Assessment of underutilized starchy roots and tubers for their applications in the food industry

A thesis submitted in fulfillment of the requirements of the degree of Master of Science

By

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March 2010

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I. Abstract

Physicochemical properties of flours and starches isolated from tubers and roots commercially available in Australia and traditionally produced in Indonesia were investigated in this study. The results showed that these flours and starches may be utilized in certain food applications. Raw starchy materials from Australia included taro, yam, and sweet potato. Due to its narrow particle size distribution (1-64 μm), taro flour would be better suited in applications which require improved binding and reduced breakability. The paste of sweet potato flour and starch had higher clarity (>30% light transmittance) compared to those of yam and taro (<10% light transmittance in both cases). All flours and starches showed variable pasting behavior. In general, all starch samples had higher viscosity than that of flour samples. Taro flour had the highest viscosity among other flour samples. Yam flour and starch were more stable against heat and mechanical treatments. An apparent shear thinning behavior was observed from the extracted mucilage. Concentration dependant flow behavior of all mucilage samples was successfully fitted by the (Ostwald) Power Law, Hershel Buckley, and Casson models.

Meanwhile, flours and starches isolated from tubers and roots grown in Indonesia also had properties suitable for certain food applications. Compared to other flour samples, cassava and canna flours contained the highest amount of total starch (TS) (77.42 and 77.13%, respectively). Taro starch had the lowest amount of TS among other starch samples with 75.44%. The highest amount of amylose was observed from yam and canna flours (25.24 and 23.19%, respectively). Among starch samples, canna starch contained the highest amylose content (30.38%), while taro had the lowest (7.64%). In terms of protein content, arrowroot flour had the highest amount (7.70%), in contrast to cassava flour which had the lowest (1.51%). Compared to other flours, canna and konjac flour were the most slowly digested which indicated by their high amount of resistant starch (RS). Canna starch had the highest swelling power and viscosity than other starches and flours. The clearest paste was observed from cassava flour and starch as opposed to konjac starch which was the most opaque paste.

Subsequently, physicochemical properties of composite flours made of wheat flours at different protein contents (low and high protein contents) and canna or konjac flours at different level substitution (0, 25, 50, 75, and 100%) were prepared and analyzed. Compared to that of wheat flour alone, the increasing level of canna flour from 0-100% significantly increased the amount of RS but decreased protein content of wheat-canna composite flours. This substitution did not alter the TS, amylose, and amylopectin contents of these mixtures. Changes of physicochemical properties were also observed in wheat-konjac composite flours. The increasing amount of konjac flour decreased the TS, amylose, amylopectin, and protein content of the mixtures. Substitution of wheat flour with 75% of canna or konjac flours in HPWC (High Protein Wheat-Canna), HPWK (High Protein Wheat-Konjac), and LPWK (Low Protein Wheat-Konjac) increased the swelling power of these mixtures at 80 and 90°C. In general, substitution of wheat flour with up to 50% of canna or konjac flours significantly decreased viscosity of composite flours. Further increase of canna or konjac flours did not cause any other observable decline. In addition, the substitution of wheat flour with canna or konjac flours increased the gelatinization temperature of all composite flours.

II. DECLARATION

"I, Aprianita, declare that the Master by Research thesis entitled "Physicochemical Properties of Some Starchy Materials from Indonesia" is no more than 60,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Si nature [redacted]

Date: 10th February, 2010

III. Acknowledgements

I wish to express sincere appreciation to my supervisor, Dr. Todor Vasiljevic, for his guidance, support, and tremendous help throughout my study. I am also grateful to Ms. Bronwyn Watson for her insightful and helpful comments with this thesis.

I would also like to thank the AusAid for providing me scholarship and to the University of Jambi, Indonesia, for giving me the opportunity to continue my study. The experience has left me with many valuable memories. The help from colleagues from Trunojoyo University, Indonesia, in providing samples from Indonesia and the Allied Mills Co. Ltd., Ballarat, Australia, in providing the wheat samples used in this study are also acknowledged.

My specials thanks to Umi Purwandari for recommending this research topic and for making various issues clear to me. Dr. Marlene Cran and Dr. Pieter Santialo are acknowledged for their valuable help with the DSC and particle analysis, respectively.

I thank the laboratory manager at Victoria University, Werribee, Australia, Mr. Dale Tomlinson and all the laboratory technicians for providing me with ongoing assistance. I am also grateful to my colleagues, Mrs Thuy Pham, Mrs. Muditha Dissanayake, Ms. Danusha Kalinga, and Ms. Lata Ramachandran, who have been more than friends throughout my studies at Victoria University.

I would especially like to thank my parents, Drs. Maddun Abbas, Dra. Ratna Dewi, and Hanum in appreciation of their love and encouragements. Nothing can reply their life time support. I am grateful to my brother and sisters, Sri Rama Diana, Adriansyah, and Shintawati, for rendering me the sense and value of brotherhood. My parents in law, Gusti Sutan and Maymuri also deserve special mention.

Lastly, and most importantly, I would like to express my deepest gratitude to my beloved husband, Asroni, for giving me such unconditional love, understanding, and for having the ability to make me laugh in any situation. For my beloved and precious sons, Fasa and Faiz, you are my source of strength and inspirations. For you I dedicated this thesis.

IV. List of Publications

Aprianita Aprianita, Umi Purwandari, Bronwyn Watson and Todor Vasiljevic. (2009). Physicochemical properties of flours and starches from selected commercial tubers available in Australia. International Food Research Journal. 16: 507 – 520.

Aprianita Aprianita, Bronwyn Watson and Todor Vasiljevic. (2008). Physicochemical properties of flours and starches derived from traditional Indonesian tubers and roots. (In preparation).

Aprianita Aprianita, Bronwyn Watson and Todor Vasiljevic. (2008). Physicochemical properties of wheat-canna and wheat-konjac composite flours. (In preparation).

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Abbreviations key:

AMG	Amyloglucosidase
cP	centi Poise
DMSO	Dimethyl sulfoxide
DSC	Differential Scanning Calorimetry
GOPOD	Glucose Determination Reagent
HPWC	High Protein Wheat Canna
HPWK	High Protein Wheat Konjac
LPWC	Low Protein Wheat Canna
LPWK	Low Protein Wheat Konjac
TS	Total Starch
RS	Resistant Starch
NRS	Non Resistant Starch

CHAPTER 1

Introduction to Thesis

1.1 Background

Rice has long served as the staple food for people in Indonesia. Attempts to substitute rice with flour-based foods have increased the import volume of wheat. Therefore, the dependency on rice and wheat as the major sources of carbohydrates has weakened food stability in Indonesia. Socially, high dependency on rice has eliminated traditional dietary patterns especially among people in rural areas. Since ancient times, a local wisdom in these areas has led people to consume non-rice foods. This pattern of consumption was influenced by culture and natural resources in these areas. However, recently, this habituation has faded with the increase in perception that food was synonymous to rice (Nasution, 2003).

To achieve food stability, there is a need to reduce dependency on rice as the main source of carbohydrates through food diversification using local sources. As one of centers of mega biodiversity, Indonesia harbors about 77 plant species such as cassava, sweet potato, breadfruit, arrowroot, canna and sago which can be used as the sources of carbohydrates (Deshaliman, 2003). These plants have potential to substitute rice as a staple food due to their carbohydrate content similar to that of rice and their ability to grow in marginal areas where paddy plants can not grow well. During dry season when rice production is limited, people in rural areas take advantage of tubers, roots, or fruits of these plants as the food sources. Moreover, compared to paddy, these plants do not require extensive maintenance and can be grown in most areas in Indonesia (Deshaliman, 2003).

However, the potential of these plants has not been utilized optimally due to the lack of knowledge of processing techniques and product development. In addition, the long-accustomed habit among local population to use rice in every meal also hindered the potential of these plants as alternative source of energy. In attempt to increase peoples' preference towards these underutilized food sources, there is a need to transform these commodities into value added products such as flours or starches (Deshaliman, 2003; Nasution, 2003). In these forms, they can be fortified with other nutrients, thus improve low content of proteins or vitamins in certain tubers and roots. Transformation into starch also increases the storage efficiency as well as the self-storage. Moreover, in the form of starch, the application of these materials can be broadened either in food or non-food industries. In food industry, starch is used for thickening, filling, binding, or taste. Sometimes, starch is converted into sweeteners. On the other hand in non-food applications, starch is used in textile, paper, plywood, adhesive, pharmaceutical, and fuel industries (Moorthy, 2002).

Results obtained from this study will enhance our understanding and knowledge about physicochemical and functional properties of some starchy materials from Indonesia as well as their ability to replace wheat flour in food industry. Thus the application of these roots and tubers in food industry can be broadened which in turn may reduce the dependency on rice and wheat as the main staple food in Indonesia. Besides strengthening food stability, utilization of these commodities may also support the sustainable agricultural development in Indonesia since these plants can be grown as intercropping crops with other plants. In addition, due to the perishability, bulkiness and the high transportation of these materials, processing of roots and tubers tend to be done near the centres of crop production. Therefore, the growth of flour and starch industries from these commodities may improve economic development in rural areas where these commodities are mainly produced.

1.2 Research Objectives

The major objective of this study was to determine the physicochemical and functional properties of flours and starches derived from some starchy tubers and roots. More specific objectives were:

(1) To determine the physicochemical and functional properties of flours, starches, and mucilage of selected tubers and roots commercially available in Australia.
(2) To determine the physicochemical and functional properties of flours and starches of underutilized tubers and roots traditionally grown in Indonesia.

(3) To examine the functional properties of wheat-canna and wheat-konjac composite flours.

1.3 Outline of Thesis

The background and objectives of this thesis are stated in Chapter 1. Chapter 2 presents a review of the literature concerning the physicochemical properties of flour and starch, underutilized starchy materials from Indonesia, and the applications of flour and starch in food industry. The physicochemical and functional properties of flours, starches, and mucilage of selected commercial tubers and roots available in Australia are represented in Chapter 3. Chapter 4 deals with the physicochemical and functional properties of flours and starches of underutilized tubers and roots traditionally grown in Indonesia. Chapter 5 deals with the physicochemical and functional properties of wheat-canna and wheat-konjac composite flours. Chapter 6 presents a summary of the research findings of this study. A list of references used is presented in Chapter 7.

CHAPTER 2

Literature Review

Flour and starch derived from cereals (wheat, rice, corn, and barley) as well as tubers and roots (potato, cassava, sweet potato, etc) play important role in human diet as the main source of carbohydrates. The application of flour and starch in food industry is determined by their physicochemical properties. Therefore, knowledge about their properties is important. The properties of flour are governed by the properties of its respective starch as the main component in flour.

2.1 Properties of flours and starches

2.1.1 Chemical properties

2.1.1.1 Amylose

In general, amylose and amylopectin are the major starch fractions. Amylose comprises for 23-31% of starch dry weight, while amylopectin comprises for 69-73%. In amylose, long chains of glucose units are joined together by α-1,4 linkages (Fig. 2.1). Amylose can be depicted as either a straight chain or a helix. The interior or the helix contains hydrogen atoms that allow amylose to form complex with free fatty acids, alcohols, lipids, or iodine.

The proportion of amylose in starch could be determined using several methods, including blue value, potentiometric, and amperometric titration. These methods are based on the formation of amylose-iodine complex that give a blue color characterized by a maximum absorption wavelength above 620 nm. This iodine reaction is the most commonly used in determining amylose content due to its specificity, sensitivity, and ease. Amylose content estimated using methods based on iodine complex formation is considered as apparent amylose content (Cui, 2005). On the other hand, potentiometric method gives an estimate of amylose content that is considered as absolute amylose content if the sample is defatted before titration. Iodometric method could also be used to measure the content of medium to long chain of α-(1→4)-glucan. Measurement of amylose content could be influenced by certain factors such as starch source, sample preparation, molecular structure of starch, long linier chain of amylopectin, and monoacyl lipids that present in starch (Cui, 2005). To prevent lipid interference, starch samples are defatted prior to measurement by extraction using solvents such as hot-*n*-propanol-water (Hoover and Ratnayake, 2005).

Size exclusion chromatography and differential scanning calorimetry (DSC) could also be used to measure the amount of amylose content in starch. In size exclusion chromatography, amylose content is determined based on elution time and peak area for different molecular size of amylose (Colonna and Mercier, 1984). The enthalpy value of amylose-lipid complex is used to calculate amylose content using DSC (Kugimiya and Donovan, 1981).

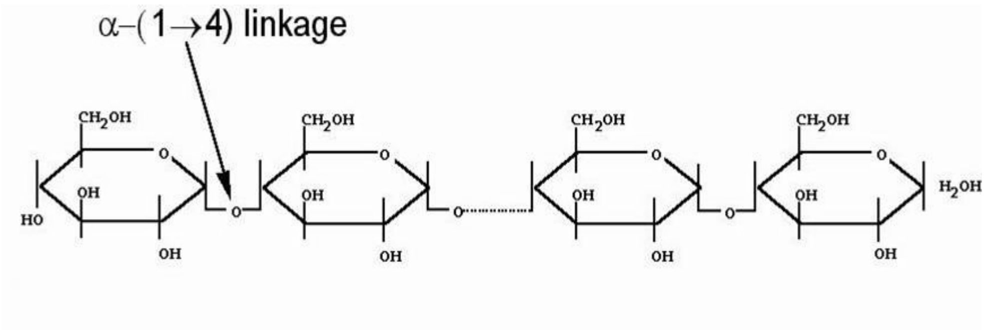


Figure 2.1 The structure of amylose molecule

2.1.1.2 Amylopectin

Amylopectin is a highly branched polysaccharide, which consists of α-D-glucopyranose residues linked mainly by several (1→4)-linkages and many non-random (1→6)-linkages to give a highly branched structure (Figure 2.2) (Thomas and Atwell, 1977; Galliard and Bowler, 1987). According to their chain length and branching points, amylopectin can be categorized into three types, namely A, B, and C chains. The A chains are the shortest and carry no branch chains. The B chains are branched by A chains or other B chains (B1, B2, B3) while the C chain carries B chains and contains the sole reducing terminal residue. Another feature of amylopectin is the presence of phosphate monoester that is covalently linked to the C3 or C6 position of the glucose monomers. The presence of phosphate monoester in high amount is usually observed from starches derived from tubers such as potato and canna (Hizukuri *et al*., 1970).

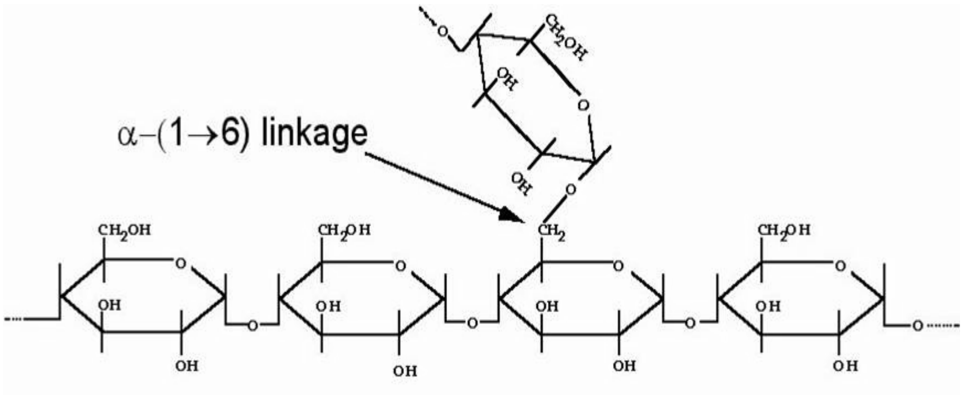


Figure 2.2 The structure of amylopectin molecule

Several methods have been used to analyze the structure of amylopectin. These methods include methylation, periodate oxidation, and partial acid hydrolysis. The linkage types and frequency of branching of amylopectin could be analyzed using methylation and periodate oxidation studies. Characterization of polysaccharides could be done using partial hydroxide with acids or enzyme. Information obtained from these studies proved that the α-D-glucopyranose residues are connected mainly by (1→4)-linkage with 4-5% by (1→6)-linkage (Guilbot and Mercier, 1985; Morrison and Karkalas, 1990). Size exclusion chromatography or ion-exchange chromatography of enzymically debranched amylopectin could be used to analyze the profile of amylopectin chain. Meanwhile, the branching enzymes such as isoamylase and pullulanase can be used to determine the ratio of A: B chain in amylopectin (Hizukuri, 1986).

2.1.2. Minor components

Proteins, phosphate, lipids, moisture, and ash are present in small amounts within the starch granules. Based on their location, these components can be classified into three groups, namely particulate material, surface components, and internal components. Particulate materials are fragments of non-starch materials. These components may interfere during starch separation process and cause impurity in the final starch or in products prepared thereafter. The amount of particulate material in these products is dependant on the source, separation process, and the extent of starch purification (Galliard and Bowler, 1987). Surface components are materials that are associated with the surface of granules and may be removed by extraction procedure without disrupting the granule internal structure (Galliard and Bowler, 1987). Surface starch granule proteins are loosely associated with the surface of granules and can be extracted using salt solution. The main components of surface lipids are triglycerides, free fatty acids, glycolipids, and phospholipids. These surface lipids can be separated using cold solution of water-saturated butanol. Internal components are materials that buried within the starch granules and required more rigorous extraction. The amount of these components varies among different sources of starch. In addition, even though they are present in small amount, these components play important roles in physicochemical properties of starch.

