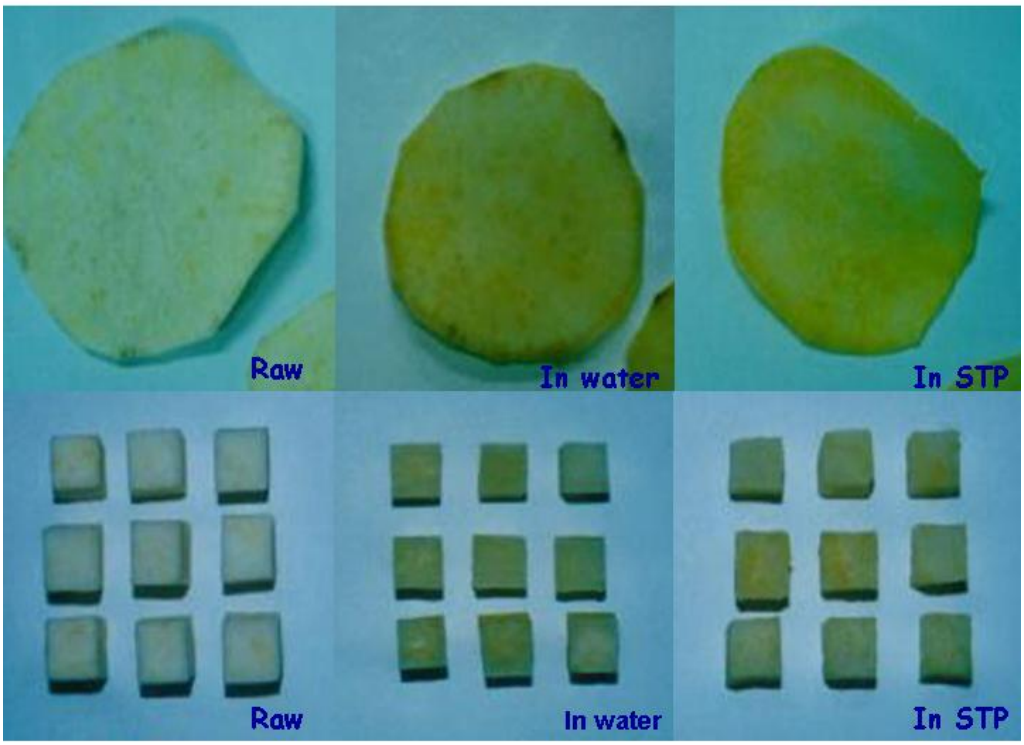


Figure 15 Colour of chips and cubes of *White* sweet potato tuber before and after blanching in water or STP solution

5.3.3 Chemical composition of RSS

The proximate composition of fried RSS is shown in Table 12. The shape of trimmed tuber before blanching did not affect the moisture, protein, fat and carbohydrate content of fried product, except ash content was affected by the different shape of raw materials ($P<0.05$). Blanching methods significantly ($P<0.05$) influenced fat, ash and carbohydrate content. Blanching in 1 % STP significantly increased ($P<0.05$) fat and ash content and therefore decreased the carbohydrate content. Based on the SP flour added into the sweet potato mashed, three parameters were significantly influenced ($P<0.05$) by the amount of SP flour, consisting of moisture, fat and carbohydrate contents.

Moisture was an important component in RSS, especially related to the factors affecting the production of RSS. The moisture content of fried sticks was affected by SP flour added, without any SP flour added into mashed sweet potato, moisture content was low and was not significant from many other values. The lower moisture content was in RSS added with 15 or 20 % SP flour compared with RSS added with SP flour from 0 to 10 %. In RSS without any SP flour, there was water which was not bound by the carbohydrate chains and trapped in the dough as free water, but when SP flour was mixed, a part of water was bound with the carbohydrate chains of SP flour by hydrogen bound. And in further frying, the free water was evaporated easily. By the increasing of SP flour added, the moisture content was decreased by the increase of dry matter content. Effects of moisture content on other RSS' characteristics were shown in Table 14, in which significantly negative correlation was aroused in hardness, fat and carbohydrate content, whereas positive correlation occurred in Hunter *L* value.

Protein content was not significantly affected ($P>0.05$) by any factors in preparation of RSS. Since sweet potato is the commodity of low protein content and considered not as a source of protein, the variation of methods preparing RSS will not give any effect on protein content without any addition of protein source. This might caused no variation of protein content of RSS produced by the given methods.

Table 12 Effect of experimental factors on proximate composition (%, w/w) of fried RSS

Treatment	Moisture	Protein	Fat	Ash	Carbohydrate
Shape :					
Sliced	34.83 $^{a\ ns}$ ±6.17	1.94 $^{a\ ns}$ ±0.36	15.29 $^{a\ ns}$ ±3.62	1.23 ^{a} ± 0.17	45.83 $^{a\ ns}$ ± 5.08
Diced	34.88 ^{a} ± 4.88	2.09 ^{a} ± 0.51	14.56 ^{a} ± 3.80	1.44 ^{b} ± 0.16	47.03 ^{a} ± 4.05
Blanching:					
Water	33.88 $^{a\ ns}$ ±3.61	2.02 $^{a\ ns}$ ±0.35	15.62 ^{a} ± 3.49	1.29 ^{b} ± 020	47.18 ^{a} ± 3.60
1% STP	35.88 ^{a} ± 6.85	2.01 ^{a} ± 0.54	14.22 ^{b} ± 3.82	1.38 ^{a} ± 0.20	45.68 ^{b} ± 5.36
%SP flour:					
0	34.15 ^{ab} ± 9.65	1.97 $^{a\ ns}$ ±0.37	18.05 ^{d} ± 4.04	1.31 $^{a\ ns}$ ±0.31	42.03 ^{d} ± 3.74
5	38.43 ^{a} ± 3.93	1.88 ^{a} ± 0.48	15.43 ^{e} ± 4.85	1.30 ^{a} ± 0.21	43.21 ^{d} ± 3.42
10	36.98 ^{a} ± 2.05	1.90 ^{a} ± 0.38	13.94 ^{e} ± 2.80	1.29 ^{a} ± 0.13	45.90 ^{c} ± 2.17
15	34.09 ^{ab} ± 2.99	2.11 ^{a} ± 0.41	13.44 ^{e} ± 2.45	1.37 ^{a} ± 0.15	49.00 ^{b} ± 2.33
20	30.62 ^{b} ± 1.40	2.23 ^{a} ± 0.54	13.74 ^{e} ± 1.91	1.40 ^{a} ± 0.15	52.01 ^{a} ± 1.83

$^{a-d}$ Means within columns for each treatments (Shape; Blanching or % SP flour), followed by different superscripts letters are significantly different at $P < 0.05$, $n = 3$

^{ns} not significant

Fat content is an important factor with respect to the quality of fried product. The existence of fat in RSS was influenced by blanching methods and the addition of SP flour on mashed sweet potato. Fat content was affected by the blanching method. It was higher when RSS produced by blanching the raw material in water than in 1 % STP. Fat absorption occurs as moisture is removed from the food during frying and there is a linier relationship between oil uptake and water content of final product (Gamble & Shelman, 1987, Varela, 1988). The moisture content of sticks before frying was similar to moisture content of dough, in view

of the fact that the higher moisture content occurred by blanching the raw materials in water than in STP solution. The high difference of moisture content before and after frying occurred in RSS prepared by blanching in water, furthermore it also generated high fat content. The decrease of moisture content of RSS during frying occurred equivalent with decreasing SP flour added. The amount of water removed from stick during frying were 39.87, 32.11, 30.42, 30.16 and 31.13 % in RSS with 0, 5, 10, 15 and 20 % SP flour added, respectively. This result is in agreement with Varela (1988) that in fried products, fat or oil absorption occurs as moisture is removed from the food during frying. The amount of water removed was parallel with fat content of the final product. It shows that the SP flour reduced the oil uptake during frying. However, the addition of SP flour generated insignificant of the fat content and adding 10 % of SP flour produced lowest fat content.

Ash content reflected all of mineral containing in RSS. RSS made from sliced roots contained lower ash content than made from diced roots. It is assumed that starch was easier to leach from chip than diced during blanching in STP solution. Consequently, the decrease in starch content will decrease the phosphate compound attached in amylose or amylopectin. As explanation before that phosphate compound was attached on the hydroxyl end of amylose or amylopectin chain and would be detected as mineral compound on ash determination. Effect of blanching method was significant different ($P<0.05$) for ash content in RSS. RSS made through blanching in STP solution contained higher fat content than those produced by blanching in hot water. It is well known

that phosphate compound attached in starch chains. On the other hand, the amount of SP flour added did not give any effect on the ash content of final product.

Carbohydrate is a major component of the RSS. Carbohydrate content of RSS was affected by the blanching method and percentage of SP flour added. Blanching method generated significant difference ($P<0.05$) on carbohydrate content. This might be caused by the different of moisture and fat contents of RSS, since carbohydrate was calculated using *by different* method. Beside that negative significant correlation occurred between carbohydrate and moisture or fat content. Carbohydrate content was affected by the percentage of SP flour and the increase of SP flour added into mashed sweet potato significantly increased ($P<0.05$) carbohydrate content. The carbohydrate content of RSS was gradually increased by increasing the amount of SP flour added.

5.3.4 Sensory properties

Sensory evaluation was conducted to evaluate the characteristics of RSS according to the preferences of panelist or consumers as shown in Table 13.

Table 13 Sensory scores[1] for colour, texture and overall acceptability of RSS made using combination 3 factor of preparation

Treatment			Sensory attributes		
Shape	Blanching	% SP flour	Colour	Texture	Overall
Sliced	Water	0	6.58 ^{a} ± 0.72	4.33 ^{g} ± 0.56	5.29 ^{ef} ± 0.95
		5	6.21 ^{ab} ± 0.93	6.83 ^{a} ± 0.56	6.38 ^{ab} ± 0.71
		10	5.21 ^{de} ± 0.78	5.96 ^{de} ± 0.55	5.67 ^{cde} ±0.70
		15	4.67 ^{f} ± 1.05	4.21 ^{g} ± 0.41	4.50 ^{hij} ± 0.59
		20	3.92 ^{gh} ± 0.83	3.67 ^{hi} ± 0.70	3.88 ^{k} ± 0.68
	STP	0	6.50 ^{a} ± 1.02	5.13 ^{f} ± 0.68	5.92 ^{bcd} ±0.50
		5	5.83 ^{bc} ± 0.70	6.54 ^{ab} ± 0.59	6.46 ^{a} ± 0.72
		10	5.04 ^{def} ±0.86	5.54 ^{ef} ± 0.66	5.04 ^{fg} ± 0.46
		15	4.17 ^{g} ± 0.76	4.13 ^{gh} ± 0.54	4.58 ^{ghi} ± 0.65
		20	3.88 ^{gh} ± 0.74	4.13 ^{gh} ± 0.90	3.92 ^{k} ± 0.65
Diced	Water	0	6.17 ^{ab} ± 0.87	4.25 ^{g} ± 0.68	5.54 ^{de} ± 0.72
		5	5.50 ^{cd} ± 0.72	6.46 ^{abc} ±0.78	5.92 ^{bcd} ±0.58
		10	5.21 ^{de} ± 0.51	6.08 ^{bcd} ±0.41	5.58 ^{cde} ±0.58
		15	4.00 ^{gh} ± 0.42	4.08 ^{gh} ± 0.50	4.08 ^{jk} ± 0.41
		20	3.29 i ± 0.62	3.38 ^{i} ± 0.65	3.33 ^{l} ± 0.56
	STP	0	6.13 ^{ab} ± 0.74	4.17 ^{gh} ± 0.38	4.88 ^{fgh} ±0.61
		5	5.38 ^{de} ± 0.58	6.79 ^{a} ± 0.59	6.04 ^{abc} ±0.46
		10	5.00 ^{ef} ± 0.51	6.04 ^{cd} ± 0.46	5.04 ^{fg} ± 0.20
		15	4.04 ^{gh} ± 0.20	4.13 ^{gh} ± 0.45	4.13 ^{ijk} ± 0.34
		20	3.58 ^{hi} ± 0.78	4.04 ^{gh} ± 0.62	3.33 ^{l} ± 0.48

[1] Hedonic scale: 1 = *dislike extremely,* 2 = *dislike moderately,* 3 = *dislike,* 4 = *dislike slightly,*; 5 = *neither like nor dislike,* 6 = *like slightly,* 7 = *like,* 8 = *like moderately,* 9 = *like extremely*

$^{a - l}$ Means within columns followed by different superscripts letters are significantly different at $P < 0.05$

Result of sensory analysis was shown in Table 13. Statistically, significant difference ($P<0.05$) was found in the interaction of three factors on RSS preparation for all sensory attributes. For colour, the preference was significantly ($P<0.05$) influenced by the shape of raw material and the percentage of SP flour added. The high score was generated by sliced sweet potato, whereas the colour preferences decreased with the alteration of SP flour. The colour preference seems to be affected by individual factor during RSS production. Sliced sweet potato generated higher score (5.20, slightly above *neither like nor dislike*) on average, compared with diced (4.83, slightly below *neither like nor dislike*), whereas the score gradually decreased from 6.34 (slightly above *like slightly*) to 3.67 (slightly below *dislike slightly*) with the increasing of SP flour percentage.

Second attribute of sensory evaluation was texture. Texture was affected by all processing factor. The high score of texture preferences was reached by RSS made with the combination of the 2 shapes of raw material, the 2 blanching methods and with 5 % SP flour added which ranged from 6.46 (midway between *like slightly* and *like*) to 6.83 (slightly below *like*). Individually, the higher score of texture was reached by blanching in STP solution.

Similarly, the high score of overall preferences of RSS was generated from the combination of the 2 shapes of raw material, the 2 blanching methods and with 5 % SP flour added which varied from 5.92 (slightly below *like slightly*) to 6.46 (midway between *like slightly* and *like*). Generally, the effect of SP flour significantly ($P<0.05$) influenced the score for sensory attributes. The scores

decreased with increasing addition of SP flour, except the first increase from 0 to 5 % SP flour.

5.3.5 Correlation among parameters

Table 14 shows that correlations between parameters determined in this study were evaluated. Dry matter has an important role in the characteristics of the products. The dry matter content of dough was highly correlated with carbohydrate, fat content and hardness of fried sticks. The dry matter of dough depended on the SP flour mixture; the higher the amount of SP flour added the higher the dry matter content, because SP flour contains approximately 94 % dry matter content which is consist of carbohydrate and small amount of fat, fibre and ash. The addition of SP flour into mashed sweet potato in dough preparation increased the amount of carbohydrate. The increase in carbohydrate content decreased fat absorption during frying, but increased the hardness. There was no correlation between hardness and fat content, but shows a positive correlation with moisture content. Thus, hardness of product was influenced by carbohydrate and moisture content. *L* and *a* values have a positive correlation with ash content. *L* and *a* values increased by the increase in ash content, whereas ash content was increased when tubers were blanched in 1% STP solution. From these findings, one can conclude that by an increase in the percentage of SP flour added causes the increase in carbohydrate content and hardness but a decrease in fat content. Moreover, blanching using 1 % STP improves the lightness and red colouration of the products.

Table 14 Correlation coefficients (r) between parameters measured of dough and RSS

	Firmness[1]	Drymatter[1]	Hardness	L	a	b	Moisture	Protein	Fat	Ash	Carbohydrate
Firmness [1]	1										
Dry matter [1]	0.89 **	1									
Hardness	0.30 *	0.53 **	1								
L	0.02	-0.23	-0.49 **	1							
a	0.37 *	0.25	0.19	0.25	1						
b	-0.07	-0.35 *	-0.50 **	0.97 **	0.35 *	1					
Moisture	-0.21	-0.24	-0.38 *	0.32 *	-0.27	-0.27	1				
Protein	0.40 **	0.30 *	-0.05	0.09	0.16	0.06	0.03	1			
Fat	-0.52 **	-0.53 **	0.19	-0.25	-0.05	-0.09	-0.34 *	-0.20	1		
Ash	0.14	0.18	0.23	0.04	0.45 **	0.06	-0.13	0.27 *	-0.06	1	
Carbohydrate	0.70 **	0.82 **	0.45 **	-0.35 *	0.22	-0.42 **	-0.42 **	0.17	-0.44 **	0.23	1

[1]: Dough

Significance correlation: * ($P<0.05$) and **($P<0.01$)

5.4 Conclusions

Shape of raw materials produced RSS having similar physical and chemical characteristics, except for the sensory attributes on colour and overall preferences. Blanching in 1 % STP solution significantly improved the quality of RSS such as firmness of dough from 186.17 N to 160.59 N and dry matter content from 32.80 % to 32.25 %, moreover, colour, fat and ash content, and also preference of texture. The SP flour added to mashed sweet potato affected the quality attributes. However, the 5 % SP flour added generated the highest value of sensory preferences. Blanching in 1 % STP for 2 minutes improves the colour attributes and generates low fat and high ash content RSS, and mixing with 5 % SP flour to the mashed sweet potato produces suitable conditions of the dough for further processing and generates high quality of sensory attributes RSS.

CHAPTER 6

THE PHYSICAL AND CHEMICAL PROPERTIES OF A RESTRUCTURED SWEET POTATO STICK FROM THREE SWEET POTATO CULTIVARS

6.1 Introduction

Sweet potato is a nutritious vegetable with a good complement of energy, vitamin and minerals. The intervention of humans by domestication and artificial selection of the sweet potato has resulted in the existence of a large number of cultivars. Cultivars differ from one to another in the physical properties and chemical composition (Tian *et al*., 1991, Kitahara *et al*., 1996, Garcia & Walter, 1998). SP contain 52 - 85 % moisture, with carbohydrates making up 80 - 90 % of total dry matter. Starch is the major component of SP, can comprise from 50 – 70 % of total dry matter (Woolfe, 1992). It was noted that the variation in starch content depends on variety. The physicochemical properties of SP starches of various cultivars have been reported (Bowkamp, 1985, Tian *et al*., 1991, Woolfe, 1992). Other important physical characteristic is flesh colour that may be exploited to introduce an attractive color into food made of sweet potato.

The popular frying products of sweet potato are French fried type products or sticks and chips. Sweet potato French fries and chips were judged to be of a good quality and acceptability by a consumer panel (Hoover & Miller, 1973, Walter & Hoover, 1986, Schwartz *et al*., 1987). Conventional processes for preparing French fries from potato fresh roots have several drawbacks. The quality of fried

product varies among varieties, in view of the fact that the cultivars differ from one to another in the physical properties and chemical composition (Tian *et al*., 1991, Kitahara *et al*., 1996, Garcia & Walter, 1998). Further difficulties arise due to physical and chemical characteristics of the raw materials such as size, shape, sugar content, solid content, etc. All these variations affect color, texture and flavour of the finished product and must be controlled. Controlling of the adequate qualities can be made by prepared *fabricated* French fries or sticks from restructured sweet potato roots (Walter & Hoover, 1986, Truong & Walter, 1994, Truong *et al*., 1995, Walter *et al*., 2002). Selecting the suitable cultivars based on chemical and physical characteristics of raw material is a key to produce the desirable french fried product.

The objectives of this study is to determine the chemical and physical properties and organoleptic characteristics of restructured sweet potato sticks (RSS) made from three sweet potato varieties, and to select the sweet potato commercial cultivars suitable in RSS production.

6.2 Materials and methods

6.2.1 Materials

Three sweet potato cultivars consist of *White*, *Yellow* and *Orange* were purchased in Pasar Borong, Selangor, Malaysia. *Orange* cultivar was studied because it was available only in a certain season and under utilized. Refined bleached and deodorized

(RBD) palm olein was obtained from a local store. Carboxymethylcelullose (CMC) and Sodium tripolyphosphate (STP) were of food grade.

6.2.2 Preparation of restructured sweet potato sticks (RSS)

The tubers were peeled, sliced into about 2.3 mm thickness and 25 mm width (Hoover and Miller, 1973). Blanching was done by dipping the chip in 1 % (w/v) STP solution for 2 min at 100 °C. Volume to weight ratio of the solutions to the SP cut was approximately 5:1 (v/w). The blanched materials were drained to about 3 minutes to remove excess water, and then mashed and CMC was added (0.3 %, w/w) as a binder. The mashed was mixed using universal mixer (Aikosha-AM-20, Saitama, Japan) with 5 % of sweet potato flour. Moulding was conducted as shown in Preparation of restructured sweet potato sticks (RSS) (section 5.2.2). The sticks were then deep fried at 163 °C for 1 min, packaged in plastic bags and frozen using fast freezing method and the stored at -20 °C until final preparation and evaluation. The RSS were prepared by deep frying at 175 °C for 2 minutes (Walter & Hoover, 1986).

6.2.3 Physicochemical characteristics of 3 sweet potato cultivars

Moisture content of raw and steamed roots was determined by an oven drying method (AOAC, 1975). The chemical characteristics of sweet potato tubers including starch, amylose and sugars content were taken from Chapter 3.

Reducing sugar of fresh tuber was expressed as total of glucose, fructose and maltose content that shown in Table 3.

Textural characteristics of sweet potato tubers were evaluated. A middle portion of raw root was cut transversely to the long axis into cylinders with 1.35 cm diameter and 2.2 cm thickness. The cylindrical samples were washed with tap water to remove adhered starch and steamed in a steamer (CPC 61, Rational, Germany) at 100 °C, atmospheric pressure for 20 minutes. Cooked samples were kept in a closed container to avoid moisture losses subjected to the test. Hardness, adhesiveness, springiness and chewiness were quantified by Texture Profile Analysis (TPA) method (Bourne, 1978) as explained in section 3.2.4. The TPA curves were obtained for 15 replicates per samples.

Firmness of dough was recorded as a force needed during extruding the dough using a stainless steel tube (75 mm inner diameter) having three of 10 x 10 mm square holes at the bottom and compression platen (SMS/P75), with 50 kg load cell fitted in the instrument. The test condition was: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, trigger force 5 g, and degree of compression 90 % of its initial height. The average of force needed to extrude the dough was calculated as firmness of the dough.

6.2.4 Physical characteristics of fried RSS

Texture of fried sticks was determined using two methods i.e. puncture and cutting-shear test. Firmness was expressed as force needed of the P/2 probe

puncturing the samples. Shearing force was a force required shearing and cutting the samples by the single downward action of the shear blade (HDP/BS). The test condition both puncture and shearing was: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, and degree of compression 110 % of its initial height.

Textural properties of RSS were determined by Texture Profile Analysis (TPA). Texture analyzer (TA.TX2i, Godalming, UK) was fitted with a 25 Kg load cell with a probe having 50 mm diameter compression plate (P/50). Each sample was compressed longitudinal for two cycles. The test condition was: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, trigger force 5 g, time between two cycles 5 second and degree of compression 35 % of its initial height. Firmness of dough, firmness and shearing force, and texture profile properties of fried sticks were expressed in Newton (N). The TPA curves were obtained for 15 replicates per samples. Data collection and analysis was accomplished by the EXTRAD Dimension Software of the texture analyzer.

Colour of fried sticks was determined by the Hunter Color Instrument (Hunter Lab, Reston, USA) and values (*L*, *a*, *b*) were collected. *L* describes Lightness (0 = black, 100 = white), *a* intensity in red (a > 0) and *b* intensity in Yellow (b > 0). Three pieces of RSS covered with plastic sheet were then used to determine the color value through the reading hole. Ten replication of reading per sample were done.

6.2.5 Chemical characteristics of dough and fried RSS

Moisture content of blanched chips, dough before extrusion, frozen sticks and fried sticks was determined by an oven drying method (AOAC, 1975). Dry matter content of dough was calculated by subtracting 100 with moisture content. Proximate analysis was determined on the final product. Moisture, protein, fat, and ash were determined by the AOAC method (AOAC, 1975). Protein was calculated as nitrogen (Kjeldahl) x 6.25. Carbohydrate was expressed as the difference from moisture, protein, fat and ash. The detail of proximate analysis was explained as in section 5.2.4.

6.2.6 Sensory analysis

Sensory evaluations were performed on all fried samples includes color, texture, flavor and overall acceptability. Forty untrained panelists evaluated the products consist of students and staff of Faculty of Food Science and Technology, UPM, Malaysia. A 7-point hedonic scale is used for scoring the samples (1 =*dislike extremely*, 2 = *dislike moderately*, 3 = *dislike slightly*, 4 = *neither like nor dislike*, 5 = *like slightly*, 6 = *like moderately*, 7 = *like extremely*). Samples are coded with 3 digits in a randomized arrangement to equalize the effect of samples sequence food preference. Sensory evaluation sheet for this study is shown in Appendix 4.

6.2.7 Statistical analysis

The experiment is arranged with a randomized complete block design with 3 replications. The data collected were analyzed by the analysis of variance (ANOVA) and the significant differences among means were determined by Duncan's multiple range test (DMRT) with 5 % of the level of significance, using MSTAT-C statistical software.

6.3 Results and discussion

6.3.1 Physicochemical characteristics of 3 cultivars

Table 15 exhibits moisture content of 3 commercial cultivars. Fresh tubers of *Yellow* cultivar had the highest moisture content followed by *Orange* and *White*. Moisture content of *White* and *Yellow* increased during steaming, but Orange decreased.