2.1.2.1 Phosphate

In various starches, phosphorus is present as phosphate monoesters (esterified phosphorus), phospholipids, or inorganic phosphate (Taggart, 2004). Compared to cereal starches, root and tuber starches contain higher amount of phosphorus. In root and tuber starches phosphorus present as phosphate monoester in which a major part is linked to C-6 and C-3 hydroxyl groups of the glucose units of amylopectin (Hizukuri *et al*., 1970). Phosphate monoesters could contribute to the high viscosity, high transparency, water binding capacity, and freeze thaw stability of the starches. Repulsion between phosphate groups on adjacent amylopectin chains may increase the hydration by weakening the extent of bonding between the crystalline domains (Galliard and Bowler, 1987). In addition, phosphate monoester on long B-chains of amylopectin may decrease the gelatinisation temperature by decreasing the interaction between double helices (Jane *et al*., 1997). In contrary, cereal starches contain only small amount of phosphorus, which is present as phospholipids. These phospholipids tend to form complex with amylose and long branched chain of amylopectin which result in limited swelling and lower transmittance of cereal flour paste (Taggart, 2004).

2.3.2.2 Lipids

Compared to tuber and legume starches, cereal starches contain higher levels of lipids associated with amylose. Since these lipids occupy the same site within amylose helices, their presence may interfere with the determination of amylose content, measured using iodine-binding method. Therefore, removal of lipid is necessary before measurement of amylose content using this method as discussed previously (Galliard and Bowler, 1987).

The effects of surface lipids on starch properties have been explained by Swinkells (1985). According to this author, surface lipids affect the diffusion of water into starch granules. As a consequence, it may alter starch properties by reducing water binding capacity, swelling and solubilization of starches. In addition, surface lipids may also create undesirable flavors by oxidation of unsaturated lipid. This lipid layer may also prevent amylose from contributing to the thickening power of gelatinized starch by forming complex with amylose in starch paste. Moreover, surface lipid may create an opaque or cloudy starch paste and film due to the presence of insoluble starch-lipid complexes (Swinkells, 1985; Craig *et al*., 1989). The formation of starch-lipid or starch-surfactant complex could improve the textural properties of some foods (Moorthy, 2002).

2.1.2.3 Proteins

Protein content within starches varies depending on the botanical sources. In general, cereal starches have higher protein content than tuber and root starches. The presence of protein can cause unwanted colour in starch and starch hydrolysis products via reaction between aminoacid groups and reducing sugars (Mailard reaction). Moreover, proteins may also affect surface charge and the rate of hydration (Cui, 2005).

2.1.2.4 Mucilage

Besides main components that have been discussed above, tubers and roots also contain viscous polysaccharide polymers called mucilage. This substance is mainly composed of water-soluble glycoproteins containing a number of different sugars such as L-arabinose, D-galactose, L-rhamnose, and D-xylose. The presence of glucuronic acid as one of mucilage constituents was detected by paper chromatographic analysis (Medina-Torres *et al*., 2000; Alves *et al*., 2002). Due to the presence of high amount of hydroxyl groups, mucilage has a great water binding capacity. Consequently the mucilage could affect gelatinization and pasting properties of their starch. A delay starch gelatinisation could be due to the interaction between mucilage and its respective starch. This interaction could also lower viscosity and reduce pasting. This effect is dependant upon the type of starch and mucilage concentration (Jiang and Ramsden, 1999).

Mucilage has potential to be used in food industry as thickener, stabilizer, and emulsifier due to its functional properties including high viscosity, high water binding capacity, and gelation ability (Cui, 2005). The incorporation of cassava mucilage into wheat flour-cassava starch composite for noodle production could improve color development of this composite flour. In addition, it was proposed that the addition of cassava mucilage into this composite could create a softer gel structure by reducing the intramolecular interaction among amylopectin and amylose molecules (Charles *et al*., 2007). The ability of mucilage to stabilize the oil in water emulsions of starch by imparting viscosity to the dispersion medium has been reported (Uhumwangho *et al*., 2005).

Mucilage also offers benefits as functional foods due to its role in prevention of certain diseases. Mucilage extracted from yam tubers, which are mainly composed of mannan-protein macromolecules, showed angiotensin converting enzyme (ACE) inhibitory activity

(Lee *et al*., 2003), and antioxidative activity (Lin *et al*., 2005; Nagai *et al*., 2006). Mucilage extracted from the roots of sweet potato also possessed ACE inhibitory activity and antioxidant activity against hydroxyl and peroxyl radicals (Huang *et al*., 2006b). Angiotensin converting enzyme (ACE) is an exopeptidase that can trigger hypertension by hydrolysing an inactive decapeptide, angiotensin I, into a potent vasoconstrictor, angiotensin II or by degrading the bradykinin, a vasodilating peptide (Mullally *et al*., 1996). Therefore, substances that inhibit ACE activity are widely used as therapeutic agent in the treatment of hypertension (Nagai *et al*., 2006).

2.2 Starch morphology

Starch is present in the form of granule, which may differ in size, shape, or the position of hilum (the original growing point of hilum) (Pomeranz, 1985; Blanshard, 1987; Hoover, 2001). Generally, root and tuber starches have a voluminous and oval shaped granule with an eccentric hilum (Pomeranz, 1985; Hoover, 2001). Granules of cereal starches may have polygonal or round shape, while legume seed starch granules have a central elongated or starred hilum (Blanshard, 1987). Usually, the size of starch granules is expressed as a range or as an average length of the longest axis. The range of granule size is 2-100 µm (Cui, 2005). Table 2.1 shows characteristics of selected starch granules. In general, granules of root starches are bigger than that of cereal starches (Swinkles, 1985).

Table 2.1 Characteristics of some starch granules (adapted from Swinkles, 1985)

Starch	Type	Size (µm)	Shape
Wheat	Cereal	2-35	Round, lenticular
Rice	Cereal	3-8	Polygonal, angular
Corn	Cereal	2-30	Round, polygonal
Cassava	Root	4-35	Oval, truncated
Canna	Root	5-44	Oval, polyhedral
Sweet potato	Root	5-25	Polygonal
Arrowroot	Root	5-70	Oval, truncated

The morphology of starch granules has been studied using specific techniques such as transmission electron microscopy (TEM), scanning electron microscopy (SEM), and atomic force microscopy (AFM). A study using SEM has revealed the presence of pores on the granule surface of some cereal starches, for example corn, sorghum, millet, rice, wheat, barley and rye. However, this kind of pores was not found in other starch granules (Fannon *et al*., 1992). More recent studies using fluorescence microscopy in corn and sorghum starches have revealed the presence of an internal cavity at the hillum. This channel connects the central cavities to the external environment (Huber and BeMiller, 1997).

2.3 Starch crystallinity

X-ray diffraction pattern reflects the different packaging of amylopectin side chains. This method has been used to study the crystallinity of starch granules (Imberty *et al*., 1991). There are three types of starch crystallinity, namely type A, B, and C. In the A type structure, the double helices are closely packaged in a monoclinic unit cell with eight water molecules per unit cell. In B type structure, the double helices are more openly packed in a hexagonal unit cell with 36 water molecules per unit cells. This difference in packaging pattern has caused a higher crystallinity of starches having A type crystallinity compared to that of starches with B-type. The A-type is characteristic of starches derived from cereals, while root starches, amylomaize starches, and retrograded starch belong to the B-type. The C type crystallites are a combination of A and B types in which the A type is more concentrated in the outer part of granule while the B type is enhanced in the inner part of granules. Smooth pea starch and various bean starches are included in this type (Wu *et al*., 1978a, b; Imberty *et al*., 1991; Bogracheva *et al*., 1998).

Certain factors may influence formation of the A or B type crystallites. These factors include the average chain length of amylopectin and moisture content in the granules (Imberty *et al*., 1991). The A type starch crystallites are formed from shorter chains of amylopectin while the B type crystallites are formed from longer chains. The amount and distribution of water within starch granules are important in the formation of starch crystallites. Water present within starch granules is considered as bound water or structural water (Paris *et al*., 1997). The increasing amount of water in starch granules may change the proportion of A and B–type crystallites by increasing the mobility of the chains in the amorphous regions. In addition, the increasing water content may also increase the formation of double helices within the granules of amylose and amylopectin (Paris *et al*., 1997).

The differences in packaging of amylopectin side chains have caused different degrees of crystallinity. In general, the A-type starches have higher degree of crystallinity compared to the B-type starches (Srichuwong *et al*., 2005a). This difference could bring some implications in functionality of starches. The higher degree of crystallinity imparts the higher structural stability that subsequently may cause a higher gelatinisation temperature since the water molecules need longer time to penetrate the crystalline areas (Moorthy, 2002; Srichuwong *et al*., 2005a).

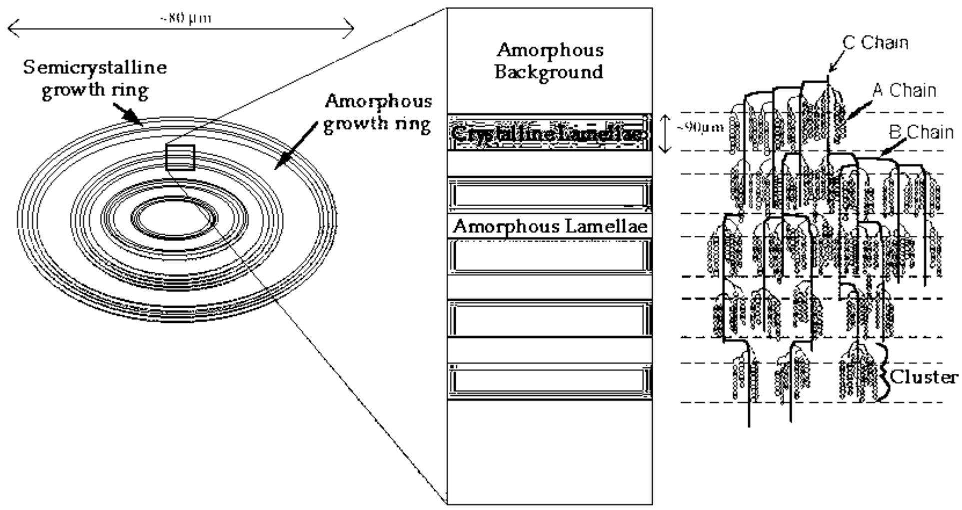


Figure 2.3. The structure of starch granule with alternating amorphous (A); The structure of amylopectin branch chains (B) (source: http://www.cheng.cam.ac.uk).

2.4 Functional properties of flours and starches

Gelatinisation, pasting, retrogradation, and syneresis are the most important functional properties of starch. The study of these properties might help our understanding of the relationship between the structural and functional properties of starch. In addition, it might also help to determine further application of starch and its relative flours.

2.4.1 Gelatinisation

Gelatinisation is the process of disruption of semicrystalline structure of starch, when a starch suspension is subjected to heating in the presence of large amount of water. During this process, heat disrupts hydrogen bonds between polymer chains weakening the granules. Then, the amorphous region, which contains less hydrogen bonds and is more susceptible to dissolution starts to imbibe water and increase in size (swelling). Amylose begins to solubilise and leaches out from the granule into the aqueous solution causing the increase of viscosity (Thomas and Atwell, 1997). Range of temperature when starch begins to undergo this change is called gelatinization temperature range.

The mechanism of gelatinisation has been studied using several analytical techniques. Microscopic examination of granules that undergo gelatinisation could reveal the integrity and size of swollen granule as well as the degree and duration of swelling (Cooke and Gidley, 1992). The X-ray diffraction technique could be used to study the changes in crystallinity and to characterize the change in crystal structure during gelatinisation (Nara et al., 1978). The FTIR technique could detect the absorption of different bond vibrations in starch molecules during gelatinisation (Goodfellow and Wilson, 1990). The loss of structural order within granules during gelatinisation could be studied using NMR technique (Cooke and Gidley, 1992). In addition, the calorimetry technique, for example differential scanning calorimetry (DSC) can be used to detect the changes of heat flow associated with both first-order and second-order transitions of starch polymers. As a result, enthalpy for the phase transition and melting temperature of starch crystallites can be determined. This technique has been widely used to investigate gelatinisation properties of root, legume, and cereal starches (Donovan, 1979).

Gelatinization characteristics are influenced by some factors, such as temperature, moisture content of starch-water mixture, starch crystallinity, the botanical source of starch, and the environmental conditions such as pressure, mechanical damage, physical modification (e.g annealing and heat-moisture treatment), and chemical modification (e.g substitution). In addition, gelatinisation temperature may increase with the presence of solvents such as sugar or salt, which may hamper the ingress of solvents into the granule (Tester *et al*., 1999).

2.4.2 Pasting

Pasting is the state that follows gelatinisation of starch. During this process, if heating continues, more granules become swollen accompanied by the increase in leaching of amylose and amylopectin from granule as well as the increase of viscosity. When most of granules have undergone this process, the starch is considered to be pasting and peak viscosity is reached (Thomas and Atwell, 1997). Thus, a starch paste is defined as a two-phase system composed of a disperse phase swollen granules and a continuous phase of leached amylose. During cooling, aggregation of amylose phase with linear segments of amylopectin will result in a strong gel (Ring, 1985). The ability of starch to form paste is useful for starch as ingredient to improve food texture. Rheological properties of starch play important roles in food and industrial processing application. Heating and shearing treatment that usually applied during processing might cause rheological changes of the paste and subsequently might affect the final product (Katayama, 2002).

There are several techniques that have been applied to study the rheological behaviour of starch paste during heating process. Dynamic rheology assesses the dynamic moduli during temperature and frequency sweep testing of the starch suspension. The storage modulus (G') represents the energy stored in the material while the loss modulus (G") indicates the energy dissipated or lost per cycle of sinusoidal deformation. Tan delta (δ), which indicates the degree of elasticity, is the ratio of G" to G' for each cycle. These parameters (G", G', and tan δ) are used to evaluate rheological properties of starch samples and its products (Eerlingen *et al*., 1995).

Pasting viscosity can be recorded using Brabander Viscoamylograph, Rapid Visco Analyzer (RVA) or others viscometers which record continuously the viscosity of pastes as a function of heating, holding and cooling temperatures (Figure 2.4). When starch granule is heated up to gelatinisation temperature in excess of water, the granule swells and viscosity increases rapidly with the rise of temperature. Temperature at the onset of this rise in viscosity is called pasting temperature (PT). As temperature increases, more starch granules gelatinise. With the increasing temperature, the starch granules begin to breakdown and at peak viscosity this breakdown gets the better. With the continuous stirring and increase in temperature, the granules rupture causing an increase in the release of amylose and amylopectin. This process caused a decrease in viscosity of the paste (Zaidul *et al*., 2007; Leon *et al*., 2008).

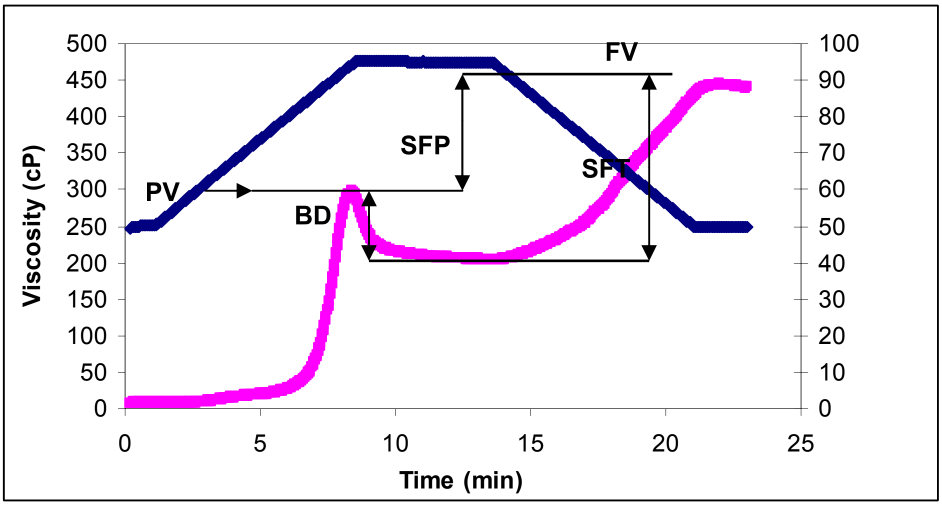


Figure 2.4 Pasting properties profile

(PV: Peak Viscosity; BD= Breakdown; SFP= Setback from peak; SFT= Setback from through; FV= Final viscosity)

2.4.3 Retrogradation

When the gelatinized starch cooled, starch molecules especially amylose with its linier stucture will re-associate thighly at various degrees which will lead to formation of a firm gel. This phenomenon is termed retrogradation (Zaidul *et al*., 2007; Leon *et al*., 2008). Retrogradation occurs in two stages. The first stage is the formation of crystalline regions from retrograded amylose. The second stage involves the formation of an ordered structure within amylopectin. At first, the formed gel is elastic and cuttable. However, with time, this gel tends to transient into rubbery structure and release water (syneresis) (Leon *et al*., 2006; Zaidul *et al*., 2007). The ability of starch to aggregate and crystallize is important since it determines the texture of starch-based food products. Retrogradation and syneresis are undesirable traits especially in refrigerated or frozen foods (Thomas and Atwell, 1997). Moreover, retrogradation also increases stiffness of food products during storage (Taggart *et al*., 2004).

2.5 The applications of flours and starches in food industry

Flours and starches have a wide application in the food and related industries. Flour is the main component for several food products such as noodles, pasta, breads, biscuits, cake, and pastry. Each of these food products has specific requirements in regard to flour quality, which is yet again influenced by the properties of the final product, food processing methods, and consumer preferences (Radley, 1976). Furthermore, starch plays an important role in food systems by stabilizing it and creating the structure of food. It also interacts with other components to deliver or maintain nutrient and flavor (Cui, 2005). The importance of starch in some food applications is elaborated further below.

2.5.1 Snack foods

In snack foods, starch is frequently used to assist in achieving desired textural and sensory attributes by improving crispiness, oil binding properties, expansions, and overall eating quality (Cui, 2005). Properties of amylose and amylopectin as the main components of starch are important for the texture creating of this kind of foods. The highly branched amylopectin could increase dough viscosity and expansion, which in turn could produce light, crispy, and expanded products. Amylose might strengthen the dough, which improves forming, and cutting properties. As a consequence, a more crunchy final texture could be obtained (Taggart, 2004). In addition, a high quality fibre-fortified snack could be developed by incorporating resistant starch (Radley, 1976; Taggart, 2004).

2.5.2 Baked products

Starch exerts its contribution in baked products through its important properties, i.e.: gelatinization, water absorption, and retrogradation (Taggart, 2004; Cui, 2005). Starch gelatinization is very important in building the structure and texture of baked products. Ability of starch to bind water could reduce the stickiness of dough, improve handling, and increase cake volume. This property could also increase moistness and softening the texture of baked products (Radley, 1976; Taggart, 2004).

Bread staling is refers to the undesirable changes that occur between the time bread is baked and consumed. This process is accompanied by crumb firming, moisture changes, crust softening, and flavour changes. There are some factors that may contribute to the staling process. These include retrogradation, moisture exclusion, brittle crumb, and low temperature (Radley, 1976). Due their differences in chemicals and physical properties, amylose and amylopectin have different behaviour during baking which subsequently cause crumb firming in a different way. During baking, amylose readily diffuses out of starch granules when they hydrate and swell (gelatinize). As the bread cools, amylose recrystallizes or retrogrades rapidly and provides the loaf initial shape and strength.

Amylopectin does not readily diffuse out of the starch granule when they gelatinized. Amylopectin retrogrades slowly upon cooling and link together during storage which causes the crumb increasingly firmer with time. Moisture changes contribute to staling through evaporation and water redistribution. Crust softening in wrapped bread is caused by an increasing of moisture from about 12 to 28%. Flavour losses and changes are occurring as some flavour components diminish faster than others (Taggart, 2004).

Ingredients, processing, and packaging are some factors that could retard the staling process. Fat could slow staling by improving loaf volume, while sweeteners slow staling by retaining moisture. Emulsifiers could reduce the tendency of amylose retrogradation. Amylopectin retrogradation could be reduced by enzymes. Proteins within the flour could hold other ingredients to provide structure to the final baked products (Radley, 1976). Flour with a low retrogradation tendency could produce bread products with enhanced storage stability through extension of the freshness (Taggart, 2004).

2.5.3 Confectionery

Starch acts as a structure builder in coatings and as the moulding medium to support the shaping of confections. In confectionaries, starch is used in the manufacture of pastes, gums, in the making of moulds, or for dusting sweets to prevent them from sticking together. Mainly, starch is selected based on its ease of cooking in high-sugar environments as well as their ease of handling during processing (Taggart, 2004). In many cases, starch is modified to produce starch with certain properties which suitable for certain applications. Acid-thinned starch is starch that has been subject to treatment in acid slurry. This starch has a faster gelatinisation, low viscosity, and could produce a weak gel. Oxidized starch, starch which has undergone oxidation, also has a low hot paste viscosity. Both of these modified starches are suitable for confections since they allow rapid and efficient cooking of starch solution in the presence of concentrated sugar syrups. Stabilized starch is a modified starch which resistant to acid degradation under dry acidic storage. This was accomplished by adding buffer (pH 6-9) to a starch slurry and drying the starch-buffer slurry. This kind of starch has a reduced starch gelatinisation temperature. Thus, is easier to cook and allows for the formation of stronger gel with increased clarity and longer self-life. Converted starch, for example dextrin, which has a good film forming capacity, could be used with high-sugar solutions to produce stable and flexible coatings (Taggart, 2004). Thin boiling starch is a modified starch which has been treated with amylase enzyme to hydrolize the ∞-1,4 glycosidic bonds. This starch has good gelling properties and low hot paste viscosity is suitable for gum drops since this type of starch allows better evaporation and pouring (Radley, 1976).

2.5.4 Gravies, soups, and sauces

Application of starches in these food products depends on the production process, which is usually influenced by pH of products and heat during processing (Taggart, 2004). Compared to neutral products, a higher-degree of cross-linking starch is required for high acid products ($pH<4.5$). The cross-linked starch is produced by reaction in which a small number of hydroxyl groups on the glucose units of amylose and amylopectin, mostly in the amorphous regions and on the surface of the granule, are modified without destroying the granular nature of starch (Radley, 1976). Meanwhile, to obtain the target of sterilisation, acidic products require shorter processing time and lower temperature. In addition, other factors such as shelf-life requirements, fill-viscosity, and heat penetration also influence the suitability of starch used in these types of food products.

Starches with high freeze thaw stability, for example hydroxypropylated starch, are suitable for chilled and frozen foods. Hydroxypropylated starch is obtained by reaction of starch with propylene oxide. Besides has a better freeze thaw stability, this modification could improve self life, cold-storage stability, clarity and texture properties of the starch paste. As a fill-viscosity, starches have an important role to provide a sufficient high viscosity during the early stage of cooking. This initial high viscosity is important to reduce unhygienic condition and prevent splashing. Starches which easily thicken and quickly to achieve their peak viscosity are suitable for this purpose (Taggart, 2004). In contrast to fruit fillings, which require starches with clear paste clarity, in general, gravies, soups, and sauces require starch with opaque paste (Radley, 1976).

2.5.5 Mayonnaise and salad dressing

The main function of starches in these products is to thicken and stabilize the dispersed phase (Radley, 1976; Taggart, 2004). Usually, these food products are processed under acidic condition and involve heat and shear process. Therefore, starches which are able to tolerate acidity, heat, and shear are suitable for these products. In addition to lipophilic starch which could stabilize emulsions, other modified starches such as crosslinked starch and stabilized starch are the most commonly used for these products (Taggart, 2004). Lipophilic starch is obtained by esterification with n-octenyl succinic anhydrate which then produced a starch structure comprising both hydrophilic and lipophilic properties. Besides could be used for mayonnaise and salad dressing, lipophilic starch could be used to replace animal-derived sodium caseinate and gum arabic (Taggart, 2004).

2.6 Underutilized starchy materials from Indonesia

A large number of root and tuber crops is grown in Indonesia. Taro (*Colocasia esculenta*), yams (*Dioscorea sp.*), sweet potato (*Ipomoea batatas*), canna (*Canna edulis*), konjac (*Amorphophalus sp*.), arrowroot (*Maranta arundinacea*), and cassava (*Manihot utilissima*) are among them. Some of them have become a major source of food, nutrition, employment, and income in relatively isolated areas. In the eastern island, especially in West Papua, sweet potato, taro, and yam form the dietary staple. Due to their high content of starch, roots and tubers have a potential to be utilized as the alternative source of carbohydrates. Unfortunately, by far, only cassava has been commercially utilized in this country. Starches from other sources have not been paid enough attention by the community and food industry (Aptindo, 2000; Deshaliman, 2003; Nasution, 2003). The economic importance of these roots and tuber crops will increase slightly to the year 2020

(Aptindo, 2000). Therefore, an improved understanding of the production and utilization of these materials is important.

Since specific physicochemical properties of these root and tuber crops will be analyzed in the proposed study, these crops will be discussed into a greater detail. Sweet potato is a crop plant with large, starchy, and sweet tasting roots. Its roots also contain a high content of dietary fiber and mucilages that have antioxidative properties (Jiang and Ramsden, 1997). Traditionally, these roots are boiled, baked, or fried by local people. Sweet potato has the potential to be processed into flour and starch to produce various food products such as biscuits and noodles (Chen *et al*., 2003a).

Arrowroot is an herbaceous perennial plant, which originally came from tropical America. This plant has potential to be developed as an alternative foodstuff due to its high nutritional values and high tolerance to diverse environmental conditions in wide ranges of habitat, ranging from canopy to arid areas (Nasution, 2003). Arrowroot starch has a high digestibility and wide food applications such as convalescent foods, weaning food, and biscuits. In addition this starch also can be used as a thickener for sauces and gravies, or used for making clear glazes for fruit pies (Radley, 1976). Konjac is produced from the tubers of *A. campanulatus*. This tuber has been used as a traditional healthy diet in many Asian countries, including Indonesia due to the presence of a soluble dietary fibre glucomannan. This fibre has been claimed to prevent some diseases such as diabetes, obesity, hyperlipidemia, and cardiovascular diseases. Konjac flour has a high viscosity that can be used individually or in conjunction with other hydrocolloids as thickening or gelling agents in food products (Nishinari *et al*., 1992).

Yam or *Dioscore* spp. is a genus that consists of several species with food and medicinal functions. The most important species are white yam (*D. rotundata*), yellow yam (*D. cayenensis*), water yam (*D. alata*), and bitter yam (*D. dumetorum*). *D. alata* is indigenous to South East Asia, while the others are from West Africa (Farhat et al., 1999). After Papua New Guinea, the second center of variation of *D. alata* is Indonesia where it has been used as alternative food and medicine for people in rural area (Deshaliman, 2003). Recently, studies have indicated the importance of this plant as an alternative source of starch for food industry due to its stability at high temperatures, mechanical stress and low pH. However, despite these advantages, this starch has a high retrogradation tendency that can limit its application especially in foods that should be stored at low temperatures (Alves *et al*., 2002; Karam *et al*., 2006).

Canna is a perennial herb with rhizomes that contain 24-30% of starch (Moorthy, 2004). Canna starch has unique properties indicated by its high phosphorous content, high paste viscosity, large particle size, and high paste clarity (Piyachomkwan *et al*., 2002; Santacruz *et al*., 2003; Thitipraphunkul *et al*., 2003; Srichuwong *et al*., 2005a). The utilisation of canna starch in transparent noodle making has been reported previously (Hung and Morita, 2005). Cassava is a perennial woody shrub, which originated in Brazil and Paraguay (Nasution, 2003). Dried roots of cassava could be transformed into flour, which could partially substitute for wheat flour in bread making. Cassava starch could be used to make breads, crackers, paste, and pearls of tapioca (Radley, 1976; Taggart, 2004). Compared to other flour and starches, cassava flour and starch have high paste clarity due to its weaker associative force (Moorthy, 2004). This property allows the application of cassava flour and starch in confectionary and pie filling which require high clarity (Radley, 1976).

As mentioned above, amongst tuber and root starches, only cassava and potato starches have been commercially exploited and become a major source of starch. The vast availability, low price, and the easy extraction of cassava starch due to its low amount of proteins, fats, and lipids as well as the absence of cereal taste are the main reasons of the development of cassava starch industry. This starch is used directly for baked or gelatinized products or manufactured into glucose, dextrins, and other products. The starch conversion industry is the largest consumer of starch. Glucose syrup and crystalline dextrose are used in large quantities in fruit canning, confectionaries, jams, jellies, preserves, ice cream, bakery products, pharmaceuticals, beverages, and alcoholic fermentation (FAO, 2006). Cassava starch has been used in sweetened and unsweetened biscuits as well as in cream sandwich to soften texture, add taste, and render the biscuit nonsticky (Taggart, 2004). Cassava starch and molasses are the major materials for the production of monosodium glutamate (MSG). This product is used as a flavoring agent for meat, gravies, sauces, and vegetables. Moreover, due to its lower cost, glucose derived from cassava starch is utilized for commercial caramel production, which in turn is used to color many foodstuffs and beverages (FAO, 2006).

CHAPTER 3

Physicochemical properties of flours and starches from selected commercial tubers available on the Australian market

3.1 INTRODUCTION

Tubers and roots are important sources of carbohydrates as an energy source and are used as staple foods in tropical and sub tropical countries (Liu *et al*., 2006). These products have nutritionally beneficial components, such as a resistant starch and mucilage. Resistant starch has been attributed with a slow digestion in the lower parts of the human gastrointestinal tract which results in the slow liberation and absorption of glucose and aids in the reduction of the risk of obesity, diabetes and other related diseases (Liu *et al*., 2006). It has been proposed that resistant starch could prevent colon cancer by encouraging production of short-chain fatty acids, especially butyrate. Butyrate is an inhibitor of enzyme Histone Deacetylase (DHACs), which involves in gene regulation by turning off the cancer's tumor suppressor genes. In addition, resistant starch could also encouraging the growth of beneficial bacteria, lowering colon pH, lowering concentrations of amonia, phenolics, and other irritants, as well as increasing the protective mucus layer (Rekha and Padmaja, 2002).

Whereas mucilage extracted from various tubers and roots has been reported to possess angiotensin converting enzyme inhibitory (Lee *et al*., 2003) and antioxidative activities (Nagai *et al*., 2006). Also tubers and roots do not contain any gluten, which is an important factor when considering a carbohydrate source. Using tubers as a source of carbohydrate instead of gluten containing carbohydrates, may aid in a reduction in the incidence of celiac disease (CD) or other allergic reactions (Rekha and Padmaja, 2002). With these benefits in mind an examination of the physicochemical properties of some representative tubers and roots was undertaken.

The food industry utilizes some tubers and roots for their flour and starch products and literature reports on the uses of such. However upon examination of available literature, it is evident that very little physiochemical characterization of these tubers' starches, flours and mucilage has been undertaken. Such an examination may demonstrate further potential uses within the food industry for the replacement of more traditional forms of carbohydrates or to produce entirely new food products. Therefore, the present study was aimed to assess the physicochemical and functional properties of the main components of some starchy tubers commercially produced in Australia, in an attempt to broaden what applications they may be used for within the food industry. The tubers assessed in this study were sweet potato, yam and taro. These tubers were sourced from Queensland Australia from local producers and harvested in March 2007. They have been analyzed in this study with the understanding that they are a representative samples from one harvest only and that all results contained in this report are for a preliminary examination into the properties of these products and that. For a more conclusive study further examination of various samples from different regions, seasons and sites would need to be examined.

3.2 MATERIALS AND METHODS

3.2.1 Materials

Matured tubers of taro (*Colocasia esculenta* var. Antiquorum), yam (*Dioscorea alata* var Round Leaf Yellow) and sweet potato (*Ipomoea batatas* var. Beauregard) were supplied by local tuber growers in Queensland (Australia). Received tubers were harvested in March 2007 and were of a uniform medium size and free from mechanical or pathological injuries.

3.2.2 Sample preparation

3.2.2.1 Flour extraction

Flour extraction was conducted following an established procedure (Alves *et al*, 2002). The tubers were peeled, washed, cut into 1-2 cm cubes, and sliced into thick chips (~5mm). These chips were then soaked in sodium metabisulphite solution(0.075%) for ~5 min and oven dried at 30°C for 40 hours until they reached ~13% moisture. Subsequently, the dried chips were milled into flour and sifted through a 300-µm sieve. The yield of flour based on weight of the raw tubers was determined. The flour was then packed into a closed container and stored under dry conditions at room temperature until used for further applications.

3.2.2.2 Mucilage separation

The mucilage concentrate was prepared following the method as described by Jiang and Ramsden (1999). The flour sample (100 g) was dispersed in 300 ml of sodium metabisulphite (0.075%) and stored at 4°C overnight. This dispersion was centrifuged (Sorvall RC 5, Beckman, MN, USA) at 14,000 *x g* for 20 min and the supernatant (mucilage) was collected. This was followed by pellet dissolution in metabisulphite solution and centrifugation under conditions as described above. The resulting supernatant was filtered using a filter paper (110 mm, Advantec) and freeze dried (Dynavac freeze drier; Dynavac Eng. Pty. Ltd., Melbourne, Australia).

3.2.2.3 Starch isolation

The pellets obtained from the centrifugation step during the mucilage separation were resuspended in a large amount of sodium metabisulphite (0.075%), and then this homogenate was passed through a 150 m sieve. The residu was washed with sodium metabisulphite (0.075%). The resulting slurry was left to stand overnight at 4^{o}C and then centrifuged (14,000 *x g*; 20 min, Sorvall). After this, the supernatant was discharded and the colored layer manually scraped off of the starch. This centrifugation step was repeated until the supernatant layer was almost colorless. After the last centrifugation, the supernatant was decanted and sodium hydroxide (0.1 M) was added to the remining sediment (starch). This was followed by addition of deionized water to wash the pellets until their pH was neutral. The recovered starch was dried using an air oven at ~35°C for 30h, ground, sieved using a 250 µm sieve. The yield of starch based on the weight of its respective flour (100 gr) was determined. The resulting starch then stored in an air tight container under dry conditions (Alves *et al*., 2002).

3.2.3 Proximate analysis of extracted components

All extracted components were assessed for moisture and protein content in accordance with the AACC methods (standards #44-15A and 46-12, respectively, AACC, 2000). Total amylose content was determined using colorimetric method after removal of lipids from flours and starches with hot 75% n-propanol for 7 hours in a Soxhlet extractor (Hoover and Ratnayake, 2005). The pure potato amylose (Sigma) and corn amylopectin (0-100% amylase, Sigma) were used to create a standard curve. Subsequently, the total amylose content of each sample was inferred from this standard curve. Since amylose and amylopectin are starch fractions, the amount of these components were expressed relative to Total Starch content. Amylopectin content was calculated by the formula: % Total starch content - % amylose content. Total starch was measured using Total Starch assay kit (Megazyme, Ireland). The resistant starch and non-resistant starch were determined using a Megazyme resistant starch assay kit (Megazyme, Ireland). The digestibility was determined based on the ratio of non-resistant starch to the total amount of resistant and non resistant starch (Liu *et al*., 2006).