The moisture content of fresh tuber is specific within the cultivar. The moisture content of samples was slightly changed after steaming in 100 °C for 20 min in the range of 1 to 4 % and it is in agreement with the result of Bradbury & Holloway (1988). The rise and fall of moisture content after cooking occurred in the stages of gelatinization process initiated by absorption of water by starch grain until maximum swelling at about 55 to 65 °C (Winarno, 1991), furthermore disorganizing of starch polymer occurred into gel by the alteration of temperature.

Generally, steaming would increase the moisture content, but the decrease which happened to the *Orange* cultivar that might be caused by the evaporation after the gelatinization was complete. As explain in Chapter 3, moisture content of steamed tubers significantly influenced by starch and amylose content. For the 3 sweet potato commercial cultivars, negative correlation occurred between moisture content of steamed tubers and starch and amylose content, with r = -0.69 and r = -0.67, respectively.

Table 15 Moisture content of 3 sweet potato commercial cultivars

Cultivar	Fresh (%)	Steamed (%)
White	73.82 ^{c} ± 0.32	75.96 ^{b} ± 0.29
Yellow	78.53 ^{a} ± 0.10	80.54 ^{a} ± 0.41
Orange	76.48 ^{b} ± 0.25	75.44 ^{c} ± 0.40

$^{a-c}$ Means within column followed by different superscripts letters are significantly different at $P < 0.05$, $n = 3$.
Data was derived from Chapter 3, Table 3.

White cultivar contained the highest starch content (19.30 %) and followed by *Orange* (14.43 %) and *Yellow* (12.34 %), however *Orange* contained the highest amylose (27.15 %) followed by *White* (25.53 %), and *Yellow* (24.84 %) as shown in Table 16. Starch content of SP tubers was reported to be varied from 8 to 29%, depending on the varieties (Onwueme, 1978, Paul & Southgate, 1979, Bradbury & Holloway, 1988a, Den, 1994).

Table 16 Starch content of fresh tuber and amylose content of starch 3 cultivars

Cultivar	Starch (%, fwb)	Amylose (%, db)
White	19.30 [a] ± 0.41	25.53 [b] ± 1.10
Yellow	12.34 [c] ± 0.72	24.83 [c] ± 0.66
Orange	14.43 [b] ± 1.00	27.15 [a] ± 1.13

[a – c] Means within columns followed by different superscripts letters are significantly different at $P < 0.05$, $n = 3$

Typical TPA curve of three commercial cultivars is shown in Figure 16. Two peaks were found generated by two compressions during measurement. The peak under axis line was expressed as adhesiveness. The time between two peaks was given to the samples to recover and it was used to calculate springiness. Springiness is an important factor, besides expressing the character of the samples; it is also used in the calculation of chewiness.

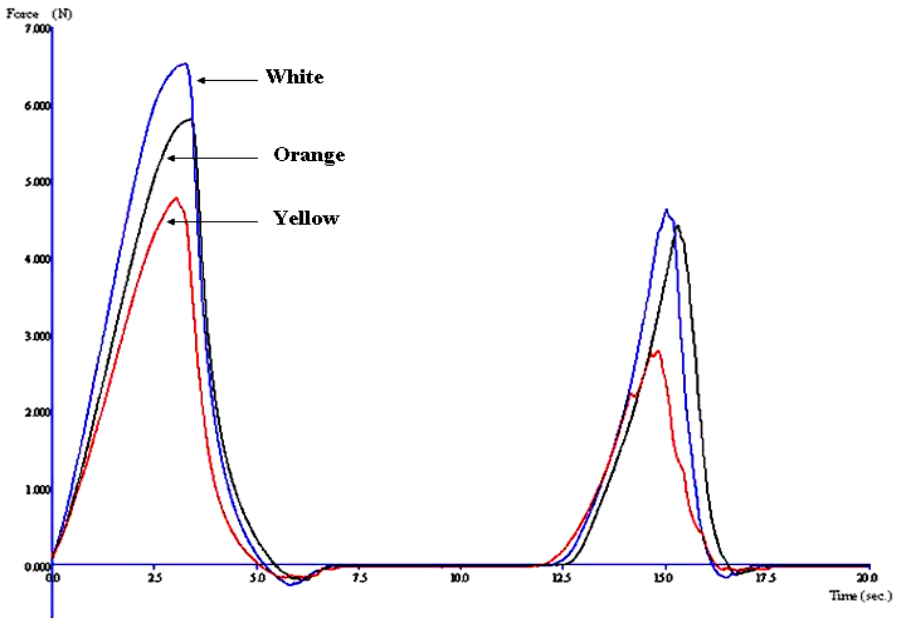


Figure 16 TPA curves of *White*, *Yellow* and *Orange* cultivars

The TPA data are shown in Table 17 for the texture profile characteristics of the 3 sweet potato cultivars. *White* had a highest hardness followed by *Orange*, and they showed insignificant different, whereas *Yellow* had the lowest hardness and demonstrated significant difference (P<0.05) with *White* and *Orange*. *White* cultivar has the lowest adhesiveness value followed by *Orange* and *Yellow*. Springiness of *White* was the highest compared with the two other cultivars. Chewiness is an important character that is expressed as the force needed to masticate the material. Based on Table 17, *White* and *Orange* showed insignificant chewiness

Table 17 Texture Profile Characteristics of 3 SP commercial cultivars

Cultivar	Hardness (N)	Adhesiveness (Ns)	Springiness (%)	Chewiness (N)
White	6.73 ^{a} ± 0.21	0.18 ^{b} ± 0.05	92.57 ^{a} ± 4.51	2.73 ^{a} ± 0.01
Yellow	4.95 ^{b} ± 0.31	0.23 ^{a} ± 0.01	84.81 ^{b} ± 1.72	1.93 ^{b} ± 0.06
Orange	5.94 ^{a} ± 0.60	0.21 ^{ab} ± 0.02	86.63 ^{ab} ± 2.38	2.53 ^{a} ± 0.25

$^{a\ -\ c}$ Means within column followed by different superscripts letters are significantly different at P < 0.05, n = 3 with 15 reading for each n

White and *Orange* cultivars found to be firmer compared to *Yellow* as shown by the value of hardness, springiness and chewiness. Even though, they showed high hardness value, *White* had the lowest adhesiveness. It exhibited that *White* was firm and elastic, but not sticky, on the contrary *Yellow* was soft and sticky. *Orange* appeared having similar characteristics with *White*. TPA attributes of

sweet potato commonly are affected by the chemical component of the tuber, such as moisture, starch and amylose content. Several studies reported that amylose-amylopectin ratio was responsible for the textural characteristics of sweet potato (Woolfe, 1992, Zhang & Oates, 1999), however Noda *et al*, (1998) explained in term of the molecular architecture of amylopectin. Beside that, the variation of TPA attributes could be explained by the varietal differences in the magnitude of degradation of starch and cell wall substances during cooking. From 3 cultivars studied showed that moisture content of steamed samples affected the TPA attributes, especially hardness; the higher the moisture content, the lower the hardness. Hardness of sweet potato tubers was high positively correlated with starch content of fresh tubers ($r = 0.92$, $P<0.01$) (Figure 17), but was not affected by the amylose content. Other component affecting the hardness was reducing sugar. Negative correlation ($r = -0.70$, $P<0.05$) occurred between hardness and reducing sugar.

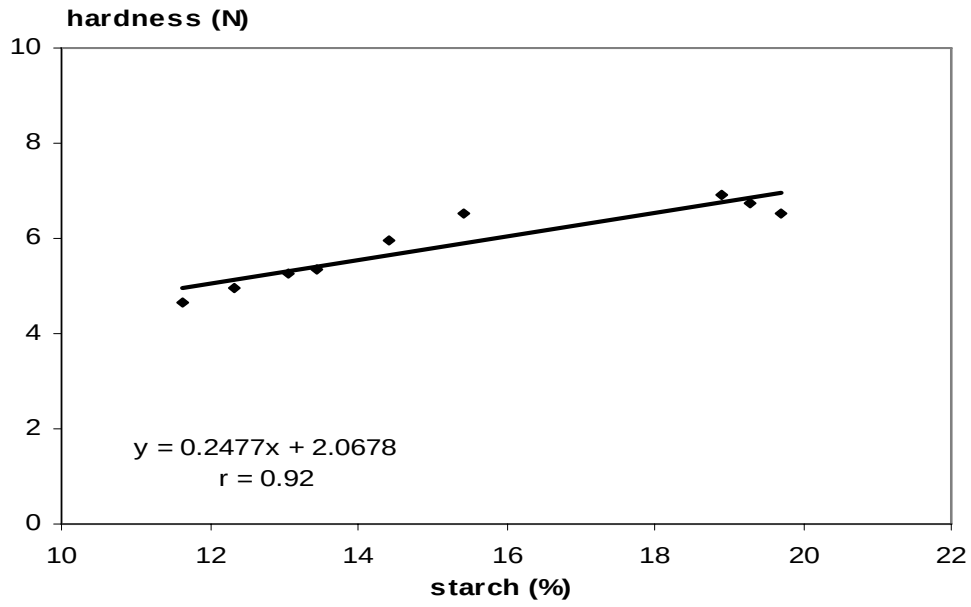


Figure 17 Correlation between hardness and starch content for combination of 3 commercial cultivars

Other texture profile attributes affected by starch and amylose content was springiness. Springiness of tubers was positively correlated with starch content (r = 0.74, P<0.01), but negatively with amylose content (r = -0.79, P<0.01) (Figure 18). Previous study found that not only starch and amylose content influenced the springiness value, but also the cooking process, including the conversion of starch into simple sugars and dextrin by amylase enzymes (Walter *et al*., 1975) and the interaction of pectic compounds with sugars or dextrins which generate certain textural characteristics (Verlinden *et al*. 1995).

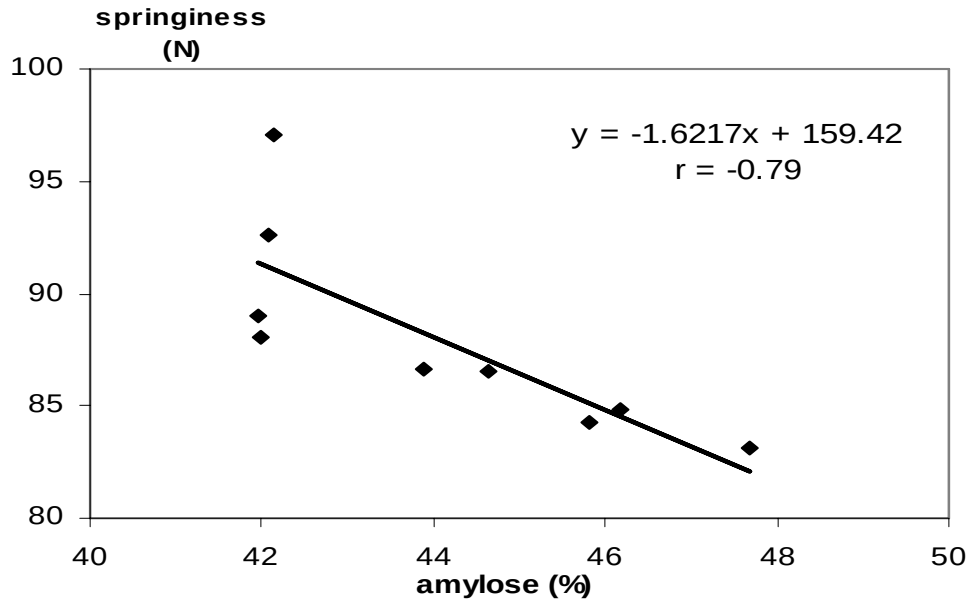


Figure 18 Correlation between springiness and amylose content for combination of 3 commercial cultivars

Chewiness was measured in term of the energy to masticate a solid food involving compressing, shearing, piercing, grinding, tearing and cutting. In the three cultivars, chewiness was positively affected by the starch content (r = 0.87, P<0.01), but negatively by reducing sugar (r = -0.84, P<0.05).

6.3.2 Moisture content changes

A moisture content change during process of food production is an important factor regarding the texture of the product. Figure 19 shows the changes of moisture content during preparing the RSS. Slight increase of moisture content was occurred in blanched chip. It could be caused by the hydration and gelatinization during blanching. In the next stage, the moisture content of mashed or dough decreased, which was caused by evaporation during mashing and adding of SP flour. The decrease of moisture content continued until the final product which in this case was caused by frying. First frying of the raw sticks was conducted at about 163 °C for 1 min, then packaged in plastic bags and frozen at -20 °C, whereas the second frying was done by deep frying in 175 °C for 2 minutes as a final preparation.