3.2.4 Particle size distribution

The particle size distributions of flour and starch samples were measured using a particle size analyzer (Coulter LS130, Coulter Corporation, FL, and USA). Before the measurement, the background reading for water was recorded and each sample was added until an obscuration of 18-20% was achieved. This was followed by sonication for 5 min to disperse any agglomerates.

3.2.5 Swelling volume

The swelling volume of flour and starch samples was measured according to Santacruz *et al* (2003). Briefly, 0.5% flour and starch suspensions were prepared in 15 mL Falcon tubes and heated in a water bath at 50, 60, 70, 80, 90 or 100°C for 30 min with constant agitation to avoid sedimentation. This was followed by centrifugation (Sorvall) at 1000 x *g* for 15 min at 20°C. The sedimented fraction was weighed and its mass related to the mass of dry starch was expressed as swelling power (w/w).

3.2.6 Paste clarity

The paste clarity was determined by measuring the light transmittance (%) according to Craig *et al* (1989). The flour and starch dispersions (1%) were prepared in a screw cap tube and heated at 100°C for 30 min with intermittent mixing. The tubes were then cooled down and stored at 4°C for 7 days. To monitor the tendency for retrogradation, the percentage of light transmittance was measured at 650 nm each day against the water blank using a spectrophotometer (Cary IE; Varian Australia Pty. Ltd., Melbourne, Australia).

3.2.7 Pasting properties

Pasting properties were determined using a starch cell (Physica Smart, Starch analyzer-Anton Paar) attached to a CR/CS rheometer (Physica MCR 33011, Anton Paar, GmbH, Germany) and established methodology (Jayakody *et al.*, 2007). A sample (7% w/w) was equilibrated at 50°C for 1 min, then heated from 50 to 95°C at 6°C/min, held at 95°C for 5 min, cooled to 50°C at 6°C/min, and held at 50°C for 2 min. The speed was 960 rpm for the first 10s, then 160 rpm for the reminder of the experiment. The pasting properties of each sample were inferred from acquired diagrams including the peak time, peak viscosity, holding strength, setback, and final viscosity.

3.2.8 Thermal properties of flours and starches

The thermal properties of the flours and starches were assessed using differential scanning calorimetry (DSC-7, Perkin Elmer, Norwalk, CT, USA). Deionized water (11 µl) was added to 3 mg of sample in an aluminium pan, which then was allowed to stand for 2 h at room temperature before analysis to ensure the equilibration of sample and water. The sample was heated from 20 to 120°C with 10°C/min heating rate. An empty aluminium pan was used as a reference in each measurement. From this experiment, the onset (To), peak (Tp), and conclusion (Tc) temperature, as well as gelatinization enthalpy (ΔH) were reported (Ratnayake *et al*., 2001).

3.2.9 Rheological properties of mucilage

Mucilage suspensions were prepared at different concentrations (2.5; 5; or 10% w/w) by adding the appropriate quantity of freeze-dried powder to deionized water. All suspensions were kept overnight to allow for complete hydration. All samples were subjected to a shear rate sweep at 20°C, from 0.01 to 100 s^{-1} in a plate and cone geometry (50 mm diameter, 1°) of the rheometer (Anton Paar), also equipped with a temperature and moisture regulating hood. The temperature was controlled with a Peltier system (Anton Paar). The data of all rheological measurements were analyzed with the supporting software Rheoplus/322 v2.81 (Anton Paar). The flow curves were fitted to three rheological models: Ostwald (Power Law), Herschel-Buckley and Casson models. Ostwald model was used to describe the relationship between shear stress and shear rate, while Herschel-Bucley model combined the Ostwad model with a yield stress variable. Casson model quantified the yield stress and high shear viscosity.

Ostwald model: $\eta = K \cdot \dot{\gamma}^{n-1}$

Herschel-Buckley model: $\sigma = \sigma_o + K' \cdot \dot{\gamma}^{n'}$

Casson models: $\sigma^{0.5} = \mathbf{K_{0c}} + \mathbf{K_c} \cdot \dot{\gamma}^{0.5}$

in which η is the apparent viscosity (Pa s); K and K' are consistency index (Pa s^n); n and n' are the flow behaviour index; $\dot{\gamma}$ is the shear rate (1/s); and σ_o and σ present yield and shear stress, respectively (Pa). Casson yield stress (σ_{oc}) was determined as the square of the intercept (K_{oc}) and consistency coefficient (K_c) was obtained from linear regression of the square roots of shear rate–shear stress data.

3.2.10 Statistical analysis

A randomized block design was applied with tubers and replications (block) as the main effects. This block structure was repeated at least three times with at least 2 sub samplings. Results were analyzed using a General Linear Model (SAS, 1996). The level of significance was present at $p<0.05$.

3.3 RESULTS AND DISCUSSION

3.3.1 Proximate analysis

The chemical composition of flours and starches extracted from the samples analyzed is presented in Table 3.1. Each species examined had different compositions. The total starch (TS) content of taro and yam flours was comparable ($p>0.05$; 80.1% and 78.1%, respectively); however, these were significantly ($p<0.05$) higher than that of sweet potato flour (65%). Examination of literature revealed TS contents for all three at higher levels so further purification of all samples was conducted and the TS was reanalyzed resulting in values comparable to literature.

Yam mucilage contained higher levels of protein (23.48%) in comparison to taro and sweet potato (13.53%) and (7.66%), respectively. However, the results obtained in this study were lower than those reported previously for yam (55.36%; Alves *et al*., 2002) and taro (20.9-40%; Jiang and Ramsden, 1999). While the difference might have been caused by a

Table 3.1. Chemical composition of flours, starches, and mucilage extracted from taro, yam and sweet potato tubers

Source	Protein (%)	Total Starch (%)	Amylose (%)	Amylopectin (%)	Moisture (%)
Flours					
Taro	6.28±0.07^{b}	80.95±0.5^{a}	6.91±1.54^{c}	74.04±2.96^{a}	8.19±0.07^{b}
Yam	10.46±0.11^{a}	78.83±1.99^{b}	18.52±1.19^{b}	60.31±1.74^{b}	10.51±0.82^{a}
Sweet potato	3.15±0.10^{c}	65.05±1.8^{c}	27.85±0.97^{a}	37.20±1.30^{c}	7.07±0.17^{b}
Starch					
Taro	1.31±0.00^{b}	88.66±1.86^{a}	16.30±1.54^{c}	72.36±1.27^{a}	8.99±0.19^{b}
Yam	3.23±0.01^{a}	81.72±2.05^{c}	38.34±1.47^{a}	43.38±0.85^{c}	11.16±0.28^{a}
Sweet potato	0.61±0.00^{c}	84.15±2.68^{b}	34.09±1.04^{b}	50.06±1.63^{b}	9.96±0.35^{b}
Mucilage					
Taro	13.53±0.153^{b}	n.dt	n.d	n.d	16.10±0.04^{a}
Yam	23.48±0.137^{a}	n.dt	n.d	n.d	17.53±0.39^{a}
Sweet potato	7.66±0.144^{c}	n.dt	n.d	n.d	11.10±0.18^{a}

All data reported on dry basis and represent the mean of three replicates. Values followed by the different superscript in each column are significantly different (*P<0.05*). n.d = not detected; n.dt = not determined

different extraction method, this could also be due to the variations of botanical origin and environmental conditions during cultivation. For example, mucilage formation is related to a plant stress response during growth and therefore related to environmental conditions (Jiang and Ramsden, 1999) as the samples were not exactly the same ones used in the reported studies and this present study, differences may be expected.

The total amylose content was very low in the taro samples while yam and sweet potato contained comparable concentrations (Table 3.1). These observations are in agreement with previous reports (Hung and Morita, 2005; Srichuwong *et al.*, 2005b). Among the flour samples, yam had the highest % protein content with 10.46% and taro 6.28% whilst sweet potato had the lowest value of 3.15%. The starches for each species as expected had reduced protein contents with the yam starch containing the highest amount of protein (3.23%) followed by the taro (1.31%) and the sweet potato (0.61%). In general the process used in this study showed that the protein content for all the starches tested was higher than those that have been reported in literature i.e.: 0.10-0.5% for yam starch (Gebre-Mariam *et al*., 1998, Alves *et al*., 2002, Freitas *et al*., 2004), 0.9-1.3% for taro starch (Tattiyakul *et al*., 2006) and 0.14-0.23% for sweet potato starch (Chen *et al.*, 2003b). However due to the samples not being exactly the same differences in results were not unexpected.

As can be seen in Table 3.2 there are significant differences in the results for each of the samples tested. Among the flour samples, taro contained the highest amount of RS (35.19%) followed by yam with (22.48%) and sweet potato with the lowest concentration of only (0.97%). As expected, the levels of NRS were inversely related to RS content with sweet potato flour containing the highest amount. Also shown is a relationship between RS content and the degree of digestibility of the samples (Table 3.2). Particularly with the starch samples, with the sweet potato starch showing the highest degree of digestibility with the lowest % content of RS. These results also show that in general, the content of RS in taro and yam was higher than that of selected cereals including rice (0.6%), wheat (0.6%), or buckwheat (0.8%) (Liu *et al*., 2006).

The structure of the starch in these species of tuber may also account for the differences in the degree of digestibility. It has been shown in previous studies that an A-type X-ray diffraction starch, that has a high proportion of short branch chain amylopectin, has inferior crystallinity and thus is more susceptible to digestion by α-amylase compared to its opposite, B-type starch (Jane *et al*., 1997). Sweet potato and taro starches have been reported to have an A-type X-ray diffraction (Srichuwong *et al*., 2005a) and had higher digestibility compared to yam starch that has a B-type X-ray diffraction (Srichuwong *et al*., 2005a).

The significance of these factors is in relation to the use of starches for food product manufacturing. The choice of starch may have significant effects especially in relation to produced food products having health benefits. As has been discussed previously in this study, lower digestibility (related to higher percentages of RS) offer health benefits for the prevention of diabetes and other related health problems.

Table 3.2. The content of resistant and non resistant starch and digestibility of flours and starches extracted from taro, yam, and sweet potato tubers

Source	Resistant starch (%)	Non-resistant starch (%)	Digestibility (%)
Flours			
Taro	35.19±3.92^{a}	35.73±2.96^{b}	50.42±2.90^{b}
Yam	22.48±2.33^{b}	18.85±0.08^{c}	45.72±2.76^{b}
Sweet potato	0.97±0.35^{c}	75.55±8.95^{a}	98.74±0.43^{a}
Starch			
Taro	44.98±5.50^{b}	47.05±2.68^{b}	51.22±4.47^{b}
Yam	68.50±8.82^{a}	13.48±7.09^{c}	16.55±9.05^{c}
Sweet potato	0.92±0.61^{c}	85.78±7.70^{a}	98.95±0.63^{a}

All data reported on dry basis and represent the mean of three independent replications. Values followed by the different superscript in each column are not significantly different (P<0.05).

3.3.2 Particle size

The particle size analysis on the flours extracted from the taro, yam and sweet potato revealed that the taro flour had the smallest mean diameter (2.02 µm) (Figure 3.1A) with a particle size distribution ranging from 1.067-64.19 µm. As opposed to the taro samples, yam and sweet potato flours and starches, contained larger particles with a distribution that resulted in two distinct peaks at 28.3 and 251 µm (Figure 3.1A, B). The results observed for the first peak are comparable to those previously reported (Farhat *et al*., 1999; Zaidul *et al*., 2007). Unfortunately, the appearance of the second peak has not been reported previously. The particle size of starch is one of the most important characteristics, which may influence other physicochemical properties such as swelling power; paste clarity, and water-binding capacity (Singh *et al*., 2003). With these factors in mind the use of taro starch may be applicable for several different applications within the food industry, particularly products that require starch that offers a smaller particle size allowing for smooth textured starch gel (Tattiyakul *et al*., 2005). Past studies have indicated this, such as, it was shown that the fine granules of taro starch improved binding and reduced breakage of a snack product (Huang *et al*., 2006).

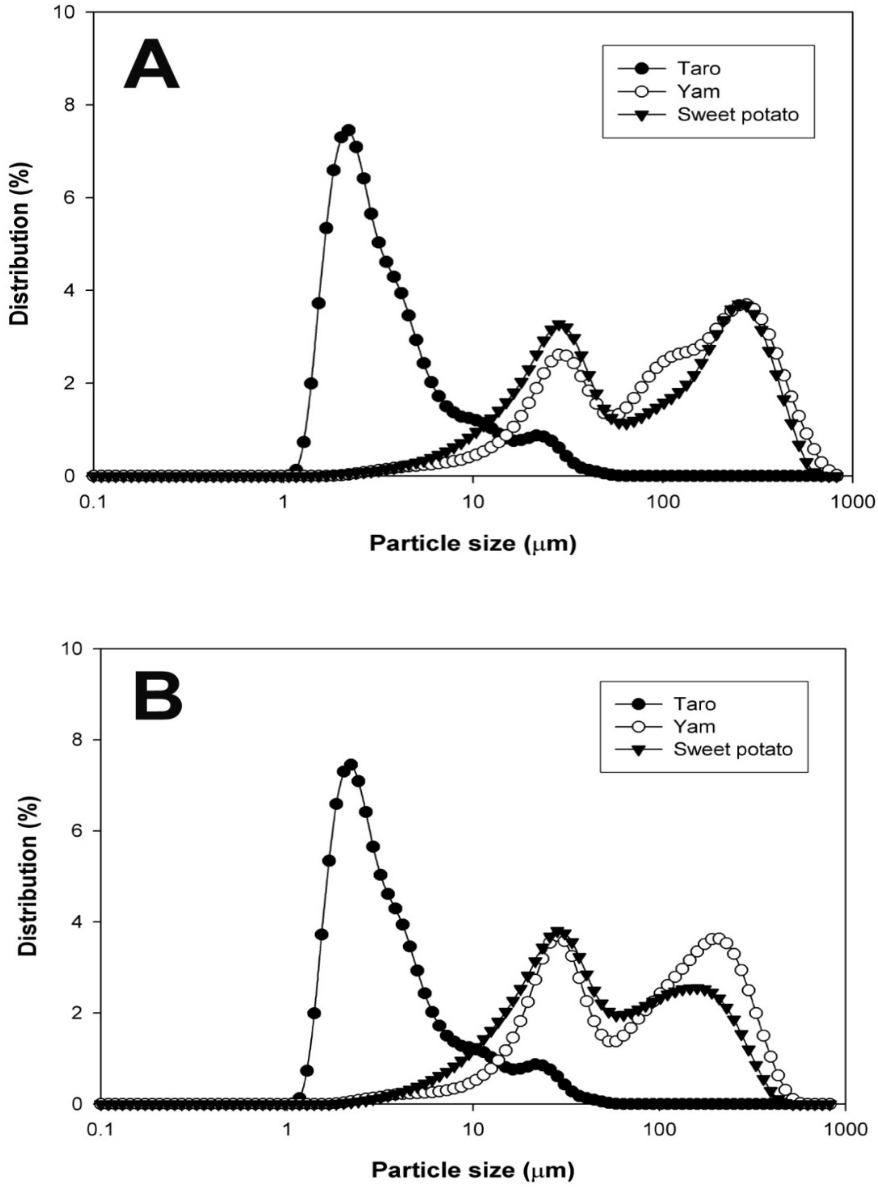
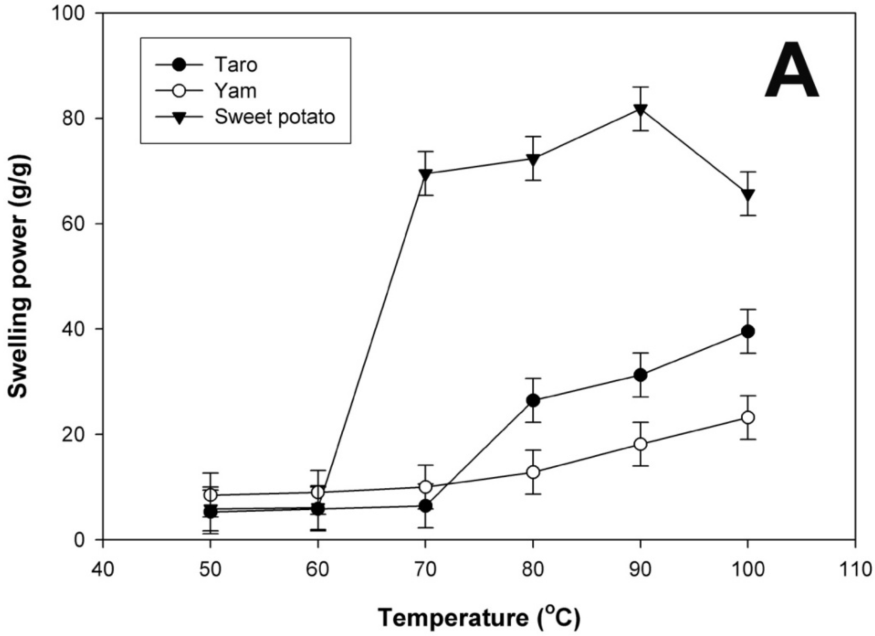


Figure 3.1 Particle size distribution of flours (A) and starches (B) extracted from taro, yam, and sweet potato tubers

3.3.3 Swelling power

The changes in swelling power of taro, yam, and sweet potato flours and starches are shown in Figures 3.2A and 3.2B. The granules of sweet potato flour swelled at a lower temperature (~60°C) in comparison to those of taro and yam, which swelled at ~70°C. The starch granules start to swell rapidly only after the temperature reached the onset of the gelatinisation temperature (Jacguier *et al*., 2006). The onset gelatinisation temperature (T_o) of taro, yam, or sweet potato flours (74.32, 74.21, and 62.56°C respectively; Table 3.4) as determined by DSC, corresponded to the start of the rapid increase of swelling power of these flours (Figure 3.2A). The swelling power of taro and yam flours increased steadily with a temperature rise from 70 to 90°C, as opposed to sweet potato flour with a rapid change of swelling power in this temperature region. At 90°C, the swelling power of the sweet potato flour was 3 to 4 times greater than that of taro and yam flours but with a poor integrity (Figure 3.2A). The swelling power of flour samples is often related to their protein and starch contents (Woolfe, 1992). A higher protein content in flour may cause the starch granules to be embedded within a stiff protein matrix, which subsequently limits the access of the starch to water and restricts the swelling power. The obtained results fit these previous observations with flours lower in protein and higher in total starch content having a higher swelling ability (Table 3.1; Figure 3.2A). In addition to protein content, a higher concentration of phosphorous may increase hydration and swelling power by weakening the extent of bonding within the crystalline domain (Singh *et al.*, 2003). Furthermore, the amylopectin is primarily responsible for granule swelling, thus higher amylose content would reduce the swelling factor of starch (Tester and Morisson, 1990). However, in the current study, there was no apparent correlation between the amylose content and swelling power of the sweet potato flour, which somewhat contradicted a negative correlation previously reported by Collado *et al*. (1999).