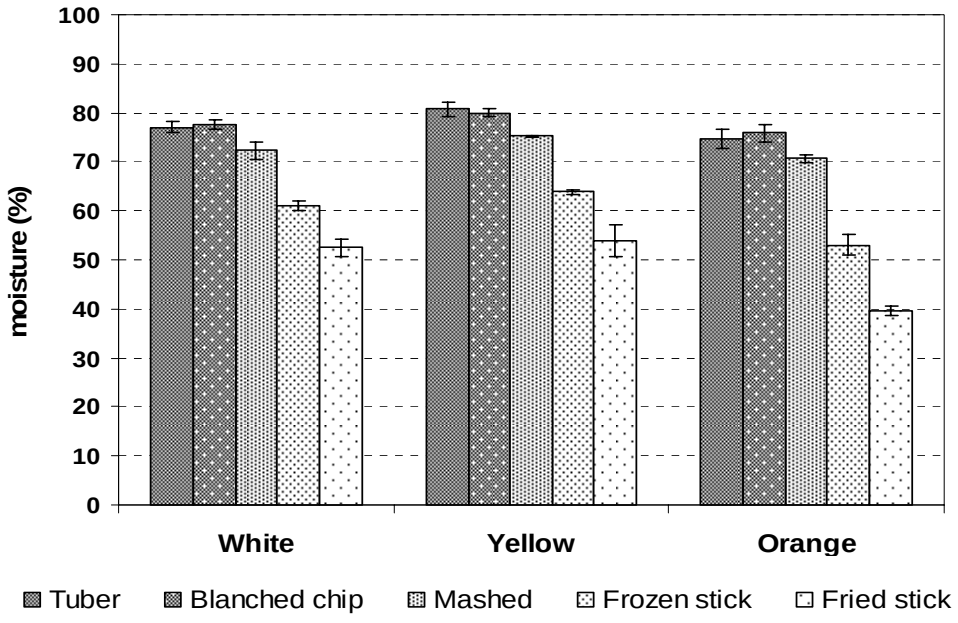


Figure 19 Moisture content changes during RSS processing.

The fluctuation of moisture content of the three cultivars followed similar tendency. Increasing of moisture content occurred during blanching in *White* and *Orange* cultivars, but small decrease occurred in *Yellow* cultivar. The addition of SP flour reduce moisture content of dough, however the decrease of moisture content in the 3 cultivars followed similar leaning. In this stage, dry mater content of dough increased significantly by the addition of 5 % SP flour. *White* and *Orange* contained 27.68 and 29.29 % dry matter or 72.32 and 70.71 % moisture content, respectively, whereas Yellow cultivar had 24.79 % dry mater or 75.21 % moisture content. The different tendency of declining moisture occurred during frying process. *White* and *Yellow* had similar tendency of decreasing moisture content, whereas *Orange* declined sharply. This occurrence might be due to the amylose content. *Orange* contained the highest amylose compared with *White* and *Yellow*. The abundance of hydroxyl groups along the amylose molecules imparts hydrophilic properties to the polymer, giving it an affinity for moisture. Because of the linier nature and the presence of many hydroxyl groups along the polymer chains, amylose molecules have tendency to orient themselves in a parallel fashion and approach each other closely enough to permit hydrogen bounding between adjacent chains. As a result, the affinity of the polymer for water is reduced. Consequently, the water trapped in dough was easily removed by the frying temperature. The decrease of moisture content from dough to final product was 19.87, 21.29 and 31.1 % for *White*, *Yellow* and *Orange*, respectively. Removing water from the food during frying affected the fat absorption, and it is found the linier relationship between oil uptake and moisture content of final product (Gamble *et al*., 1987, Varela, 1988).

6.3.3 Physicochemical characteristics of RSS

Table 18 exhibits the physical characteristics of dough. Dry matter content of dough generated from *White* and *Orange* was not significant different (P>0.05), and considered higher than *Yellow*.

Table 18 Physical characteristics of dough made from 3 cultivars

Cultivars	Dry matter (%)	Firmness (N)
White	27.68 [a] ± 1.81	112.3 [a ns] ± 28.56
Yellow	24.79 [b] ± 0.13	125.1 [a] ± 42.00
Orange	29.29 [a] ± 0.77	116.1 [a] ± 8.10

[a – b] Means within columns followed by different superscripts letters are significantly different at P < 0.05, n = 3.
ns = not significant

There was no significant different on firmness of mashed sweet potato during extrusion process. Although the dry matter content of dough showed sign of difference, the firmness exhibited insignificant difference. It seems that the texture of dough was not only influenced by moisture but also by other factors chemical components.

Textural characteristics of RSS made of 3 cultivars were shown in Table 19. Textural characteristics of RSS was evaluated using three methods i.e. puncture test, cutting-shear test and TPA. Each method generated the specific result of the RSS texture. Puncture test was applied to evaluate the force needed to penetrate

the samples using suitable probe, and expressed as firmness. In puncture test, result showed that the firmness value of *White* RSS was the highest and different from two other samples, whereas *Orange* was higher than *Yellow* RSS. Cutting-shear test generated the force needed to cut the RSS. The value of shearing force was higher than puncture test. However, *White* cultivar generated the highest shearing force, but insignificant different with *Orange*. Similar to puncture test, *Yellow* generated RSS having the lowest shearing force.

Table 19 Physical characteristics of RSS made from 3 cultivars

Physical characteristics	Cultivars		
	White	Yellow	Orange
Moisture (%)	52.45 ^{a} ± 1.91	53.92 ^{a} ± 3.33	39.61 ^{b} ± 0.83
Firmness (N)	1.02 ^{a} ± 0.08	0.52 ^{b} ± 0.04	0.71 ^{c} ± 0.06
Shearing force (N)	4.72 ^{a} ± 0.13	2.38 ^{b} ± 0.05	3.97 ^{a} ± 1.04
TPA:			
Hardness (N)	13.65 ^{a} ± 1.53	8.19 ^{b} ± 0.24	15.37 ^{a} ± 1.51
Springiness (%)	78.33 ^{a} ± 0.05	70.67 ^{b} ± 0.05	71.33 ^{ab} ± 0.07
Cohesiveness (Ns)	0.38 ^{a} ± 0.02	0.36 ^{b} ± 0.06	0.23 ^{c} ± 0.02
Chewiness (N)	3.45 ^{a} ± 0.34	1.90 ^{b} ± 0.40	1.86 ^{b} ± 0.39

$^{a-c}$ Means within rows followed by different superscripts letters are significant different at $P < 0.05$, n = 3 with 15 reading for each n

The two destructive methods generated similar tendency of the result. RSS made from *White* had the highest value of firmness and shearing force, and *Orange*

produced RSS with medium firmness and shearing force, though for shearing force it was not significant different. *Yellow* cultivar generated the RSS with the lowest firmness and shearing force. Firmness and shearing force value of the samples found having similar tendency of hardness, and starch and amylose content of raw materials. Moreover, it was proven by positive correlation between starch and firmness ($r = 0.95$, $P<0.05$), and shearing force ($r = 0.82$, $P<0.05$), whereas the amylose content generated negative correlation by $r = -0.78$ and $r = -0.66$ with firmness and shearing force, respectively. According to the statistical calculation, it appeared that the puncture test was more sensitive than shear test proved by lower coefficient of variation compared with shear test. Even though, shear test still need to be done due to know the force needed to cut the sample as a simulation of biting the RSS as conducted by many researchers.

Based on TPA (Table 19), *White* and *Orange* cultivars produced RSS with the higher hardness value than *Yellow*. This result followed the tendency of hardness of the tubers (Table 17). The similar pattern was also occurred in springiness. RSS made from *White* and *Orange* cultivars showed higher springiness value than *Yellow*. RSS made from *White* cultivar showed the highest cohesiveness and followed by *Yellow* and Orange, moreover *White* and *Orange* generated RSS that were higher in chewiness value than Yellow. The responsibility of starch content in texture profile attributes was demonstrated by the correlation on hardness ($r = 0.55$, $P<0.05$) and chewiness ($r = 0.86$, $P<0.05$), whereas amylose content was influenced springiness and chewiness with $r = -0.80$ ($P<0.05$) and 0.60 ($P<0.05$), respectively. Other characters influenced the texture profile attributes was pasting properties of the starch. Peak viscosity showed highly correlated with springiness

and chewiness by r = 0.95 (P<0.05) and 0.98 (P<0.05), respectively. It means that sweet potato having starch with high peak viscosity, produced RSS with high springiness and chewiness. Highly cohesiveness value caused by the low setback value of the starch and showed r = - 0.99 (P<0.05).

Other physical characteristic of the RSS was colour. According to the result of the colour measurement, *White* RSS had the highest *L* value meaning it was brighter compared with *Yellow* and *Orange* RSS. It might be because of the colour of raw materials and the changes during RSS preparation. Non enzymatic browning might be occurred during preparation of RSS, such as Maillard and caramelization that occurred in the present of sugars.

Table 20 The colour of RSS made from 3 cultivars

Cultivars	L	a	b
White	$55.63^{a} \pm 4.06$	$6.17^{b} \pm 0.48$	$16.33^{a} \pm 1.54$
Yellow	$44.09^{b} \pm 2.50$	$5.84^{b} \pm 1.11$	$12.63^{b} \pm 1.36$
Orange	$45.28^{b} \pm 1.27$	$21.84^{a} \pm 1.87$	$16.94^{a} \pm 1.90$

$^{a-b}$ Means within columns followed by different superscripts letters are significantly different at P < 0.05, n = 3 with 15 reading for each n

The *a* and *b* value expresses the intensity of redness and yellowness respectively. Statistically, *White* and *Yellow* RSS had similar *a* value and exhibits significant difference (P<0.05) with Orange which had a very high *a* value. The colour of *Orange* RSS was the combination of high redness (*a*) and high yellowness (*b*). Comparing RSS picture in Figure 20 with the colour attributes in Table 20, *White*

RSS was seen brighter than *Yellow* which was resulted of significantly higher *L*. The dissimilarity of *Orange* with *White* and *Yellow* RSS was the redness value. *Orange* cultivar produced RSS having very high redness colour.

Colour is the important quality attribute regarding the consumer responses of the product. The Colour of RSS depended on the colour of tubers. *White* cultivar produced white frozen sticks and light yellow RSS, and *Yellow* cultivar generated darker frozen sticks and RSS compared to White. Moreover, bright orange frozen sticks and RSS was produced from *Orange* cultivar (Figure 20). Colour of fresh tubers was the decisive factor to the colour of RSS. The colour of RSS became darker after final frying compared to frozen RSS. The colour change occurred during frying which might be caused by browning, as explained in Chapter 5.

Browning that occurred in RSS production seem dominated by non enzymatic, since the browning enzymes might be inactivated in blanching and first frying. This phenomenon was proved by negative correlation between colour values with reducing sugar of the tubers with r = - 0.68 and r = - 0.79 for *a* and *b* value, respectively.

1a. Frozen White RSS

1b. Fried White RSS

2a. Frozen Yellow RSS

2b. Fried Yellow RSS

3a. Frozen Orange RSS

3b. Fried Orange RSS

Figure 20 Frozen and fried RSS made from *White, Yellow* and *Orange* cultivars.

The chemical characteristic of RSS made of 3 cultivars is shown in Table 21. Fat is considered to be an important factor in fried product. Oil absorption occurs as moisture is removed from the food during frying (Varela, 1988) and there is a linear relationship between oil uptake and water content of final product (Gamble *et al*., 1987).

Table 21 Chemical characteristics of RSS made from 3 cultivars

Chemical characteristics	Cultivars		
	White	*Yellow*	*Orange*
Frozen stick:			
Moisture (%)	61.10 ^{b} ± 0.88	63.91 ^{a} ± 0.47	53.08 ^{c} ± 2.09
Fat (%, db)	15.68 ^{b} ± 0.87	16.98 ^{b} ± 1.94	32.94 ^{a} ± 3.18
Fried Stick:			
Moisture (%)	52.45 ^{a} ± 1.91	53.92 ^{a} ± 3.33	39.61 ^{b} ± 0.83
Fat (%, db)	21.44 ^{b} ± 1.59	24.80 ^{b} ± 4.15	35.91 ^{a} ± 0.48
Protein (%, db)	3.59 ^{a} ± 0.42	2.55 ^{b} ± 0.38	2.74 ^{ab} ± 0.17
Carbohydrate (%,db)	71.83 ^{a} ± 1.75	69.40 ^{a} ± 3.51	59.19 ^{b} ± 0.62
Ash (%, db)	3.13 ^{ab} ± 0.59	3.25 ^{a} ± 0.26	2.17 ^{b} ± 0.05

$^{a-c}$ Means within rows followed by different superscripts letters are significantly different at $P < 0.05$, $n = 3$

Fat content of frozen and fried RSS made of *Orange* was higher than *White* and *Yellow*. It's because the decreasing of moisture content from mashed to frozen, and frozen to fried RSS was higher than others. As explained in previous chapter, the high fat content in restructured product occurred by the fat replacing water during frying.