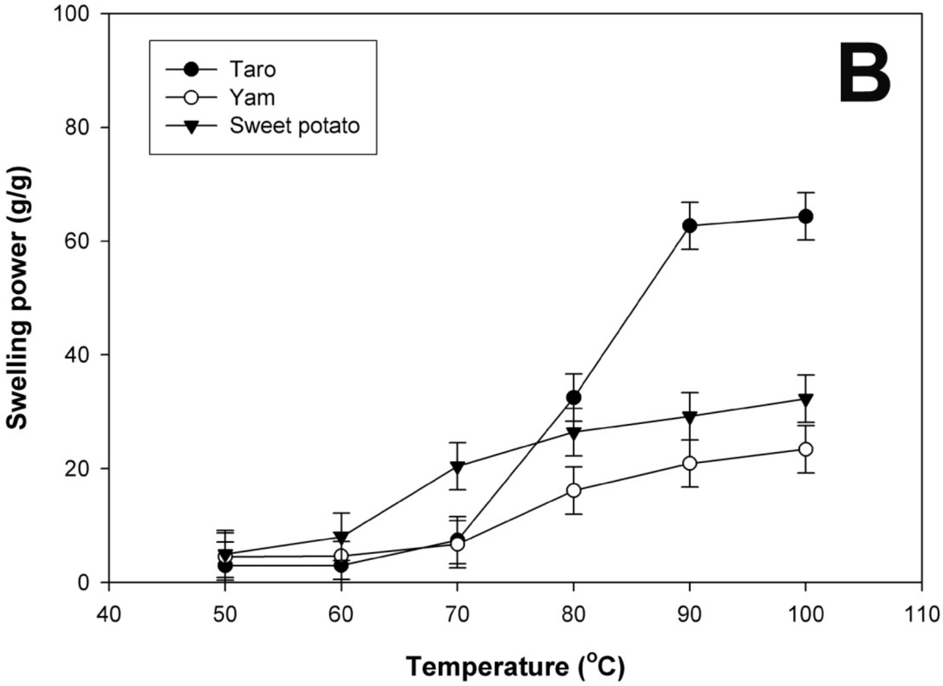


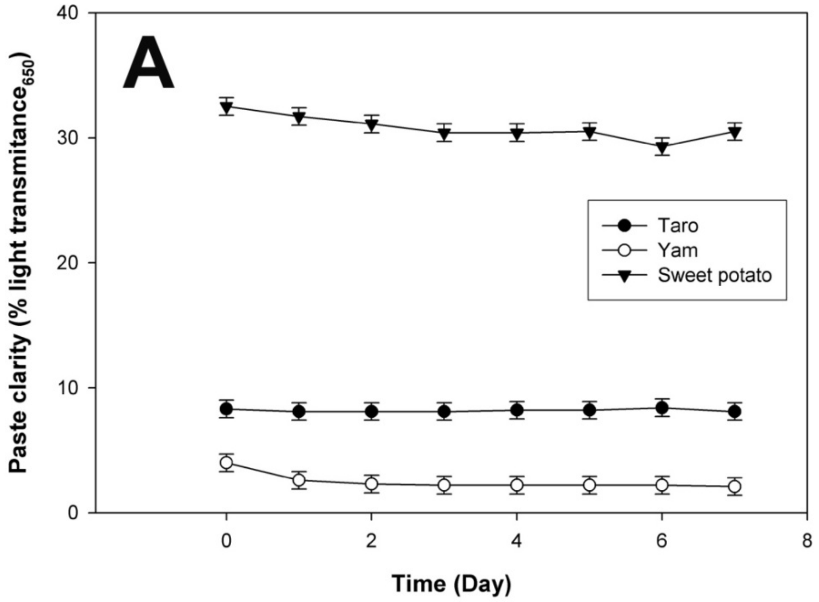
Figure 3.2 Swelling power of flours (A) and starches (B) extracted from taro, yam, and sweet potato tubers.

3.3.4 Paste clarity

As depicted in Figure 3.3A, sweet potato flour had a higher paste clarity compared to taro and yam flours during the 7-day storage. This large difference was alleviated upon starch extraction, which resulted in comparable paste clarities of sweet potato and taro starches at the end of the testing period. Paste clarity is another important property of flour or starch that governs which applications different flours or starches may have for food processing. For example transparent starch paste is required to thicken fruit pies as opposed to opaque paste, which is more suitable for salad dressing (Craig *et al*., 1989). The results presented here indicate differences in paste clarity, which may determine which species of tuber's flour, or starch may be used for different applications in the food industry. There are many factors that may also influence paste clarity such as amylose, lipid and protein contents, (Craig *et al*., 1989) botanical source, particle size of granules, total solids concentration, degree of granule dispersion, and the capacity of granules to form aggregates (Amani *et al*., 2005) these have not been examined to any great extent in this study. However the results here for the sweet potato indicate that its flour and starch may offer high enough paste clarity for use in food products requiring this.

3.3.5 Pasting properties

The pasting behavior of the tuber's starches was studied by observing changes in the viscosity of a starch system based on the rheological principals (Huang *et al*., 2006). Among the flour samples, taro and yam flours had the highest peak time (Table 3.3), which may indicate a greater structural rigidity in comparison to sweet potato flour (Leon *et al*., 2006). This structural rigidity was also observed from the low swelling power as discussed previously. In regard to the pasting temperatures, the sweet potato flour had the highest (80.98°C) with the yam flour having the lowest (72.75°C), which could be related to the starch concentrations of the samples (Table 3.1) with sweet potato having the lowest TS content yet the highest pasting temperature.



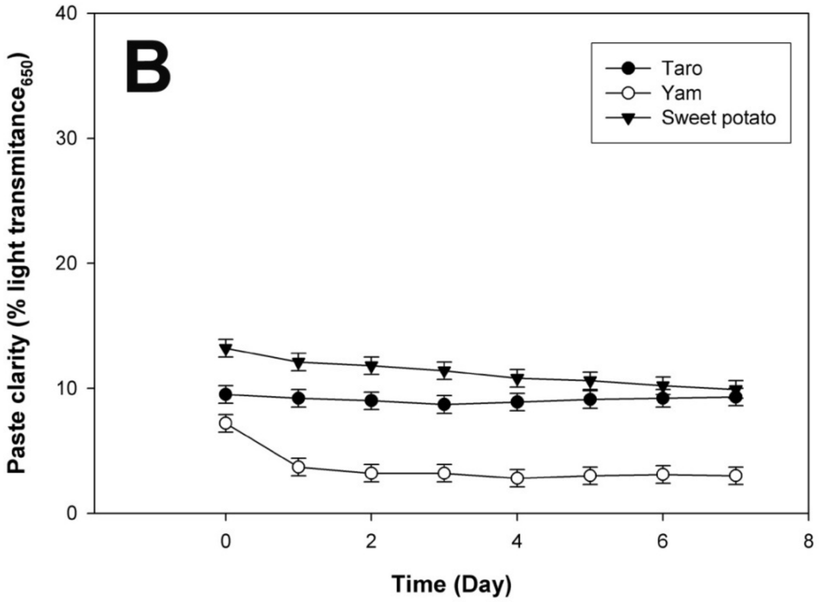


Figure 3.3. Paste clarity of flours (A) and starches (B) extracted from taro, yam, and sweet potato

Also sweet potato flour had lowest peak viscosity as opposed to the taro flour (Table 3.3). This observation might have been influenced by lower rigidity of starch granules in sweet potato, which in turn caused instability and consequently disruption upon the heating and stirring treatment (Leon *et al*., 2006). On the other hand, the higher peak viscosity of the taro flour compared to other flour samples could be due to the small granule size (Figure 3.1A), which also led to higher swelling power (Figure 3.2A) and subsequently higher viscosity. However, the viscosity of this flour decreased substantially afterwards, likely due to lower protein content and free leaching of amylose and amylopectin from the granules (Leon *et al*., 2006). Taro flour also showed a retrogradation tendency, indicated by the rise of viscosity during cooling period (Leon *et al.*, 2006; Zaidul *et al*., 2007). Yam flour also had a tendency toward retrogradation.

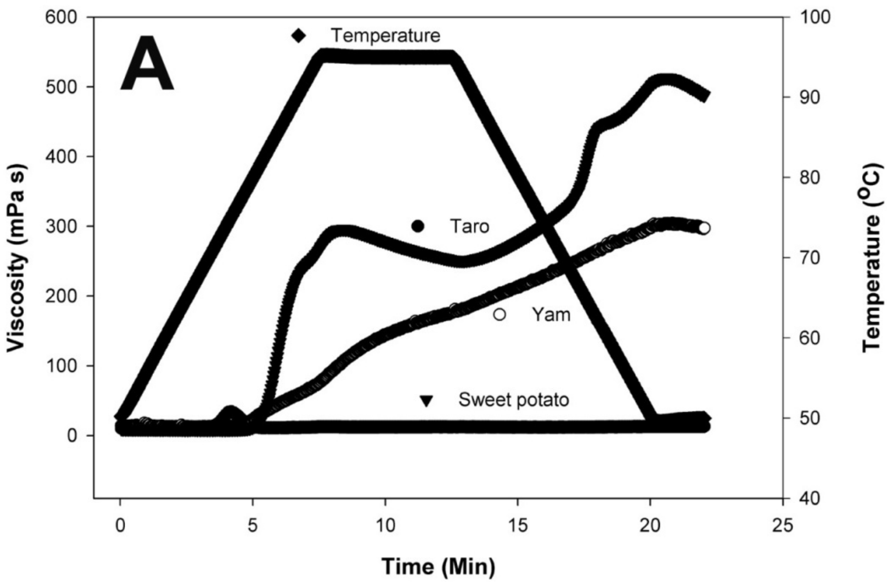
However the presence of a higher protein content in the yam flour might have prolonged the starch swelling and gelatinization process leading to a steady increase of viscosity during the heating period with no apparent breakdown (Figure 3.4A). These results indicate that yam flour may be suitable for use in food products that require continuous thermal processing such as food for elderly and children (Rincon and Padilla, 2004).

The starch samples had similar pasting characteristics to their respective flours but with a higher viscosity, with the exception for the sweet potato starch (Figure 3.4A, B). These results were not unexpected since this difference could have been caused by the presence of other components in flour such as mucilage, proteins, and lipids that would interfere with the pasting process. The lower starch content in a flour sample may also lower its viscosity (Alves *et al*., 2002) as can be seen in Table 3.1, that sweet potato had the lowest reported result for starch content. In addition to a low pasting temperature, sweet potato starch also had the highest peak viscosity most likely caused by the low protein content in this sample (Table 3.1). Sweet potato and taro starches also showed a substantial granular breakdown as indicated by the decrease of viscosity after peak viscosity.

Table 3.3. Pasting characteristics of flours and starches extracted from taro, yam, and sweet potato

Pasting characteristics	Flour			Starch		
	Taro	Yam	Sweet potato	Taro	Yam	Sweet potato
Peak T^2 (min)	8.53± 0.00^{a}	8.51±0.36^{b}	5.21±0.06^{c}	7.33± 2.66^{c}	8.53± 0.00^{a}	7.91± 1.53^{b}
Past T (^{o}C)	75.12± 0.04^{b}	72.75±2.61^{c}	80.98±0.62^{a}	72.89± 0.03^{a}	72.32± 0.03^{b}	64.48± 0.01^{c}
PV (cP)	265.87±40.06^{a}	n.a	34.52±3.86^{b}	671.57±14.25^{a}	n.a	1238.33±20.85^{c}
HS (cP)	250.60±37.19^{a}	n.a	11.12±0.65^{c}	421.90± 7.40^{b}	n.a	910.33±18.55^{a}
BD (cP)	15.27± 3.41^{b}	n.a	23.41±3.33^{a}	249.70± 7.65^{b}	n.a	328.03±36.05^{a}
SFP (cP)	221.50±25.34^{a}	n.a	-21.55±3.21^{b}	291.20± 9.97^{b}	n.a	275.70±15.98^{c}
SFT (cP)	236.80±27.67^{a}	n.a	1.85±0.19^{b}	540.90±12.75^{a}	n.a	603.77±20.30^{a}
FV (cP)	487.40±64.63^{a}	297.47±38.22^{b}	12.96±0.84^{c}	962.80±19.99^{a}	914.53±10.96^{a}	1514.00±31.75^{b}

Each mean presents an average of three independent observations; *Peak T - peak time; Past T - pasting temperature; PV - peak viscosity; HS - holding strength; BD - breakdown; SFP - setback from peak; SFT - set back from through; FV - final viscosity; n.a. – not available; Values followed by the different superscript in each row are significantly different ($P<0.05$).



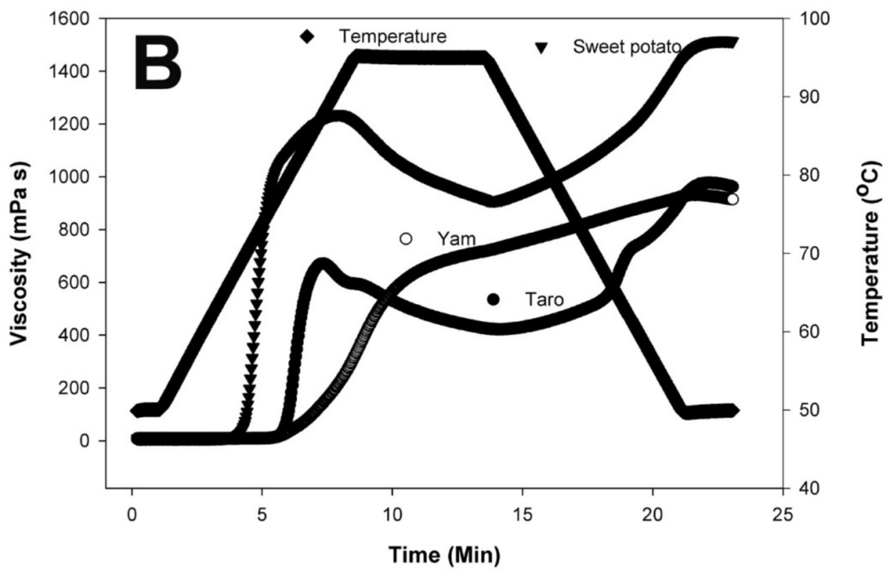


Figure 3.4 Pasting properties of flours (A) and starches (B) extracted from taro, yam, and sweet potato

3.3.6 Gelatinisation properties

The flour samples in this study had a higher gelatinisation temperature than the corresponding starches (Table 3.4). This is most likely due to the presence of other components in flour such as proteins and lipids that would obstruct the swelling of granules and thus increase the amount of heat required to reach the final swelling. Similar observations have been reported previously (Jane *et al*., 1992).

The taro flour and starch had the highest gelatinisation temperatures (T_o, T_p, and T_c), followed by yam and sweet potato (Table 3.4). This indicated higher stability of taro starch crystallites upon heating (Sasaki and Matsuki, 1998). The findings in this study also confirmed observations reported by Srichuwong *et al* (2005b). The perfectness of the taro starch crystallites is also reflected in its ΔH (gelatinisation enthalpy) value, which was lower than those of yam and sweet potato. ΔH is an indicator of a loss of molecular order within the granule, which increases with a decline of the degree of starch crystallinity (Tester and Morrison, 1990).

The gelatinisation temperatures of yam flour and starch were in the range from 74.21 to 84.67°C and 69.18 to 81.5°C, respectively (Table 3.4). In comparison to taro and sweet potato, yam flour and starch had a narrower range of gelatinization temperature. These results confirmed previous observations (Alves *et al*., 2002; Moorthy, 2002); however, they were slightly lower than some other reports (Srichuwong *et al*., 2005b; Farhat *et al*., 1999; Jayakody *et al*., 2007), these differences may be explained as the samples were not exactly the same.