Protein is not an important compound in sweet potato and its product and it is well known that SP is not a source of protein. However, protein content of RSS was between 2.55 and 3.59 % (db) and whereas carbohydrate ranged from 59.19 to 71.83 % (db) within the 3 cultivars. The result found that RSS was a good source of mineral based on the ash content.

6.3.4 Sensory properties

Table 22 presents the mean panel scores for quality attributes of RSS affected by different raw materials. With regards to colour, the panels significantly ($P<0.05$) preferred RSS made from *Orange* cultivar having the bright orange colour compared to *White* and *Yellow*. The mean score of Orange RSS was 5.80 (slightly below *like moderately*), whereas White RSS had a mean score 5.37 (midway between *like slightly* and *like moderately*). There was no significant different ($P>0.05$) of the texture preferences decided by the panel with the mean score around 5.0 (*like slightly*). Although the firmness or shearing force or hardness measured by instrument exhibit the different value, the panel did not detect any differences, or in other words the texture was in the range of their preferences.

Table 22 Sensory scores[1] for colour, texture, flavour and overall acceptability of RSS made from 3 cultivars

Cultivars	Colour	Texture	Flavour	Overall Acceptability
White	5.37 [b] ± 0.65	4.91 [a ns] ± 0.70	5.11 [ab] ± 0.72	5.06 [b] ± 0.34
Yellow	4.86 [c] ± 0.49	4.89 [a] ± 0.53	4.91 [b] ± 0.58	4.97 [b] ± 0.30
Orange	5.80 [a] ± 0.63	5.34 [a] ± 0.64	5.26 [a] ± 0.70	5.46 [a] ± 0.51

[a – c] Means within columns followed by different superscripts letters are significantly different at $P < 0.05$. ns = not significant

[1] Hedonic scale: 1 = *dislike extremely*, 2 = *dislike moderately*, 3 = *dislike slightly*, 4 = *neither like nor dislike*, 5 = *like slightly*, 6 = *like moderately*, 7 = *like extremely*

The panel significantly ($P<0.05$) preferred the RSS made of *White* and *Orange* for flavour, which had a mean score slightly above 5.0 (*like slightly*). Flavour of RSS might be from the specific sweet potato flavour and also the flavour produced during processing such as caramelization. Caramelization flavour is produced when sugars contained in sweet potato were burned by the frying temperature. Although the significant difference ($P<0.05$) was found for overall acceptability, the mean sensory score was slightly different and above *like slightly*. The significant difference ($P<0.05$) was found for overall acceptability between RSS made from *Orange* with *White* and *Yellow*. From these finding, one may conclude that *Orange* cultivars generated the high preferences of colour, flavour and overall acceptability.

6.4 Conclusions

RSS is a *fabricated* product from mashed sweet potato which is moulded into finger like and fried to be a French fry type. Textural characteristics of 3 commercial cultivars varied significantly. *White* and *Orange* had a hard texture, elastic and not sticky, whereas *Yellow* was soft, less elastic and sticky. These characteristics were affected by starch and amylose content of the tubers. *White* cultivar contained high starch with medium amylose content, *Yellow* had low starch with low amylose content, and *Orange* contained medium starch with high amylose content. *White* cultivar produced RSS having yellow bright colour, high firmness and low fat content, whereas *Orange* cultivar generated RSS with bright orange colour, medium firmness but high fat content. RSS made of both varieties were evaluated as acceptable by a sensory panel. RSS made from *White* and *Orange* cultivars were preferred with sensory score above the average. *White* and *Orange* sweet potato cultivars were suitable as a raw material to produce a convenient RSS.

CHAPTER 7

THE EFFECT OF PREPARING METHODS ON SENSORY PREFERENCES OF A RESTRUCTURED SWEET POTATO STICK

7.1 Introduction

Sweet potato (SP) is a starchy crop which is used in tropical countries. It is well known that SP not only provide energy, but also an excellent source of vitamins and minerals, dietary fibre and protein (Edmond & Ammerman, 1971, Lanier & Sistrunk, 1979, Picha, 1985a). Despite these general nutritional excellences, SP is still under-utilized.

Cooked sweet potato products present a large diversity of structural, sensory and functional properties according to the methods and intensity of cooking. Such effects were reported on SP tubers (Sarhan, 1975, Walter *et al*., 1975, Reddy & Sistrunk, 1980, Shen & Sterling, 1981, Bradbury *et al*., 1988c), because of their wide variation characteristics.

The fried products of sweet potato are French fried-type products or sticks or chips. Sweet potato French fries and chips were judged to be of a good quality and acceptability by a consumer panel (Hoover & Miller, 1973, Walter & Hoover, 1986, and Schwartz *et al*. 1987). Conventional processes in preparing French fries from

fresh roots have several drawbacks. Further difficulties arise due to physical and chemical characteristics of the raw materials such as size, shape, sugar content, solid content, etc. All these variations affect the color, texture and flavor of the finished product and must be controlled. Controlling of the adequate qualities can be made by preparing *fabricated* French fries or sticks from restructured sweet potato roots (Walter & Hoover, 1986, Truong & Walter, 1994, Truong *et al*., 1995, Walter *et al*., 1999).

Frying is the one of process step in preparing food. During deep-fat frying water in the crust will evaporate and move out of the food. In order for the flow of vapor to continue, sufficient water has to be able to migrate from the core of the food to the crust and the crust has to remain permeable. The fact that the vapor leaves voids for the fat to enter later, is the reason why fat uptake is largely determined by the moisture content of the food (Gamble, *et al.* 1987a, Lamberg, *et al*.1990, Mehta & Swinburn, 2001, Saguy & Pinthus, 1995; Southern, *et al*. 2000). Similarly, sections of the food with more moisture loss also show more fat uptake (Gamble *et al.* 1987b). Some even argue that the total volume of fat will equal the total volume of water removed (mass balance) (Pinthus *et al.* 1993). In addition, par-fries can be frozen destined for reheating on the further process. The parfried and frozen French fries are commonly prepared for eating by deep fat frying in oil. More recently, microwave oven have been applied for reheating of fried frozen food products. The power absorption or specific absorption rate for a particular product depends upon a variety of physical and chemical factors. The high frequency energy excites polar molecules (such as water) contained within the food product and heat is generated as a result. A

characteristic of microwave reheating is thus that the product is warmed uniformly throughout, leading to a greater generation of water vapour from the interior of the product. This increases the moisture migration effect referred to above. However the oven reheated products is in most cases not the equivalent of a product that has been completely deep fried.

The objectives of this study was to examine the effect of deep frying and baking in microwave oven on the texture attributes and sensory preferences of restructured sweet potato sticks (RSS) which was suitable for final preparation of RSS.

7.2 Materials and methods

7.2.1 Materials

Three commercial SP cultivars consist of *White, Yellow* and *Orange* flesh colors were purchased in Pasar Borong, Selangor, Malaysia. Refined bleached and deodorized (RBD) palm olein was obtained from a local store. Carboxymethylcelullose (CMC) and Sodium tripolyphosphate (STP) were of food grade. All chemicals and solvents used were of analytical grade unless otherwise specified. Sweet potato-flour (SP flour) was prepared in Food engineering laboratory, Faculty of Food Science and Technology, UPM. Sweet potato flour from the three cultivars was prepared as explained in previous chapter in section 5.2.1.

7.2.2 Preparation of restructured sweet potato sticks (RSS)

An RSS was prepared from 3 cultivars using method as explained in previous chapter in section 6.2.2. The final preparation included two methods of processing. Firstly, the RSS were prepared by deep frying in refined bleached and deodorized (RBD) palm olein at 175 °C for 2 minutes. Secondly, the RSS was baked microwave oven (MO) (Panasonic, model NN-K573MF) in hi power (1100 W) for 3 minutes (Lewthwaite *et al.*, 1997)

7.2.3 Physical characteristics

Texture of fried sticks was determined by the cutting-shear test using texture analyzer (TA.TX2i, Godalming, UK). Shearing force is a force required to shear and cut the samples by a single downward action of the shear blade (HDP/BS) of the texture analyzer. The test condition was: pre-test speed 2 mm/s, test speed 1 mm/s, post test speed 2 mm/s, and degree of compression 110 % of its initial height. Shearing force of fried stick was expressed in Newton (N). Textural properties of RSS were determined by Texture Profile Analysis (TPA) as explained in previous chapter in section 6.2.4. Data collection and analysis were accomplished by the EXTRAD Dimension Software of the Texture Analyzer.

The colour of fried sticks was determined by the Hunter Color Instrument (Hunter Lab, Reston, USA) and values (L, a, b) were collected using method as explained in previous chapter in section 6.2.4.

7.2.4 Sensory analysis

Sensory evaluations are performed on all fried samples includes color, texture, flavor and overall acceptability. Forty untrained panelists evaluated the products consist of students and staff of Faculty of Food Science and Technology, UPM, Malaysia. A seven point hedonic scale is used for scoring the samples (1 = *dislike extremely*; 2 = *dislike moderately*, 3 = *dislike slightly*, 4 = *neither like nor dislike*, 5 = *like slightly*, 6 = *like moderately*, 7 = *like extremely*). Samples are coded with 3 digits in a randomized arrangement to equalize the effect of samples sequence food preference. Sensory evaluation sheet on this study is shown in Appendix 4.

7.2.5 Statistical analysis

The experiment is arranged with a two factor randomized complete block design. The first factor was three commercial cultivars including *White, Yellow* and *Orange.* The second factor was methods of preparation i.e. deep fat frying and baking in microwave oven. The data collected were analyzed using analysis of variance (ANOVA) and the significant differences among means were determined by

Duncan's multiple range test (DMRT) with 5 % of the level of significance, using MSTAT-C statistical software.

7.3 Results and discussion

7.3.1 Textural characteristics of RSS

A textural parameter is an important aspect of food quality. Therefore, attention to this attribute is critical in new product development. Textural characteristics of this product were evaluated using two methods, cutting-shear test and texture profile analysis (TPA). In term of texture evaluation, shearing test is the method that describes any cutting action that causes the product to be divided into two pieces. TPA is the method that imitates the action of jaws and extracted from the resulting force vs time curve a number of textural parameters that high correlated with sensory evaluation (Bourne, 2002).

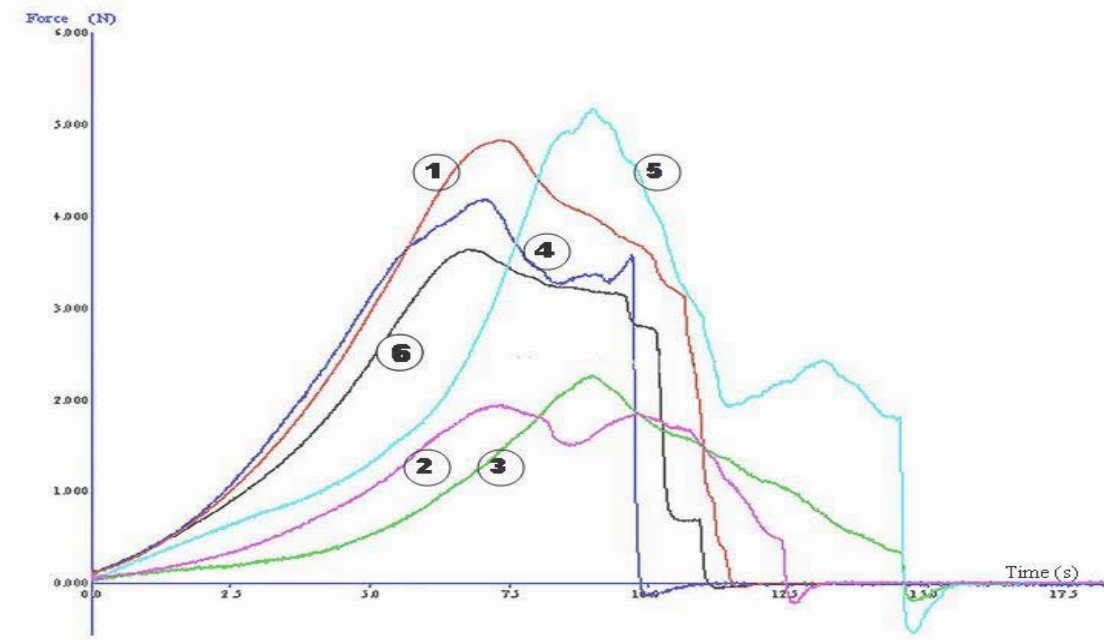


Figure 21 Cutting-shear test curve of restructured sweet potato sticks made from three cultivars and prepared using two methods of cooking. (1 = *White* RSS-deep fried, 2 = *Yellow* RSS-deep fried, 3 = *Orange* RSS-deep fried, 4 = *White* RSS-microwave oven, 5 = *Yellow* RSS-microwave oven, 6 = *Orange* RSS-microwave oven)

Textural characteristics of RSS made from three cultivars are exhibited in Table 23. Shearing force of RSS was significantly ($P<0.05$) affected by cultivars and methods of cooking individually, furthermore the interaction between two factors was significant different ($P<0.05$). *White* cultivar produced RSS having high shearing force especially after prepared by deep frying, but lower force when prepared using microwave oven. It might be due to the evaporation of water occurred immediately on the surface of sticks upon it contact with hot oil. The evaporation will also lead to shrinkage and development of surface porosity and roughness. On the contrary, *Yellow* RSS needed lower force to cut the RSS prepared by deep frying than that by microwave oven. Similar with *Yellow*, *Orange* RSS had similar tendency, low

shearing force in deep fried but high in microwave oven. As shown in Figure 21, the peak of the curve is expressed as maximum force needed to cut the samples into two pieces.

Table 23 Textural characteristics of RSS prepared by deep frying and baking in microwave oven

Sources	Shearing Force (N)	T P A			
		Hardness (N)	Springi-ness (%)	Cohesive ness (Ns)	Chewi ness (N)
Cultivar:					
White (W)	4.59 ^{a} ±0.46	6.29 ^{a} ± 0.66	94.5 $^{a\text{-ns}}$±2.0	0.65$^{a\text{-ns}}$±0.02	3.84 ^{a} ± 0.42
Yellow (Y)	3.49 ^{b} ±1.66	4.95 ^{b} ± 0.81	95.8 ^{a} ± 3.0	0.66 ^{a} ± 0.02	3.14 ^{b} ± 0.70
Orange (O)	2.88 ^{c} ± 0.71	4.28 ^{c} ± 0.75	94.9 ^{a} ± 3.0	0.65 ^{a} ± 0.01	2.50 ^{c} ± 0.61
Cooking:					
Deep frying(DF)	3.07 ^{b} ± 1.45	4.54 ^{b} ± 0.96	94.1 $^{a\text{-ns}}$± 2.0	0.65 ^{b} ± 0.01	2.68 ^{b}± 0.63
Microwave(MO)	4.24 ^{a} ± 0.65	5.80 ^{a} ± 0.90	96.0 ^{a} ± 3.0	0.66 ^{a} ± 0.02	3.65 ^{a} ± 0.57
Interaction:					
W x DF	5.00 ^{a} ± 0.09	5.70 ^{b} ± 0.06	94.1 $^{a\text{-ns}}$± 3.0	0.65$^{a\text{-ns}}$±0.01	3.48 ^{c} ± 0.08
Y x DF	1.98 ^{e} ± 0.09	4.22 ^{d} ± 0.18	93.2 ^{a} ± 3.0	0.65 ^{a} ± 0.01	2.51 ^{e} ± 0.11
O x DF	2.23 ^{d} ± 0.03	3.71 ^{d} ± 0.68	94.9 ^{a} ± 3.0	0.64 ^{a} ± 0.01	2.05 ^{f} ± 0.04
W x MO	4.17 ^{b} ± 0.08	6.89 ^{a} ± 0.09	94.9 ^{a} ± 1.0	0.66 ^{a} ± 0.03	4.21 ^{a} ± 0.18
Y x MO	5.01 ^{a} ± 0.07	5.68 ^{b} ± 0.11	98.4 ^{a} ± 1.0	0.64 ^{a} ± 0.02	3.77 ^{b} ± 0.18
O x MO	3.53 ^{c} ± 0.01	4.84 ^{c} ± 0.10	94.9 ^{a} ± 3.0	0.65 ^{a} ± 0.07	2.96 ^{d} ± 0.12

$^{a-f}$: Means within columns for each treatments (Cultivar; Cooking or Interaction), followed by different superscripts letters are significantly different at $P < 0.05$, n = 3 with 15 reading for each n

^{ns} : Not Significant

The textural attributes of RSS for TPA were hardness, springiness, cohesiveness and chewiness. TPA hardness of RSS was significantly ($P<0.05$) affected by the combination of cultivars and method of cooking. The RSS made from *White* cultivar produced the higher hardness value when baked in microwave oven compared with deep frying. This occurrence happened in *Yellow* and *Orange* cultivar as well. Moreover, baking in microwave oven generated the higher hardness than frying. This result was consistent in which *White* always generated the highest hardness among the three cultivars. Methods of cooking significantly ($P<0.05$) affected the texture of RSS. Reheating using microwave oven notably increased the hardness of the product as a result of evaporation. In microwave oven, the high frequency microwave radiation passed through the food product. The excitation of water molecules generated heat from inside the products, and then followed by evaporation within the food product (Lang, 2006). This increased the moisture migration effect referred to above, without any compensating crisping effect that bared the vapour flow. As a result, the interior of the product was uniform and dry, but tough and strong from the compression force. Springiness indicates how well product physically recover after it has been deformed. The springiness of RSS was statistically not affected by cultivars, cooking methods or the combinations. It means that whatever the cultivar used and method of cooking produced RSS of similar springiness. RSS made from the 3 cultivars and prepared by deep frying or baking in microwave oven generated high springiness value (>90 %). Cohesiveness of RSS was influenced only by the methods of cooking. Microwave oven significantly ($P<0.05$) caused higher cohesiveness than deep frying. Chewiness is the parameter expressing the force needed to masticate the product resulted from the calculation of hardness, springiness and cohesiveness.

Determination of TPA chewiness proved that there was interaction between cultivars and cooking method. The calculation showed that White RSS had lower chewiness value when fried than those baked in microwave oven. This occurrence reappeared in *Yellow* and *Orange* RSS, but the chewiness value of *Yellow* was higher than *Orange.* The chewiness value of RSS made of *Yellow* and *Orange* prepared using two methods of cooking ranged from 2.05 to 3.78 N. The lowest chewiness was occurred in *Orange* RSS by deep fried and Yellow by microwave oven. It proved that baking using microwave oven generated the higher chewiness of RSS. *White* cultivar showed high chewiness value which produced by the two method of final preparation.

7.3.2 Colour attributes of RSS

The colour attributes evaluated including Lightness (*L*), redness (*a*) and yellowness (*b*). All three colour attributes tested were influenced by the interaction of cultivars and methods of cooking (Table 24). Lightness value of RSS was significant different ($P<0.05$) among the combination of three cultivars cooked by the two methods. RSS made from *White* cultivar showed the higher *L* value after it was prepared by microwave oven compared to by deep frying. On the contrary, RSS made from *Orange* exhibited lower lightness value when prepared by microwave oven than prepared by deep frying. *Yellow* RSS had the lowest *L* value regardless of methods of preparation used. The high *L* was achieved by baking in microwave oven, and frying produced the darker RSS. Browning occurred in fried products are considered to be produced by protein-carbohydrates reactions, i.e. the *Maillard* reaction, lipids can

also play a role in non-enzymatic browning. Particularly, the reaction of lipid oxidation products with amines, amino acids, and proteins has long been related to the browning observed in many foods during processing and storage. The intensity of browning has been primarily correlated with losses of lysine, histidine, and methionine while the main reactive compounds from lipids were aldehydes, epoxides, hydroxyketones, and dicarbonylic compounds (Pokorny´, 1981). Non-enzymatic browning seems to be dominated by caramelization of sugars in the frying temperature. Based on the value of *L* in the combination of cultivars and cooking methods, baking in microwave oven generated higher *L* value than frying. The pictures of RSS prepared by deep frying and baked in microwave oven are displayed in Figure 22.

Redness and yellowness were used when *a* and *b* value read positive (>0). As explained in previous chapter, the colour of the product was certainly affected by the colour of raw material. On the other hand, methods of preparation definitely influenced the colour attributes. Based on the method of reheating methods, deep frying produced higher *a* value than microwave oven significantly ($P<0.05$), especially for RSS made from *White* and *Yellow* cultivars. It might be the browning and dehydration occurred on the surface of sticks immediately when the product immersed into oil. On the other hand, microwave oven produced lower *b* value of *Yellow* and *Orange* RSS.

Table 24 Colour value of RSS made from 3 cultivars prepared using two methods.

Sources	L	a	b
Cultivar:			
White (W)	44.35 ^{a} ± 1.77	4.61 ^{b} ± 1.14	11.92 ^{b} ± 0.24
Yellow (Y)	37.39 ^{c} ± 0.37	3.23 ^{c} ± 0.39	7.59 ^{c} ± 0.35
Orange (O)	40.93 ^{b} ± 0.61	10.97 ^{a} ± 1.21	12.99 ^{a} ± 0.27
Cooking:			
Deep frying (DF)	40.61 ^{b} ± 2.37	6.39 $^{a\ ns}$ ± 2.83	10.96 ^{a} ± 2.41
Microwave (MO)	41.17 ^{a} ± 3.82	6.15 ^{a} ± 4.40	10.71 ^{b} ± 2.56
Interaction:			
W x DF	42.80 ^{b} ± 0.80	5.64 ^{c} ± 0.21	11.81 ^{d} ± 0.31
Y x DF	37.63 ^{e} ± 0.34	3.57 ^{d} ± 0.16	7.87 ^{e} ± 0.27
O x DF	41.40 ^{c} ± 0.49	9.96 ^{b} ± 0.23	13.20 ^{a} ± 0.23
W x MO	45.89 ^{a} ± 0.08	3.57 ^{d} ± 0.08	12.02 ^{c} ± 0.14
Y x MO	37.15 ^{e} ± 0.25	2.89 ^{e} ± 0.08	7.32 ^{f} ± 0.08
O x MO	40.46 ^{d} ± 0.20	11.97 ^{a} ± 0.75	12.78 ^{b} ± 0.01

$^{a\ -\ e}$ Means within columns for each treatments (Cultivar; Cooking or Interaction), followed by different superscripts letters are significantly different at $P < 0.05$, n = 3 with 15 reading for each n

^{ns} not significant

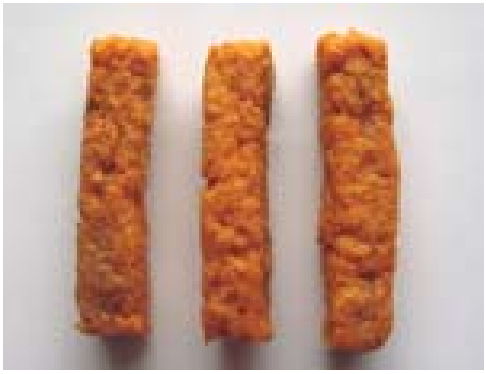
1a. White RSS – deep fried

1b. White RSS - baked

2a. Yellow RSS – deep fried

2b. Yellow RSS - baked

3a. Orange RSS- deep fried



3b. Orange RSS - baked

Figure 22 RSS made of 3 cultivars prepared using deep frying and baking in microwave oven.

7.3.3 Sensory properties

Table 25 presents the mean sensory scores for quality attributes of RSS affected by different raw materials and the two methods of final preparation. Cultivars and methods of cooking affected the panel's preference for the attributes of sensory quality individually and there is no interaction between both of cultivars and cooking methods on sensory preferences.

Considering the colour, there were significant different among ($P<0.05$) RSS made from three cultivars or methods of preparation individually. Panels preferred RSS made from *Orange* cultivar having the bright orange color. The mean colour score for *Orange* RSS was 5.51 (midway between *like slightly* and *like moderately*), *White* RSS had a mean score of 5.10 (slightly above *like slightly*), while *Yellow* was 4.64 (midway between *neither like nor dislike* and *like slightly*). The high score of *Orange* RSS might be due to the attractive bright orange colour which showed by the combination of *L* value (40.93), *a* value (10.97) and b value (12.99). *White* was second to the panels' preference having *L, a* and *b* for 44.31, 4.61 and 11.92, respectively, whereas the lowest colour preference was given to *Yellow* RSS. Other factor affecting panels' preferences were cooking methods. The panels preferred RSS prepared using deep frying than using microwave oven. It might be that the panels preferred the RSS having high *a* and *b* values that produced by deep frying. This proved by positive correlation between preference of colour and Hunter *a* or *b* value as shown in Figure 23, a and b.