Table 3.4. Gelatinization parameters of flours and starches of taro, yam, and sweet potato

Samples	Gelatinization parameters				
	To (°C)*	Tp (°C)*	Tc (°C)[1]	Tc- To (°C)[2]	ΔH (J/g dry starch)
Flours					
Taro	74.32±2.01[a]	79.75±3.72[a]	87.13±3.70[a]	12.81±1.69[b]	6.95±0.79[a]
Yam	74.21±2.11[a]	78.53±0.71[a]	84.41±0.06[a]	10.20±-1.45[b]	6.83±1.44[a]
Sweet potato	62.56±5.09[b]	73.57±1.58[a]	82.69±5.79[a]	20.13±0.71[a]	8.74±8.60[a]
Starch					
Taro	70.95±0.63[a]	78.53±0.73[a]	84.67±0.86[a]	13.72±0.23[b]	6.28±0.22[b]
Yam	69.18±1.44[a]	76.08±0.39[b]	81.50±1.42[b]	12.32±0.02[b]	9.34±1.45[a]
Sweet potato	56.96±0.81[b]	67.97±0.09[c]	75.02±0.73[c]	18.05±-0.08[a]	7.42±0.94[b]

All means present the average of three independent replications. Values followed by the different superscript in each column are significantly different ($P<0.05$). [1] To, Tp, and Tc indicate temperature of onset, midpoint and end of gelatinization, respectively. [2] Tc-To indicates the gelatinisation temperature range; [3] Enthalpy of gelatinization ΔH (J/g dry starch)

3.3.7 Rheological properties of mucilage

Flow behavior of mucilage solutions was assessed using controlled shear rate rheology. The data acquired during these measurements were fitted using three different rheological models, namely the Ostwald (Power law), Herschel-Buckley, and Casson. Table 5 shows the results for the main parameters in these models and corresponding R^2. In general, all three models are used to describe the flow of materials that deviate from Newtonian flow and fairly well described the flow as indicated with R^2 above 0.91. The mucilage source and its concentration had a significant ($P<0.05$) effect on all parameters of these models. The Herschel-Buckley model produced the best fit showing a clear direct relationship between concentration and pseudoplasticity; however, yield stress showed no apparent trend and was fairly similar among all tubers. The apparent differences in consistency indexes among these solutions at the same concentration, point out likely differences in composition, which needs to be further explored.

The results from this present study have demonstrated the different properties of each species of tuber examined here for their flour, starch and mucilage. These results also offer an indication of the applications in the food industry, for which each species may be suited. The results for each of the examined tubers has confirmed results found in literature, that in general, most of the tuber and root starches have higher viscosity and paste clarity in comparison to cereal starches (Craig *et al*., 1989) allowing them to be used as thickeners in certain applications such as sauces, soups, and dairy desserts. Also tuber starches gelatinize at low temperatures with a rapid and uniform swelling of granules, which is very important for noodle making (Chen *et al.*, 2003a).

The results found in the present study also indicate that taro may have applications for use in several different food products due to its fine granules and small particle size and may offer improved binding and reduced breakage of products, as was shown in past studies by Huang *et al*., (2006). Taro also has a smooth-textured gel (Tattiyakul *et al*., 2005), which would make it suitable for noodle processing, which requires a smooth mouth feel and avoidance of a grainy texture (Moorthy, 2002). Furthermore taro starch may have applications in bread production as a finer particle size is required for better light reflection on the porous structure of bread giving whiter bread crumbs and better consumer perception (Kaletunc and Kenneth 1999). Also as it has a high content of resistant starch therefore the use of taro in any of the above products may offer additional health properties.

Past studies have also shown that sweet potato flour may potentially be used in noodle processing and bread production as well (Chen *et al*., 2003a), while its starch can be used as an ingredient in bread, biscuits, cake, juice and noodles (Zhang and Oates, 1999). The main application of yam flour currently is in the production of bread and snacks (Alves *et al*., 2002). Also this rather preliminary assessment of mucilage from tubers has shown that these protein rich extracts could be used in various preparations with no noticeable effect on viscosity, as well as offering health promoting benefits such as, their angiotensin converting enzyme inhibitory (Lee *et al*., 2003) and antioxidative activities (Nagai *et al*., 2006). However these factors require further investigation.

Table 3.5 Flow behaviour of taro, yam and sweet potato mucilage at various concentration fitted by Herschel-Buckley, Ostwald, and Casson models.

Source	Conc. %	**Herschel-Buckley**				**Ostwald**			**Casson**		
		σ (mPa)	K (mPas^n)	n	R^2	K (mPas^n)	n	R^2	K (mPas)$^{1/2}$	K (mPas)$^{1/2}$	R^2
	10	2.53	14.68	0.68	0.96	13.55	0.54	0.97	54.20	42.35	0.95
Sweet potato	5	3.27	2.59	0.95	0.98	11.44	0.59	0.97	51.82	28.31	0.91
	2.5	2.82	1.02	0.99	0.98	10.38	0.64	0.96	48.94	25.47	0.93
	10	1.52	45.55	0.82	0.98	17.58	0.24	0.93	38.18	155.69	0.95
Yam	5	2.83	5.47	0.93	0.97	13.91	0.50	0.94	55.17	51.65	0.93
	2.5	2.27	2.37	0.92	0.97	12.57	0.56	0.99	50.54	34.53	0.96
	10	1.29	14.28	0.57	0.93	55.70	0.53	0.99	50.55	48.90	0.92
Taro	5	1.18	4.64	0.79	0.96	20.85	0.57	0.94	48.98	40.69	0.99
	2.5	0.79	2.69	0.86	0.94	12.57	0.73	0.92	35.49	33.03	0.96

All data reported represent the mean of three independent replications.

3.4 CONCLUSION

As this study has shown there are a great many potential applications for tuber starch, flour and mucilage, within the food industry. Each of these components having different physiochemical or beneficial health properties, which may be further examined for either the development of entirely new food products or for the replacement in current food products from the more traditional sources of starch and flour. The examination of the various physicochemical properties found here in this study demonstrates the potential of these products in food processing. Such results may allow for informed choices or diversity of choice when sourcing new ingredients or ingredients with properties to enhance product production and development.

Based on the results of the physicochemical properties of their main extracts (flour, starch, mucilage), taro, yam and sweet potato it can be seen that these tubers products, have a good potential to be used in the food industry. The high viscosity of taro starches would make them very useful in food applications where high thickening power is desired as well as the small particle size being useful for noodle or bread production. The stability of yam flour and starch against heat and mechanical treatment would also be useful in many food applications. The low viscosity of sweet potato flour is desirable in the food industry for applications that require lower viscosity and the high paste clarity would make it useful for products where this is required as a thickening agent In addition to the useful individual properties of these tubers, the high amount of resistant starch and the slow digestibility make the use of these tubers and roots valuable alternative carbohydrate sources, in terms of also offering health benefits such as, aiding in the prevention of certain diseases such as obesity and hypertension. Added to this, the absence of gluten in these tubers would be advantageous for producing foods for people suffering from celiac disease and may also aid in its prevention. Therefore these tubers may be seen as having very broad applications within the food industry.

CHAPTER 4

Physicochemical properties of flours and starches derived from traditional Indonesian tubers and roots

4.1 INTRODUCTION

For a long time, rice has served as the main staple food for people in Indonesia. This dependency has weakened food stability in this country due to its inability to increase rice production to adequately address current demographic expansion. In addition, natural disasters such as floods, drought, and earthquakes frequently disturb the availability of this commodity on the Indonesian market. Attempts to overcome this problem through food diversification and rice substitution with other starch-based foods have resulted in an increased importation of wheat (Aptindo, 2004). To achieve food stability, there is a great need to reduce the dependency on rice and wheat as the main sources of carbohydrates through food diversification using local sources.

Indonesia has many plants, out of which tubers and roots have the potential to be used as alternative staple foods. Some of these plants are cassava, sweet potato, taro, arrowroot, canna, konjac and sago (Aptindo, 2004). These tubers and roots have carbohydrate contents and nutritional value very similar to that of rice and wheat. In comparison to cereals, tubers and roots contain relatively high amounts of resistant starch, an important form of starch, which is non-digestible, and therefore acts as fiber (Liu *et al*., 2006). Therefore, these traditional starchy plants may be important in the human diet to reduce the risks of obesity, cardiovascular diseases and diabetes. In addition to this, these tubers and roots are free of gluten and therefore may also replace wheat in certain food applications to reduce the incidence of celiac disease (CD) or other allergic reactions to gluten (Hung and Morita, 2005).

Flour and starch from tubers and roots can be used to substitute wheat flour in certain food applications (Raja and Sindhu, 2000; Chen *et al*, 2003a; Charles *et al*., 2007; Mepba *et al*., 2007). However, the potential of these plants has not been utilized fully. The lack of knowledge of processing techniques and product development is one of the main problems. In addition, the local Indonesian population perceives these tubers and roots as a poor and primitive food, which also hinders the potential of these plants as alternative sources of carbohydrates. In an attempt to increase people's preference towards these underutilized food sources, there is a need to transform these commodities into more acceptable forms such as flour or starch (Aptindo, 2004). Such forms could be fortified with other nutrients, thus improving their low protein or vitamin content, or processed further to increase the stability and consequently shelf life of these commodities to achieve a sustainable food supply. Moreover, these materials could be applied widely either in food or non-food industries.

Enhancing our knowledge of the properties of different starchy underutilized tubers and roots from Indonesia may result in different applications in the food or non-food industry and also aid the Indonesian population to lessen their dependence on the wheat import. The aim of this study was to assess the important physical and chemical properties of the main compounds, namely flours and starches, of underutilized tubers and roots traditionally produced in Indonesia, for their applications in the food industry.

4.2 MATERIALS AND METHODS

4.2.1 Materials and sample preparation

Matured tubers and roots of taro (*Colocasia esculenta* var Bentul), yam (*Dioscorea alata* var Krimbang), sweet potato (*Ipomoea batatas* var Kalasan), canna (*Canna edulis* var Ganyong merah), konjac (*Amorphophallus campanulatus* var Mutiara), arrowroot (*Marantha arundinaceae* var Creole), and cassava (*Manihot utillisima* var Muntilan) were collected from Tulung Agung (East Java, Indonesia). The tubers and roots were transformed into chips by peeling, washing, cutting these materials into 1-2 cm cubes, and slicing into thick chips. These chips were then oven dried at 30°C for 40 hours until the final moisture content of approximately 13% was reached. This preparation took place in Tulung Agung and all samples were delivered to Victoria University. Upon delivery, samples were irradiated (25 kGy, Steritec, Dandenong, VIC, Australia) and further processed.

Flour was obtained by grinding dried chips and sifting coarse materials through a 300 µm sieve. The yield of flour based on the weight of the raw tubers was determined. For starch isolation, a flour sample (100 g) was dispersed in 300 ml of sodium metabisulphite (0.075%) and stored at 4°C overnight. Subsequently, this dispersion was passed through a 150 m sieve. The residu was washed with sodium metabisulphite (0.075%). The resulting slurry was left to stand overnight at 4°C and then centrifuged (Sorvall RC 5, Beckman, MN, USA) at 14,000*xg* for 20 min and supernatant was discarded. The colored layer manually scraped off of the starch. This step was repeated until the supernatant layer was almost colorless. After the last centrifugation, the supernatant was decanted and sodium hydroxide (0.1 M) was added to the remining sediment (starch). The deionized water was then added to wash the pellets until their pH was neutral. The recovered starch was dried using an air oven at ~35°C for 30h, ground, sieved using a 250 µm sieve. The yield of starch based on the weight of its respective flour (100 gr) was determined. Then the resulting starch was stored in an air tight container under dry conditions.

4.2.2 Proximate analysis of extracted components

Moisture and protein content of flours and starches were analyzed following established protocols (#44-15A and #46-12, respectively; AACC, 2000). Total amylose content within the flour and starch samples was determined after lipid removal with hot 75% n-propanol for 7 hours in a Soxhlet extractor (Hoover & Ratnayake, 2005). Amylose and amylopectin contents were expressed relative to the Total starch content. Amylopectin content was calculated by the formula: % Total starch content - % amylose content. Total starch was measured using Total Starch assay kit (Megazyme, Ireland). A total starch assay kit (Megazyme, Ireland) and a Megazyme resistant starch assay (Megazyme, Ireland) kit were used to measure total starch and the resistant starch content, respectively. Digestibility of samples was determined based on the ratio of non-resistant starch to total amount of resistant and non-resistant starch (Liu *et al*., 2006).

4.2.3 Particle size distribution

A Coulter counter (LS130, Coulter Corporation, FL, USA) was used for assessment of particle size distributions of samples. The background reading for water was recorded before each measurement and sample was added until an obscuration of 18-20% was achieved. Sonication for 5 min was performed to disperse any agglomeration.

4.2.4 Swelling power

Flour and starch dispersions (0.5%) were prepared in falcon tubes and heated in a water bath at 60, 70, 80, or 90^{o}C for 30 min with constant agitation to avoid sedimentation. This was followed by centrifugation (Sorvall) at 1,000-x *g* for 15 min at 20^{o}C. The sedimented fraction was weighed and its mass related to the mass of dry starch was expressed as swelling power (w/w) (Santacruz *et al*., 2003).

4.2.5 Paste clarity

Paste clarity of flour samples was determined based on the percentage of their light transmittance at 650 nm against the water blank using a spectrophotometer (Cary IE; Varian Australia Pty. Ltd., Melbourne, Australia) (Craig *et al*., 1989). The flour and starch dispersions (1%) were prepared in a screw cap tube and heated at 100°C for 30 min with intermittent mixing to avoid sedimentation. The tubes were then cooled down at room temperature for 1 hour and the percentage of light transmittance was measured. To monitor retrogradation tendency, the tubes were stored at 4^{o}C for 7 days and the percentage of light transmittance was measured each day.

4.2.6 Pasting properties

The pasting properties of flour and starch were investigated using a starch cell (Physica SmartStarch analyzer, Anton Paar) attached to a CR/CS rheometer (Physica MCR 33011, Anton Paar, GmbH, Germany) using the method described elsewhere (Jayakody *et al*., 2007). An aqueous sample containing 7%w/w of either flour or starch was prepared and equilibrated at 50°C for 1 min, then heated from 50 to 95°C at 6°C/min, held at 95°C for 5 min, cooled to 50°C at 6°C/min, and held at 50°C for 2 min. The speed was 960 rpm for the first 10s, then 160 rpm for the reminder of the experiment. The pasting properties of each sample were inferred from acquired diagrams.

4.2.7 Thermal properties

Differential scanning calorimetry (DSC-7, Perkin Elmer, Norwalk, CT, USA) was used to assess the gelatinisation temperatures including onset (T_o), peak (T_p), and endset (T_e) temperature, as well as gelatinization enthalpy (ΔH) of each sample. Flour and starch samples were prepared by adding deionized water (11 μl) to 3 mg of sample in an aluminum pan (BO160932, Perkin Elmer), which was allowed to stand overnight at room temperature before analysis to ensure the equilibration of sample and water. The sample was heated from 20 to 100°C with 10°C/min heating rate. An empty aluminum pan was used as reference in each measurement (Ratnayake *et al*., 2001).

4.2.8 Statistical analysis

A randomized block design was applied in the design of all experiments, with tubers and replications (block) as the main effects. This block structure was repeated at least three times with at least 2 sub samplings. Results were analyzed using General Linear Model procedure of the SAS systems (1996). The level of significance was preset at $p<0.05$. The relationships between the different properties of flours and starches were determined using Pearson correlation analysis.

4.3 RESULTS AND DISCUSSION

4.3.1 Physicochemical properties

Proximate composition of flours and their isolated starches is shown in Table 4.1. Cassava and canna flours contained similar amounts of total starch (TS) (77.42% and 77.13%, respectively), which was significantly higher ($p<0.05$) than that from other sources (Table 4.1.). Further purification has increased the amount of TS. Except for taro starch that contained less TS (75.36%), other starches had similar content of TS. Lower TS content for taro and sweet potato flours has been reported previously (60.7% and 64.4%, respectively) (Liu *et al.*, 2006). In contrast, TS of yam and arrowroot flours determined in the present study was lower than in other reported studies i.e. 88.71% and 85%, respectively (Raja and Sindhu, 2000; Alves *et al.*, 2002). Overall, TS of starch samples in this study was lower than other studies (Alves *et al.*, 2002; Piyachomkwan *et al.*, 2002; Chen *et al.*, 2003b). The observed differences in raw materials could be caused by multiple factors including tuber and root maturity at harvesting, botanical origin, analytical methods, irradiation applied in the current study, and high endogenous α-amylase activity (Moorthy, 2002; Abera and Rakhsit, 2004; Yadav, *et al.*, 2006).

Canna and yam flour contained similar amounts of amylose (32.72% and 33.06%, respectively), followed by arrowroot (29.39%), sweet potato (26.80%) and konjac (21.78%). Taro and cassava had the lowest amounts of amylose of all with 17.33% and 13.05%, respectively. Among the starch samples, canna contained the highest amount of amylose (35.01%) followed by yam (23.70%), arrowroot (21.90%) and konjac (21.28%) that had similar amounts. Sweet potato and cassava also contained comparable concentrations of amylose (15.92% and 14.65%, respectively) while taro was the lowest with only 10.14%. Similar amylose contents of canna and yam starch have been reported in other studies (Srichuwong *et al*., 2005a; Punchar-anon *et al*., 2007). On the contrary, amylose content of sweet potato, arrowroot, konjac, and taro starches obtained from this study was lower than previously reported (Woolfe, 1992; Moorthy, 2002; Hung and Morita, 2005; Srichuwong *et al*., 2005a). Amongst the flour samples analyzed in this study, canna and yam flours contained similar amounts of amylose to that of wheat flour (Zaidul *et al*., 2007).