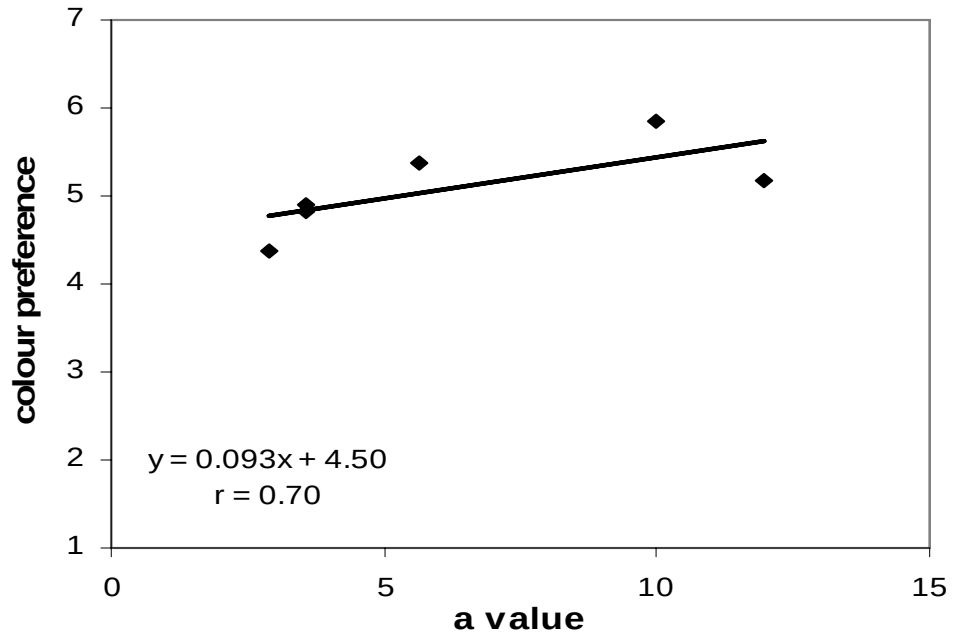
Table 25 Sensory scores[1] for colour, texture, flavour and overall acceptability of RSS made of 3 cultivars with 2 methods of preparation

Sources	Colour	Texture	Flavour	Overall
Cultivar:				
White (W)	5.10 [b] ± 0.65	4.66 [b] ± 0.73	4.97 [a-ns]±0.67	4.88 [b] ± 0.46
Yellow (Y)	4.64 [c] ± 0.56	4.51 [c] ± 0.69	4.81 [a] ± 0.62	4.69 [c] ± 0.49
Orange (O)	5.51 [a] ± 0.67	4.86 [a] ± 0.76	4.95 [a] ± 0.73	5.11 [a] ± 0.55
Cooking:				
Deep frying (DF)	5.38 [a] ± 0.70	5.06 [a] ± 0.66	5.07 [a] ± 0.69	5.16 [a] ± 0.43
Microwave (MO)	4.79 [b] ± 0.62	4.30 [b] ± 0.60	4.75 [b] ± 0.63	4.63 [b] ± 0.49
Interaction:				
W x DF	5.38 [a-ns]±0.63	4.95 [a-ns]± 0.71	5.13 [a-ns]±0.72	5.07 [a-ns]±0.35
Y x DF	4.90 [a] ± 0.50	4.90 [a] ± 0.55	4.90 [a] ± 0.59	4.97 [a] ± 0.28
O x DF	5.85 [a] ± 0.62	5.33 [a] ± 0.66	5.20 [a] ± 0.72	5.43 [a] ± 0.50
W x MO	4.83 [a] ± 0.55	4.38 [a] ± 0.63	4.83 [a] ± 0.59	4.68 [a] ± 0.47
Y x MO	4.38 [a] ± 0.49	4.13 [a] ± 0.61	4.73 [a] ± 0.64	4.40 [a] ± 0.50
O x MO	5.18 [a] ± 0.55	4.40 [a] ± 0.55	4.70 [a] ± 0.65	4.80 [a] ± 0.41

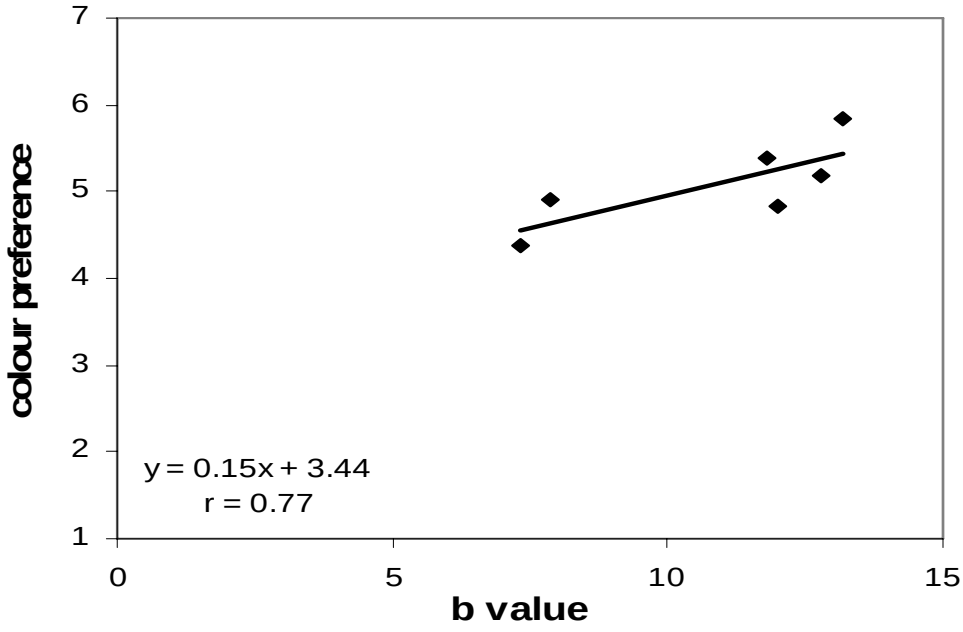
[1] Hedonic scale: 1 = *dislike extremely*, 2 = *dislike moderately*, 3 = *dislike slightly*, 4 = *neither like nor dislike*, 5 = *like slightly*, 6 = *like moderately*, 7 = *like extremely*

[a – c] Means within columns for each treatments (Cultivar; Cooking or Interaction), followed by different superscripts letters are significantly different at $P < 0.05$

[ns] not significant



a Colour preferences vs a-value

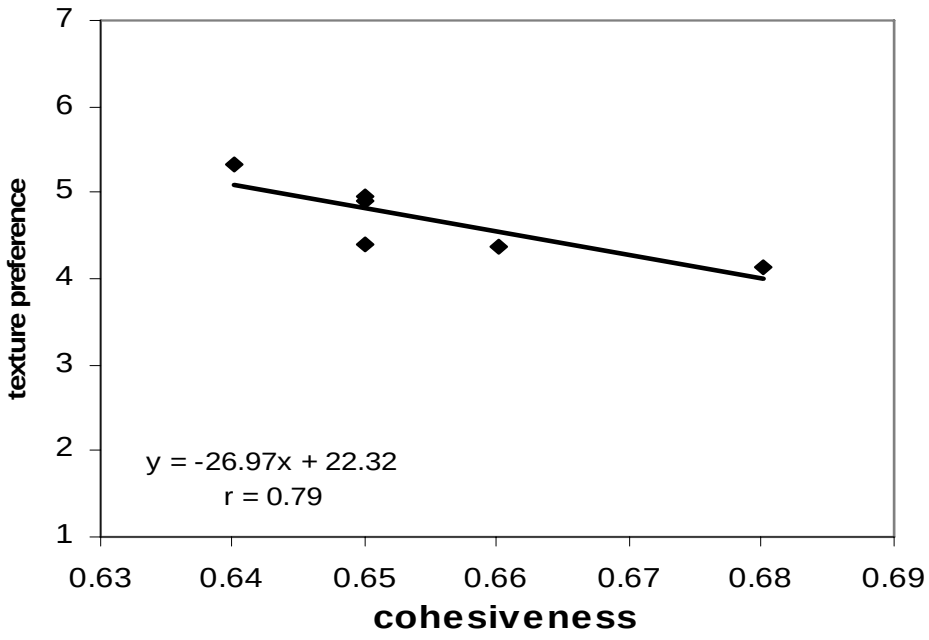


b Colour preferences vs b-value

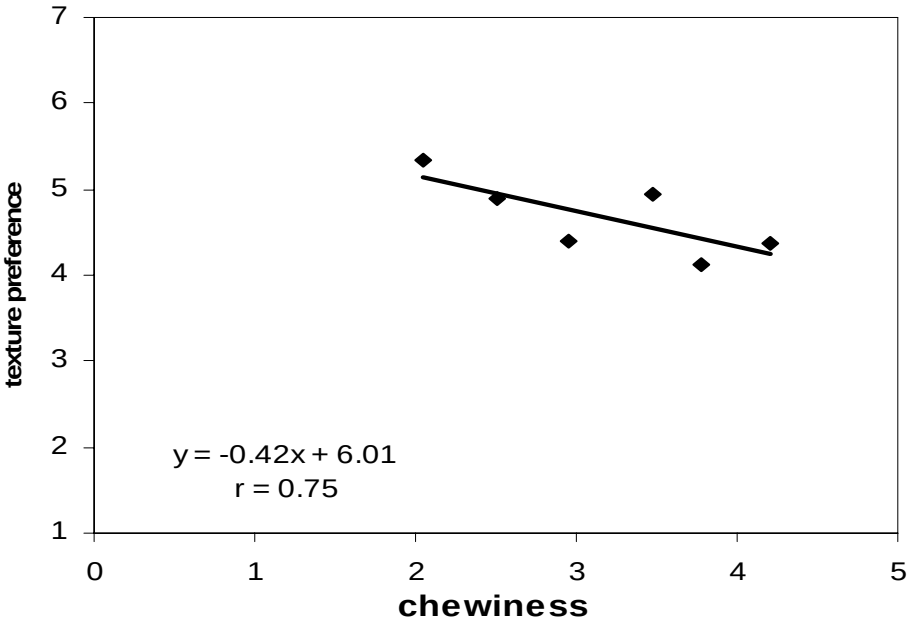
Figure 23 Correlation between colour preference with *a* and *b* values of RSS made from 3 cultivars and prepared using 2 methods

In texture, panels preferred the RSS made from *Orange* cultivar that was significant different ($P<0.05$) compared with *White* or *Yellow*. Mean score of Orange RSS was 4.86, (slightly below *like slightly*) whereas *White* and *Yellow* were 4.66 and 4.51 respectively. Relating to method of preparation, panels preferred the RSS cooked using deep frying, with a score of 5.06 (slightly above *like slightly*) compared with baked in microwave oven having score of 4.30. There was a negative correlation ($P<0.05$) between TPA parameters (cohesiveness and chewiness) and texture preference (Figure 24, a and b). It might be the panel's preference was due to the soft texture of RSS, which was produced using deep frying.

Flavour is a sensory attribute which combine taste and aroma. In this study, panels' preference for the flavour was only affected by the method of cooking ($P<0.05$). Panels preferred RSS cooked by deep frying with a score of 5.38 (slightly above *like slightly*), compared with microwave oven with a score of 4.79 (slightly below *like slightly)*. Flavour was generated during frying, when the samples touched the hot oil and several changes occurred. Evaporation, browning and crisping were occurred immediately in deep frying on the surface of the sticks which generated the specific flavour.



a Texture preferences vs cohesiveness



b Texture preferences vs chewiness

Figure 24 Correlation between texture preference with cohesiveness and chewiness of RSS made from 3 cultivars and prepared using 2 methods

Mean scores of overall acceptability of samples were influenced by cultivar and method of cooking, and no interaction existed between the two in choosing the most acceptable product. *Orange* cultivar seems to be a good raw material of RSS. The scores of *Orange, White* and *Yellow* were 5.11 (slightly above *like slightly*), 4.88 (slightly below *like slightly*)and 4.69 (slightly below *like slightly*) respectively. Deep frying generated RSS having mean score of 5.16 (slightly above *like slightly*) compared with microwave oven with 4.63 (slightly below *like slightly*). Generally, panels preferred RSS made from Orange cultivar and followed by White and Yellow. Also, deep frying as a method for RSS cooking preparation was highly acceptable.

7.4 Conclusions

The final preparation significantly affected the characteristics of RSS. The most suitable condition of producing RSS was using deep frying for final preparation, especially for RSS made from *White* and *Orange* commercial cultivars. RSS made of *White* cultivar had hard texture, bright yellow colour and slightly below *like slightly* in sensory scores, *Orange* RSS on the other hand had softer texture, bright orange colour and slight above *like slightly*.

CHAPTER 8

GENERAL CONCLUSIONS AND RECOMMENDATIONS

8.1 General conclusions

The work presented in this thesis was concerned with the characteristics of several sweet potato accessions which consist of 17 UPM collection accessions and 4 commercial cultivars available in the Malaysian's market and thus providing information for further studies in sweet potato product development. The product developed was *fabricated* or restructured French fries type-product and named as Restructured Sweet potato Sticks (RSS). The study included the use of commercial cultivars that are available throughout the year, the method of preparation, the determination of physical and chemical characteristics, and acceptability of the product.