Table 4.1. Chemical composition of flours and starches extracted from taro, yam, sweet potato, canna, arrowroot, konjac, and cassava

Source	Protein (%)	Total Starch (%)	Amylose (%)	Amylopectin (%)	Moisture (%)	Yield (%)
Flours						
Taro	5.53 ± 0.18^{c}	65.38±3.19^{b}	17.33± 2.52^{d}	48.05±1.94^{e}	8.91±0.59^{c}	19
Yam	5.26 ± 0.08^{c}	70.15±5.72^{b}	33.06± 1.18^{a}	37.09±7.31^{d}	9.52±0.13^{bc}	14
Sweet potato	3.26 ± 0.20^{e}	64.00±1.84^{b}	26.80± 2.78^{b}	37.20±4.37^{b}	9.96±0.25^{b}	30
Canna	4.19 ± 0.02^{d}	77.13±3.22^{b}	32.72± 2.04^{a}	44.41±1.44^{c}	10.96±0.14^{a}	25
Arrowroot	7.72 ± 0.01^{a}	62.26±0.27^{b}	29.39± 1.39^{b}	32.87±1.73^{c}	9.37±0.20^{bc}	32
Konjac	6.23 ± 0.04^{b}	68.54±0.84^{b}	21.78± 2.34^{c}	46.76±1.81^{b}	9.50±0.11^{bc}	12
Cassava	1.43 ± 0.17^{f}	77.42±0.90^{a}	13.05± 2.57^{d}	64.37±4.01^{b}	9.55±0.48^{bc}	40
Starch						
Taro	0.64 ± 0.05^{b}	75.36±2.06^{b}	10.14±1.60^{e}	65.22±0.72^{a}	9.79±0.35^{bc}	21
Yam	0.61 ± 0.15^{b}	82.10±3.47^{a}	23.70±2.37^{b}	58.40±2.95^{b}	10.78±0.09^{b}	15
Sweet potato	0.52 ± 0.09^{b}	87.14±3.78^{a}	15.92±0.96^{cd}	71.22±4.61^{b}	10.12±0.62^{bc}	18
Canna	0.79 ±0.09^{b}	88.05±0.86^{a}	35.01±0.58^{a}	53.04±1.10^{c}	12.32±0.48^{a}	16
Arrowroot	0.64 ±0.20^{b}	84.22±4.38^{a}	21.97±1.35^{c}	62.25±2.15^{b}	10.21±0.43^{bc}	12
Konjac	1.05 ± 0.18^{b}	82.38±3.84^{a}	21.28±2.53^{c}	61.10±5.61^{b}	10.59±0.16^{b}	18
Cassava	0.44 ± 0.09^{b}	85.45±2.83^{a}	14.65±1.55^{d}	70.08±2.53^{e}	8.94±0.66^{bc}	36

All data reported on dry basis and represent the mean of three replicates. Values followed by the same superscript in each column are not significantly different (p<0.05)

Amongst flour samples, arrowroot contained the highest amount of protein (7.70%), followed by konjac (6.22%), taro, yam, canna (5.53; 5.26 and 4.19%, respectively) and sweet potato (3.26%). Cassava flour contained the lowest amount of protein with only 1.51%. The protein content of taro and yam flour was in line with previous reports i.e.: 2.7-5.4% and 6.9%, respectively (Alves *et al*., 2002; Mbofung *et al*., 2006). As expected, the level of protein content within the flour samples was decreased significantly after starch isolation. Konjac starch contained the highest percentage (1.05%) of protein while the other starches have similar amounts. The protein content of taro observed here was slightly lower than what has been reported before i.e. 0.19-1.3% (Tattiyakul *et al*., 2006). For yam and sweet potato, the protein level was similar to that previously reported (0.5% and 0.45%, respectively) (Moorthy, 2002), while the protein levels of canna and cassava starches were higher than that reported in other studies (0.05-0.2% and 0.1%, respectively) (Piyachomkwan *et al*., 2002; Freitas *et al*., 2004). This difference might be caused by the starch isolation method, variation in botanical origin and local climate during cultivation (Jane *et al*, 1992; Moorthy, 2002).

All flours and starches observed here have a lower protein content compared to that of wheat flour (Zaidul *et al*., 2007). For some food production applications, the protein content of wheat flour is too high and can be diluted with other starches of lower protein content. This is the case with biscuit making. The protein content of the mixture required is around 7.0-8.5% for sweet biscuits or 8.4-10% for biscuit sponge (Radley, 1976). Therefore, the flours and starches studied here have the potential to partially substitute wheat flour to obtain composite flours with acceptable protein contents for certain food applications.

Canna and konjac flour had similar amounts of resistant starch (56.43% and 51.70%) and had the highest amount of resistant starch amongst all of the flour samples (Table 4.2.). Arrowroot contained a lower amount of resistant starch (33.24%) and cassava contained 19.25%. Taro and yam had comparable amounts of resistant starch (11.91% and 10.85%, respectively) while sweet potato had the lowest amount with only 4.68%. A low amount of resistant starch in sweet potato flour has been reported also by Liu *et al* (2006) with the amount of 3.4%. Since having the lowest amount of resistant starch, sweet potato flour would be the most digested among these assessed flours. Among the starch samples, canna contained the highest amount of resistant starch (70.87%) and therefore would be the least digested. This percentage of resistant starch in the canna starch was much higher than that of other starches such as konjac (20.96%), arrowroot (15.97%), yam (13.17%), cassava (10.36%), sweet potato (10.21%) and taro (3.30%).

The differences in the degree of digestibility among the samples assessed in this study are more likely due to the differences in their crystallinity. Starch with A-type crystallinity has inferior crystals due to the high proportion of short branch chain amylopectin. Thus, this type of starch is more susceptible to digestion by α-amylase. As a consequence, the A-type starch has a higher digestibility compared to the B-type starch (Jane *et al*., 1992). The results obtained in this study are in agreement with this statement. In general, starches with B-type of crystallinity such as sweet potato, taro, arrowroot and cassava have a higher digestibility compared to canna that has A-type (Srichuwong *et al*., 2005a). Others factors that might also influence digestibility are amylose content, particle size (Snow and O'Dea, 1981) and amylopectin chain length distribution (Srichuwong *et al.*, 2005a).

In this study, resistant starch content was negatively correlated (r= -0.974) with digestibility of the samples. A similar result has been reported previously (Gelencser *et al*., 2008). According to the author, interaction between resistant starches with other starch components may influence the digestibility by α-amylase. A significant negative correlation was also observed between amylose content and digestibility (r= -0.868). It was proposed that, the low amount of amylose might cause reduction in the compactness of the amorphous region of starch granules and subsequently increase susceptibility of starch toward α-amylase digestion (Sandstedt *et al*., 1961; Wickramasinghe and Noda, 2007).

Based on their proximate analysis, flours and starches studied here could bring benefits for some food applications. Having high amount of amylose, canna flour and starch are potential to partially replace wheat flour in snack food formulation to obtain products with a crunchy texture. Amylose within flour or starch could strengthen the dough, which in turn improves the forming and cutting properties of dough to produce snack foods with a crunchy texture (Taggart, 2004). As mentioned earlier, the low protein content of these flours and starches is beneficial to dilute protein content of wheat flour to produce composite flours that fulfill the requirement of protein content for certain food applications, for example biscuits making (Radley, 1976).

Table 4.2. The content of resistant and non-resistant starch, and digestibility of flours and starches extracted from taro, yam, sweet potato, canna, arrowroot, konjac, and cassava

Source	Resistant starch (%)	Non resistant starch (%)	Digestibility (%)
Flours			
Taro	10.85 ± 1.46[d]	30.83 ± 1.73[d]	74.04 ± 1.52[bc]
Yam	11.91 ± 0.29[d]	56.80 ± 5.93[c]	82.57 ± 1.79[ab]
Sweet potato	4.68 ± 0.74[d]	84.66 ± 1.23[a]	94.77 ± 0.72[a]
Canna	56.43 ± 4.43[a]	28.11 ± 1.21[d]	33.32 ± 2.70[d]
Arrowroot	33.24 ± 0.78[bc]	62.00 ± 3.51[bc]	65.11 ± 3.87[c]
Konjac	51.70 ± 0.14[a]	29.61 ± 2.97[d]	36.39 ± 3.28[d]
Cassava	19.25 ± 3.87[cd]	72.09 ± 2.97[ab]	78.95 ± 4.03[b]
Starch			
Taro	3.30 ± 1.22[d]	91.16 ± 2.66[a]	96.50 ± 1.32[a]
Yam	13.17 ± 0.80[cd]	80.69 ± 4.25[bc]	85.94 ± 1.36[bc]
Sweet potato	10.21 ± 0.41[d]	86.81 ± 4.12[ab]	89.46 ± 0.81[b]
Canna	70.87 ± 1.75[a]	22.11 ± 1.84[e]	23.77 ± 1.91[e]
Arrowroot	15.97 ± 0.05[c]	77.10 ± 4.38[bc]	82.81 ± 0.83[cd]
Konjac	20.96 ± 0.67[b]	73.92 ± 4.03[c]	77.88 ± 1.23[d]
Cassava	10.36 ± 1.22[d]	41.38 ± 2.96[d]	79.95 ± 2.56[d]

All data reported on dry basis and represent the mean of three replicates. Values followed by the same superscript in each column are not significantly different (p<0.05)

The high digestibility of some of these starchy materials might be beneficial for food preparations especially for infants and the elderly who require more readily digestible food (Radley, 1976). On the other hand, the low digestibility of canna flour and starch could be important in the prevention of obesity, diabetes and other related diseases, when they are used as a food ingredient (Liu *et al.*, 2006). Besides bringing nutritional advantages, the incorporation of flours or starches that contain resistant starch might also offer processing benefits especially in low-water systems due to its low water-binding capacity and negligible impact on dough viscosity and rheology. Moreover, in such a system, the presence of resistant starch might also bring textural benefits. A more expanded, light, and crispy texture could be obtained for snacks containing resistant starch (Taggart, 2004).

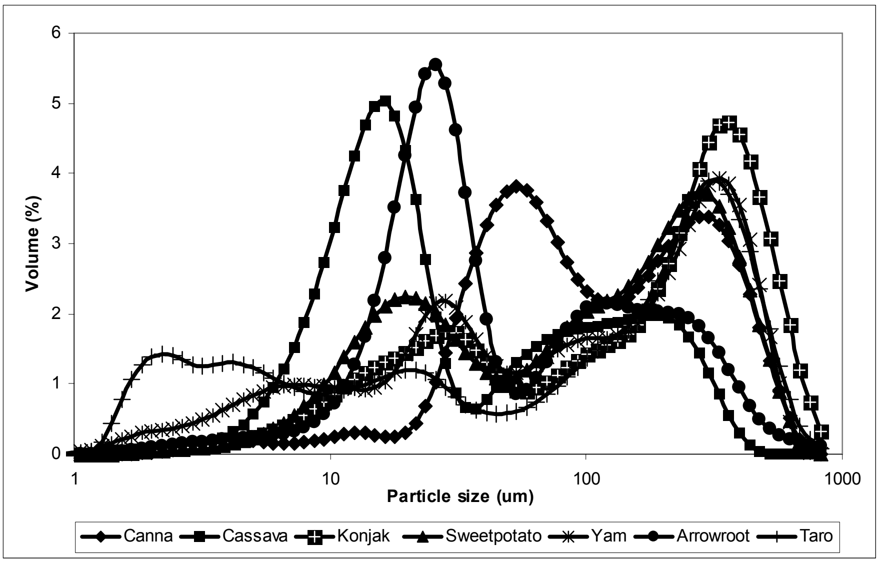
4.3.2 Particle size

Particle size distribution patterns of the flour samples are represented in Figure 4.1A. In general, all of flour samples had two distinct populations of granule. Sweet potato, taro, yam and konjac flours had a similar pattern of distribution with a high proportion of larger granules centered at 288.4; 315.8; 345.9; and 378.9 µm, respectively. A small proportion of small granules were also observed, indicated by the presence of the second peak at 19.65 µm for sweet potato; 2.42 for taro and 28.29 µm for both yam and konjac flours. The range of granule size of sweet potato and yam was not clearly different but was slightly lower than that of the taro and konjac flours. Thus, these two flours were more homogenous than taro and konjac flour. As opposed to cassava and arrowroot flours which had a different distribution pattern, these flours had high amount of small granules (17.14 and 27.03 µm), respectively. Cassava flour had a narrower size range than that of arrowroot. While, the proportion of small (53.51 µm) and large granules (315.8 µm) within the canna flour was not significantly different. It was predicted that the presence of smaller granules in sweet potato, taro, arrowroot, cassava and canna flour were mainly associated with starch granules. While for yam and konjac flour, the smaller granule could be related to particle clusters.

Among the starches, canna had the largest mean diameter of granule size (56 µm) followed by arrowroot (27.03 µm) and sweet potato (18.78 µm) (Figure 4.1B). Konjac and cassava had a same mean diameter (15.65 µm) while taro had the smallest (2.31 µm). The results obtained for canna, taro, sweet potato, konjac was in agreement with previous studies (Santacruz *et al.*, 2003; Hung & Morita; 2005; Srichuwong *et al.*, 2005b; Zaidul *et al.*, 2007). However, the mean diameter for arrowroot and yam starch was lower than previously reported by Srichuwong *et al* (2005b). As expected, further purification of flour samples eliminated the presence of other components such as lipids and proteins. Thus, purification resulted in starches with more homogenous granular size distribution (Figure 4.1B). Arrowroot starch was the most homogenous while taro starch was the least homogenous. In general, there were two types of distribution patterns in the starch samples. Canna and arrowroot starches showed a unimodal distribution while taro, yam, sweet potato, konjac and cassava showed a bimodal pattern.

The size of starch granule is important in determining the suitability of starch for certain food application (Tattiyakul *et al*., 2005; Huang *et al*., 2006). In this study, taro starch, which has a small particle size, could be used for several food products especially which require a smooth texture (Tattiyakul *et al*., 2005). In snack food production, the fine granule of taro starch could improve the binding and reduce the breakage of the final products (Huang *et al*., 2006). The fine particle size of taro starch might allow a better light reflection on the porous structure of bread. In turn, it might yield whiter breadcrumbs, which is more preferable by the consumers (Moorthy, 2002).

A



B

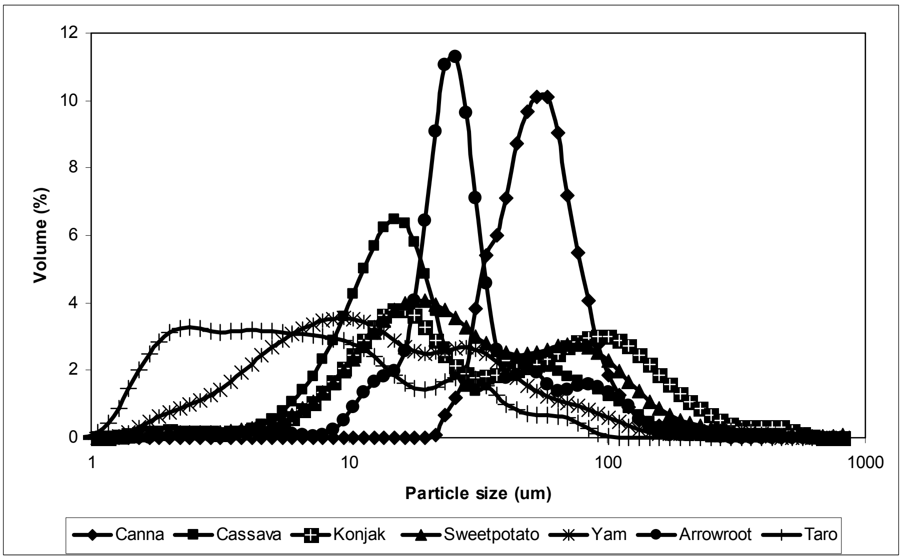


Figure 4.1. Particle size distribution of flours (A) and starch (B) isolated from taro, cassava, sweet potato, canna, arrowroot, konjac, and cassava

4.3.3 Swelling power

In general, there were two patterns of swollen granules of the flour samples shown during heating from 50 to 90°C (Figure 4.2A). The first group consisted of yam, taro and cassava. Their granules started to swell at ~60°C, then, the swelling power was increased steadily with the temperature from 70 to 90°C. The swelling powers of these flours were not significantly different throughout this temperature range and at 90°C these granules maintained their integrity. The second group consists of sweet potato, canna, konjac and arrowroot. Except for canna, granules of these flours start to swell sharply at ~70°C and reached their maximum swelling power at 80°C. However, as opposed to the first group, further heating to 90°C has caused these granules to lose their integrity. Overall, at 90°C, swelling power of flours within the second group was higher than that of flours in the first group which may be due to the extensive and stronger intermolecular bonding within the granules of flours in the first group (Leon *et al*., 2006).

The amount of other components such as amylose, protein, lipids, amylopectin, phosphorous, and particle size may influence the swelling pattern (Tester and Morrison, 1990; Moorthy, 2002; Thitipraphunkul *et al*., 2003). Amylose could reinforce the internal network and restrict the swelling ability (Ridley, 1976). While proteins may lower the swelling power by being embedded in the starch granules within a stiff protein matrix and subsequently limit the access of water into the starch granule. However, despite of their reducing effects on swelling power as mentioned above, in this study, protein and amylose contents showed a positive but weak correlation with swelling power (r= 0.109 and r= 0.498, respectively). In this case, it was proposed that other factors might delude the effects of amylose and protein content on swelling power.