The physical and chemical characteristics of the cultivars are important information on the development of the cultivars. Seventeen accessions from UPM collection exhibited great variation on physical and chemical characteristics. Some accessions had similar characteristics within the colour group, however, some were similar with member of the other groups. The four commercial cultivars followed similar trend. Average moisture content of the 17 accessions provided by UPM and 4 commercial cultivars was 74.56 %. The variation of moisture content of steamed roots revealed the characteristic of the

cultivar which generate about 75.41 % in average, and it was proved to be affected by moisture content of fresh root significantly. As a source of carbohydrate, starch and amylose content were important to be identified, especially due to their influence on texture attributes. Starch content of 17 accessions and 4 cultivars in this study varied from 10 to 25 % (fwb), with the average were 14.33, 13.14, 14.30 and 20.80% (fwb) or 53.31, 53.20, 53.20 and 52.20 % (db) for white, yellow, orange and purple groups, respectively. The amylose content varied from 19.15 to 28.80 % (db), which purple accessions contained the highest amylose content (27.48 %) and followed by orange (26.86 %), white (24.74 %) and yellow (23.58 %).

Peak force deformation and hardness of steamed samples were significantly affected by starch and amylose content of the tubers. Commercial cultivars exhibited lower hardness value compared to 17 accessions within the group of flesh colour. Based on adhesiveness value, 17 accessions had lower adhesiveness values than the 3 commercial cultivars (*White, Yellow* and *Purple*). *Low* adhesiveness value referred to cultivar having values in the range from 0.07 to 0.127 Ns was qualified by 10 UPM collection accessions; *medium* was from 0.128 to 0.184 Ns which consist of 6 accessions and *Orange* commercial cultivar, whereas *high* was from 0.185 to 0.24 Ns which dominated by the commercial cultivars (*White, Yellow and Purple*) and yellow no. 10123.

On springiness, wide variation was found for 17 accessions and 4 cultivars studied, additionally it occurred also within the flesh colour groups. Orange groups had the highest mean value and followed by white, purple and orange

groups. Wide variation of chewiness value occurred which ranged from 170.00 to 576.86 N. The overall mean of the data was 324.20 N. Based on flesh colour groups, the mean value was 279.33, 328.20, 303.72, and 438.76 N for white, yellow, orange and purple, respectively.

Pasting properties of starch is an essential feature on characteristics of the starch. Variation of gelatinization temperature was from 71.5 to 80.0 °C for 17 accessions and 4 commercial cultivars, in which white flesh group showed higher than three other groups and varied from 75.5 to 79 °C, yellow varied from 75.5 to 79.3 °C, whereas orange and purple groups considered lower having variation from 71.5 to 75.4 °C. *Yellow* commercial cultivar had the highest gelatinization temperature and followed by *White*, *Orange* and *Purple* i.e. 80, 78.8, 75.4 and 72.9 °C, respectively. Peak viscosity of 20 samples studied varied from 380 to 711 BU, except for *Purple* which had >1000 BU. Setback varied greatly, which is common for sweet potato starch, especially for the 17 UPM accessions which ranged from 94 to 273 BU, except for *Orange* and *Purple* that showed high setback value i.e. 304 and 619 BU, respectively.

On the second study, two commercial cultivars were used i.e. *White* and *Yellow*, however the characteristics of both cultivars were determined in the previous work. Results showed that the time of steaming was significantly affected by the physical characteristics of the samples. Steaming for more than 10 minutes would generate “cooked” tissue. *Yellow* cultivar showed more adhesive and more elastic than *White*; moreover, *White* was less chewiness than *Yellow*. It was recommended that the use of *White* cultivar as a raw

material of mashed products would have several advantages, such as easier to mash, less tendency to stick to the cooking tools and low elasticity.

The developed method of making RSS was conducted using *White* cultivar as a raw material. The work was carried out looking into the shape of raw materials, blanching methods, and controlling dry mater of the dough before moulding. Chips showed better shape for blanching compared to cube, because of its smaller thickness, and therefore heat is transferred more efficiently. Blanching in boiling water for 2 minutes appeared not enough to prevent browning, compared with that in 1 % STP solution. Blanching in 1 % STP solution significantly improved the quality such as firmness and dry matter content of dough, colour, fat and ash content, and also texture of the final products. The subsequent step was controlling the dry matter of the dough. Dry matter or moisture content is an important factor in controlling the firmness of dough. Mashed products containing more than 73 % by weight of water tend to puff undesirably during frying. The dough itself is too soft to handle and it tends to disintegrate prior to completion of frying.

Addition of sweet potato flour into mashed sweet potato was aimed at controlling the dry matter content and also as an effort to produce RSS from 100 % sweet potato. The sweet potato flour added to mashed sweet potato affected quality attributes gradually as the variation of sweet potato flour added. The mixing of 5 % sweet potato flour to the mashed SP produced suitable conditions of the dough for further processing. Furthermore the 5% sweet potato flour added generated RSS with the highest value of sensory

preferences. As a result, blanching in 1 % STP for 2 minutes improves the colour attributes and generates low fat and high ash content RSS, and mixing with 5 % sweet potato flour to the mashed sweet potato produces suitable conditions of the dough for further processing and generates high quality sensory attributes RSS. Regarding storage, prefried was found to a better technique before frozen storage, while final product could be prepared by deep fat frying.

The suitable method of preparing RSS explained above was then applied by using three commercial cultivars i.e. *White, Yellow* and *Orange* as raw materials. Textural attributes of 3 commercial cultivars varied significantly. *White* and *Orange* cultivars had hard texture, elastic and not sticky, whereas *Yellow* was soft, less elastic and sticky. This was shown from the values for hardness, springiness and chewiness. These characteristics were affected by starch and amylose content of the tubers. *White* cultivar contained high starch with medium amylose content, *Yellow* had low starch with low amylose content, and *Orange* contained medium starch with high amylose content. The evaluation of RSS found that the characteristics of RSS were significantly varied based on the physical and chemical distinctive characteristics of the raw materials. *White* cultivar generated RSS with the highest value of firmness and shearing force, and *Orange* produced RSS with medium firmness and shearing force, though the shearing force is not significantly different.

As for puncture test, *Yellow* generated RSS having the lowest shearing force. Chewiness is the parameter expressed the force needed to masticate the product

resulted from the calculation of hardness, springiness and cohesiveness. *White* cultivar produced the RSS with higher chewiness value than *Yellow* and *Orange*. These textural characteristics seem to be affected by carbohydrate content of raw materials. *White* cultivar produced RSS having yellow bright colour, high firmness and low fat content, while *Orange* cultivar generated RSS with bright orange colour, medium firmness but high fat content. RSS made from *White* and *Orange* cultivars were preferred with sensory scores above the average values. The explanation above illustrates that *White* and *Orange* sweet potato cultivars are suitable to make a convenient restructured product.

The last study was looking at the characteristics of RSS prepared by deep frying and microwave oven for final product preparation. Shearing force of RSS was significantly affected by the interaction between cultivars and methods of cooking. RSS made from *White* cultivar had a high shearing force particularly after deep frying, but it had lower value when baked in microwave oven. On the contrary, *Yellow* RSS had lower shearing force for the RSS prepared by deep frying than that baked in microwave oven. Similar to *Yellow*, *Orange* RSS had similar pattern, with low shearing force in deep frying but high in microwave oven.

Based on TPA parameters, the hardness of RSS was lower when prepared by deep frying compared to microwave oven. White cultivar however, produced the RSS with the highest value of hardness, and followed by *Yellow* and *Orange*. RSS produced from three commercial cultivars and using two

methods of final preparation resulted in equal springiness with an average springiness value above 90 %. Chewiness is a parameter expressed as a force needed to masticate a product resulted from the calculation of hardness, springiness and cohesiveness. Determination of TPA chewiness proved that there was interaction between cultivars and cooking method, but generally, deep frying generated lower chewiness value of RSS made from the three cultivars compared with using microwave oven. *White* RSS had the highest chewiness followed by *Yellow* and *Orange.*

Other quality attribute was colour. Microwave oven generated higher L value, especially for White RSS, but the opposite occurred for Orange RSS. RSS made from White cultivar had *redder* when prepared using deep frying. This might be due to the browning and dehydration which occurred on the surface of the sticks immediately when the product immersed into oil. On the other hand Orange RSS would be *redder* and less *yellow* in microwave oven than deep frying. Evaluating the acceptability of sensory attributes by untrained panel was expected to be able to figure out the consumer acceptance. Colour is the first attribute catching the attention of the panel. RSS made of Orange was the most preferred by panel, followed by *White* and *Yellow.* This tendency was also observe for texture and overall acceptability. Based on method of preparation, panels preferred RSS prepared using deep frying for all sensory attributes. One may conclude that the most suitable condition of producing RSS was using White and Orange commercial cultivars as raw materials and using deep frying for final preparation.

Based on the findings of this study, the physico-chemical characteristics of 17 accessions from UPM and 4 commercial cultivars of sweet potato was made available and could be used as basic information on the breeding activities or product development. Technology for producing restructured sweet potato sticks (RSS) was developed and able to generate high quality product acceptable to consumers. Beside that, this finding is an attempt to expand the utilization of sweet potato as food product. Therefore sweet potato consumption can be increased when people are convinced of its nutritional goodness, as well as palatability.

8.2 Recommendations

Restructured Sweet potato Sticks could be produced using *White* or *Orange* cultivars. The tubers were peeled, sliced into about 2.3 mm thickness and 2.5 cm width. Blanching was done by dipping the chip for 2 min at 100 °C in 1 % (w/v) STP solution. The blanched materials were drained for about 3 minutes to remove excess water, and then mashed and CMC was added (0.3 %, w/w) as a binder. The mashed was mixed with 5 % of sweet potato flour. Moulding could be done using simple extruder having 3 of 1x1 mm square holes. The sticks were then deep fried at 163 °C for 1 min, packaged in plastic bags and frozen using fast freezing method and the stored at -20 °C until final preparation and evaluation. The frozen RSS was prepared by deep frying in 175 °C for 2 minutes.

Finally, restructured sweet potato sticks could be developed using sweet potato tubers having the chemical and physical characteristics of tubers, and also pasting properties on the starch were as follows: (1) chemical characteristics: moisture content was 71 – 74 %, starch content was 14.4 – 19.3 %, amylose content was 25.5 – 27.2 % (db), reducing sugar was < 1.1 % (db), sucrose was 1.7 – 2.9 % (db); (2) physical characteristics: hardness was 5.9 – 6.7 N, adhesiveness was 0.17 – 0.24 Ns, springiness 86.6 – 92.6 % and chewiness 253 – 273 N; (3) pasting properties: peak viscosity was 527 – 598 BU and setback was 178 – 304 BU.

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APPENDICES

Appendix 1 Cultivation field of sweet potato collection, UPM, Serdang, Selangor, Malaysia

Appendix 2 Sweet potato seller in Pasar Borong, Selangor, Malaysia

Appendix 3 Sensory evaluation sheet

SENSORY EVALUATION SHEET

Product: Restructured Sweetpotato Sticks

Name: Date:

You are presented with 20 samples. Please evaluate every sample based on their Colour, Texture and Overall acceptability.

9 = like extremely

8 = like moderately

7 = like

6 = like slightly

5 = neither like nor dislike

4 = dislike slightly

3 = dislike

2 = dislike moderately

1 = dislike extremely

Attribute	385	548	429	297	307
Colour					
Texture					
Overall					

Attribute	635	219	374	531	715
Colour					
Texture					
Overall					

Continued

Attribute	475	349	297	792	371
Colour					
Texture					
Overall					

Attribute	423	478	902	593	285
Colour					
Texture					
Overall					

Comment: ……
……

Thank You

Appendix 4 Sensory evaluation sheet

SENSORY EVALUATION SHEET

Product: Restructured Sweetpotato Sticks

Name: Date:

You are presented with 6 samples. Please evaluate every sample based on their Colour, Texture, Flavor and Overall acceptability.

7 = like extremely
6 = like moderately
5 = like slightly
4 = neither like nor dislike
3 = dislike slightly
2 = dislike moderately
1 = dislike extremely

Sample	Colour	Texture	Flavor	Overall acceptability
385	……	……	……	……
548	……	……	……	……
429	……	……	……	……
597	……	……	……	……
307	……	……	……	……
396	……	……	……	……

Comment: ……
……

Thank You

BIODATA OF THE STUDENT

Joko Susilo Utomo was born on July 23, 1961 in Banyuwangi, East Java, Indonesia. He studied in the Department of Agriculture Food Processing, Faculty of Agriculture Technology at University Gadjah Mada, Yogyakarta, Indonesia and graduated with Ir (Insinyur) degree in food technology from the university in 1986.

He started working for Indonesia Legume and Tuber Crops Research Institute (ILETRI) at Malang, Indonesia, in 1986, as a researcher in Post Harvest Section. In 1991, he was recommended by the Agency of Agriculture Research and Development (AARD), Ministry of Agriculture, Republik Indonesia to continue his study, and obtained his Master Science in 1994 from School of Graduate Studies at University Gadjah Mada.

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