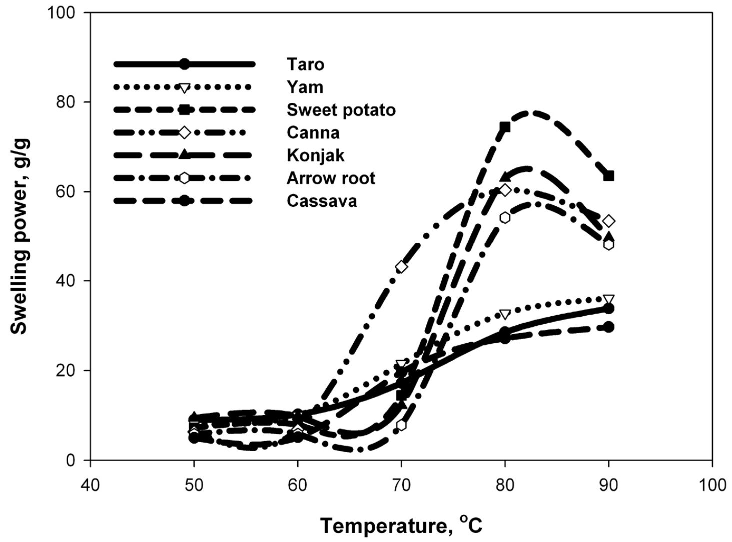
Among the starch samples, canna showed the highest swelling power (Figure 4.2B). Sweet potato and arrowroot had an intermediate value while yam, taro and konjac had the lowest swelling power. The high swelling power of canna starch has been reported in other studies (Wickrsmasinghe *et al*., 2005; Peroni *et al*., 2006). The authors proposed that the high phosphorous content, the large granule size and the high number of hydrogen bonds formed between the very long-branch chains of amylopectin and water would contribute to the high swelling power of canna starch.

Having a high swelling power, canna starch is suitable for food applications that require a high swelling ability. In noodle making, this starch might be suitable for noodle types, which require a soft and smooth texture with a high elasticity such as Yellow alkaline noodle (YAN) and Japan noodle. However, this starch is not suitable for Chinese wet noodles, which requires a firmer bite and springy texture (Fu, 2008).

4.3.4 Pasting properties

Among flour samples, canna and sweet potato had similar peak viscosity and higher than that of the other flours. Taro, yam, arrowroot and konjac had similar peak viscosities while cassava had the lowest (Table 4.3.; Figure 4.3A). Cassava flour that had the lowest peak and breakdown viscosity was the most resistant toward the heat and stirring treatment. The highest setback viscosity was observed in yam and canna flour indicating the high retrogradation tendency of these flours (Leon *et al*., 2006; Zaidul *et al*., 2007). The overall viscosity of canna starch was higher than that of the other starches. The viscosity of canna starch was even higher than that of its respective flour. This difference could be mainly due to the difference in properties of these starches. These presence of other components such as lipids and protein that may interfere with the pasting process and the lower amount of the starch content in the flour could also attributed to this difference. However, this trend was not observed from the other starch samples that had lower viscosities than their respective flour.

A



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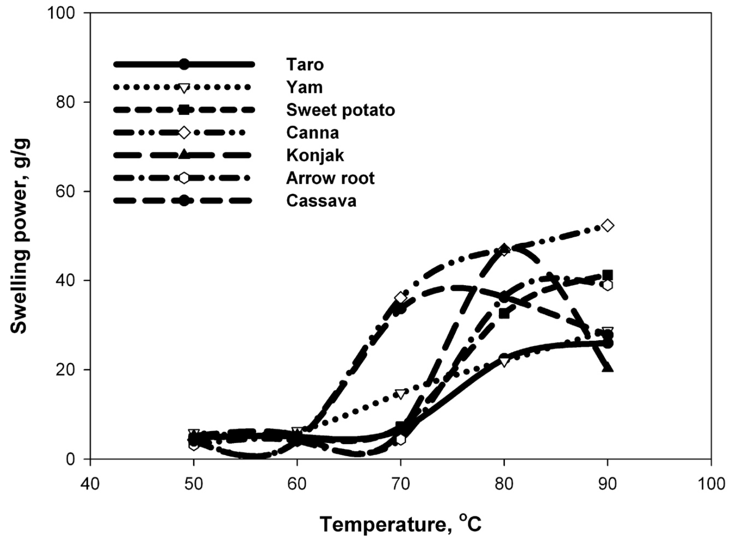


Figure 4.2. Swelling power of flours (A) and starches (B) isolated from taro, cassava, sweet potato, canna, arrowroot, konjac, and cassava

In the current study, swelling power and amylose content appeared to be the major factors affecting pasting properties of flour and starch samples. A significant positive correlation was observed between swelling power and peak ($r = 0.783$, $p \leq 0.05$), breakdown ($r = 0.815$), and final viscosities ($r = 0.785$). Similarly, amylose content was also significantly positively correlated with peak viscosity, breakdown, and final viscosity ($r = 0.817$, 0.788, and 0.820, respectively). Swelling power and amylose content could influence some of the pasting properties of starch since the pasting process itself involves granular swelling, leaching out of amylose, and disruption of granules during heating as has been described previously (Tester and Morisson, 1990).

In general, the viscosity of samples obtained in this study was significantly lower than reported elsewhere (Collado *et al*., 1999; Srichuwong *et al*., 2005b). Irradiation and activity of α-amylase could be some of the causes of this drastic viscosity reduction (Yadav *et al*., 2006; Pimpa *et al*., 2007). Another factor that might have contributed to the lower viscosities in this study was the effect of storage time. The increasing of disulphide bonds formation between protein networks that can occur during starch aging could lower the pasting viscosity of starch (Martin and Fitzgerald, 2002).

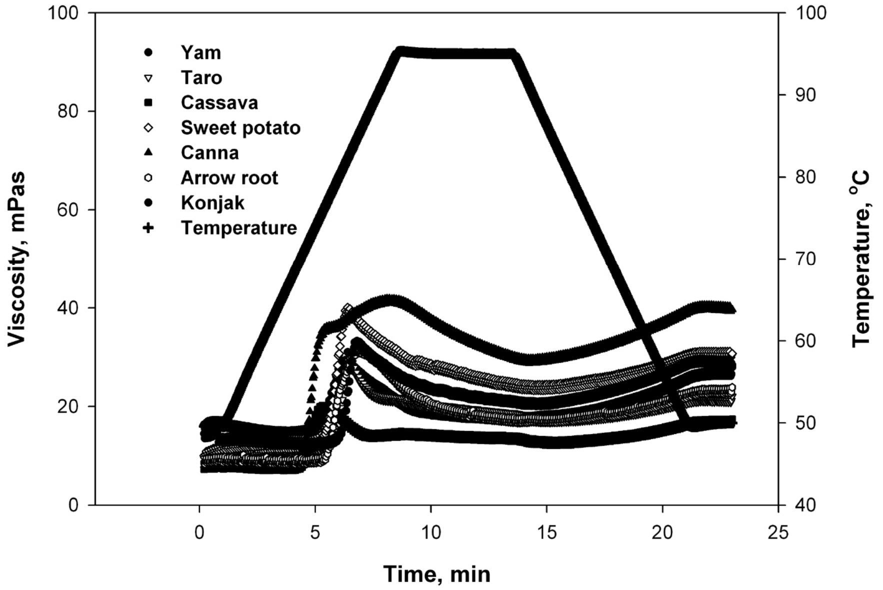
All flours and starches examined in this study have lower viscosity (peak, breakdown, setback and final viscosities) compared to that of wheat flour (Zaidul *et al*., 2007). The low viscosity of the flour and starches in this study is beneficial for some food applications such as confectionary (soft candy and gum drops), weaning foods, and other liquid foods (Radley, 1976; Muyonga *et al*., 2001). In addition, these low viscosity flours and starches can be used to avoid the use of chemically modified starch which attempted to produce starch with low viscosity such as oxidized starch and thin boiling starch (Hoover, 2001; Cornell, 2004). The low setback value of these samples indicates their low retrogradation tendency and is important for frozen or cold storage foods. In addition, the lower breakdown viscosity of these samples compared to that of wheat flour reflected the more stable these samples toward heat and mechanical treatment during processing. This property is crucial especially for food production that involved heat and mechanical treatment for example canned foods (Radley, 1976).

Table 4.3. Pasting characteristics of flours and starches extracted from taro, yam, sweet potato, canna, arrowroot, konjac, and cassava

Source	Pasting characteristics							
	Peak Time (sec)	Past Temp (°C)	Peak vis (cP)	H strength (cP)	B down (cP)	SFP (cP)	SFT (cP)	Final vis (cP)
Flours								
Taro	389.77±0.06^{c}	62.83±1.25^{bc}	30.00±0.69^{b}	16.84±0.45^{c}	13.16±0.47^{c}	-7.91±0.43^{bc}	5.25±0.11^{c}	22.09±0.36^{c}
Yam	377.80±0.00^{c}	58.53±0.93^{c}	31.03±2.34^{b}	18.13±1.65^{c}	12.91±1.66^{c}	-2.66±0.57^{a}	10.25±1.49^{ab}	28.38±1.81^{b}
Sweet potato	385.77±6.99^{c}	66.63±1.60^{ab}	41.19±1.39^{a}	23.29±1.24^{b}	17.90±0.72^{a}	-10.46±3.13^{c}	7.44±2.51^{bc}	30.72±2.18^{b}
Canna	485.85±11.95^{a}	65.15±0.87^{b}	41.68±2.38^{a}	29.89±2.53^{a}	13.79±0.81^{c}	-2.70±1.17^{a}	9.09±1.22^{ab}	38.98±2.61^{a}
Arrowroot	415.50±3.73^{b}	70.13±0.44^{a}	32.11±1.84^{b}	16.35±0.44^{c}	15.76±1.42^{ab}	-8.22±0.49^{bc}	7.54±0.94^{bc}	23.89±1.35^{c}
Konjac	407.77±0.06^{b}	66.09±2.72^{ab}	33.76±0.49^{b}	21.41±0.61^{b}	15.55±0.22^{ab}	-5.13±0.87^{ab}	9.15±1.00^{b}	28.63±1.07^{b}
Cassava	317.83±0.06^{d}	64.42±2.43^{b}	20.21±0.42^{c}	12.00±0.24^{d}	8.20±0.29^{d}	-2.81±0.13^{a}	5.39±0.19^{c}	17.39±0.55^{d}
Starch								
Taro	378.10±0.00^{ab}	73.66±9.44^{a}	14.96±0.91^{e}	9.42±0.14^{c}	5.53±0.78^{d}	-1.04±1.04^{a}	4.50±0.26^{b}	13.92±0.12^{d}
Yam	381.00±21.2^{ab}	66.84±6.88^{b}	18.26±0.58^{cd}	9.79±0.26^{c}	8.47±0.85^{bc}	-3.07±1.30^{a}	5.40±0.45^{b}	15.42±0.71^{cd}
Sweet potato	380.85±3.05^{ab}	59.89±5.52^{d}	21.79±0.21^{b}	12.12±0.03^{bc}	9.67±0.19^{b}	-2.70±0.22^{a}	6.97±0.03^{b}	19.09±0.00^{b}
Canna	373.80±6.93^{b}	66.19±1.33^{b}	71.30±1.17^{a}	35.18±1.69^{a}	36.12±1.02^{a}	-23.05±1.52^{b}	13.07±2.14^{a}	48.25±2.57^{a}
Arrowroot	383.90±0.00^{ab}	68.72±1.50^{b}	18.95±0.28^{c}	11.67±0.28^{bc}	7.29±0.01^{cd}	-0.81±0.19^{a}	6.47±0.20^{b}	18.14±0.47^{bc}
Konjac	399.83±3.41^{a}	62.60±0.91^{c}	18.94±0.85^{c}	13.56±1.87^{b}	5.38±1.34^{d}	-0.98±0.41^{a}	4.39±1.65^{b}	17.96±1.07^{bc}
Cassava	361.80±6.93^{b}	61.37±0.93^{c}	16.24±0.77^{de}	10.44±0.72^{c}	5.81±0.48^{d}	-1.16±0.76^{a}	4.66±0.98^{b}	15.10±0.49^{cd}

Each mean presents an average of three independent observations; Values followed by the same superscript in each column are not significantly different (p<0.05). Peak T, peak time; Past T, pasting temperature; Peak vis, peak viscosity; H strength, holding strength; B down, breakdown; SFP, setback from peak; SFT, set back from through; Final vis, final viscosity.

A



B

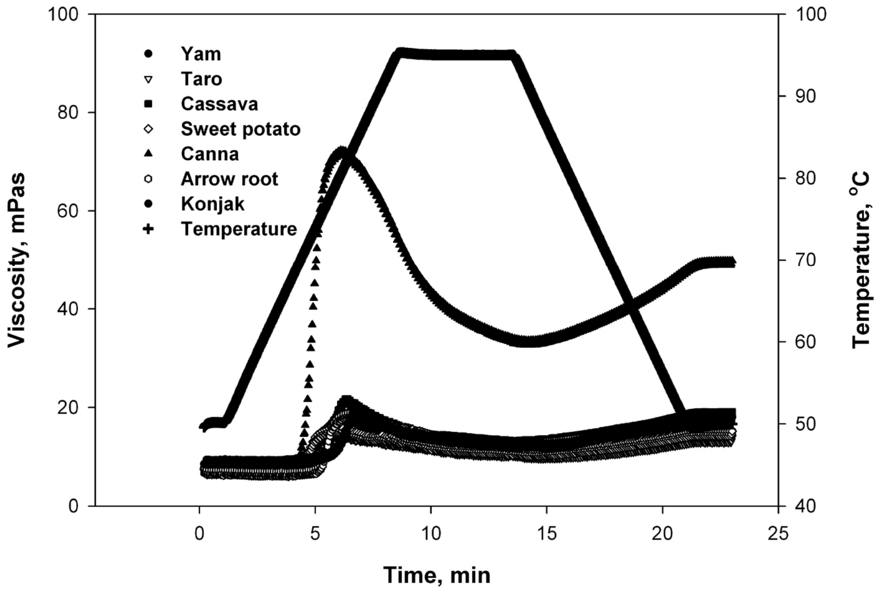


Figure 4.3. Pasting properties of flours (A) and starches (B) isolated from taro, cassava, sweet potato, canna, arrowroot, konjac, and cassava

4.3.5 Thermal properties

The thermal properties of the flour and starch samples are presented in Table 4.4. The onset and peak temperature of gelatinisation of konjac starch were the highest among the six starches. This indicated the higher stability of its starch crystallites. The perfectness of konjac starch was also reflected by the high ΔH (gelatinisation enthalpy) value. A number of factors may influence gelatinisation temperature, including the molecular architecture of amylopectin, the formation of lipid complexes, degrees of crystallinity, and the proportion of crystalline regions (Kaur and Singh, 2005). In the current study, protein content had a negative correlation with gelatinization temperature (r= -0.025, -0.061 and -0.061 for To, Tp, and Tc, respectively). Similar correlation between amylopectin content and To, Tp, and Tc was also observed (r= -0.025, -0.061 and -0.061, respectively). The negative correlation between amylopectin content and gelatinization temperature could be caused by the irradiation which has been applied to the samples. Irradiation may decrease the crystallinity of amylopectin molecules in the samples by cutting the long-branch chain of amylopectin into short-straight chain molecules (Jane *et al*., 1997). Thus, less energy was required to initiate the gelatinisation and as consequence, a lower gelatinization temperature was required (Hoover and Ratnayake, 2002).

Overall, the gelatinisation temperature and ΔH of the starch samples examined in this study was lower than previously reported (Hung and Morita, 2005; Srichuwong *et al*., 2005b; Jayakordy *et al*., 2007; Puncha-arnon *et al*., 2007). Differences in genetic, environmental factors, time of harvest, and seasonal variations might cause this discrepancy. The lower gelatinization temperatures of flour and starch samples examined in this study bring some benefits in some food applications especially when some of other ingredients added to the product are heat-labile at high temperature. These flours and starches with lower gelatinisation temperature also could be applied in food processing that involve a low temperature such as batter coating or processed meat products. In addition, this low gelatinisation temperature allow easier cooking. As a consequence, the efficiency of food processing could be increased by reducing the time and heat during cooking process (Radley, 1976; Moorthy, 2004).

Table 4.4. Thermal properties of flours and starches extracted from taro, yam, sweet potato, canna, arrowroot, konjac, and cassava

Source	Gelatinisation characteristics			
	To (ºC)	Tp (ºC)	Tc (ºC)	ΔH (J/g dry starch)
Flours				
Taro	51.04[d]	51.82[e]	55.89[d]	2.89[d]
Yam	61.99[cd]	73.98[bc]	81.80[b]	7.47[b]
Sweet potato	71.23[b]	77.37[ab]	82.86[b]	4.14[c]
Canna	66.87[c]	70.52[c]	79.41[bc]	4.79[c]
Arrowroot	69.63[c]	74.87[bc]	80.91[b]	2.92[d]
Konjac	73.87[a]	81.20[a]	89.62[a]	1.89[e]
Cassava	64.90[c]	71.46[c]	76.52[bc]	2.25[de]
Starch				
Taro	69.73[c]	75.38[b]	80.23[b]	7.66[b]
Yam	61.36[cd]	69.45[c]	76.67[bc]	7.76[b]
Sweet potato	62.96[cd]	73.57[bc]	80.55[b]	11.35[a]
Canna	64.12[c]	69.87[c]	77.56[bc]	11.49[a]
Arrowroot	65.00[c]	72.54[c]	84.03[b]	11.75[a]
Konjac	71.11[b]	77.76[a]	82.66[b]	11.11[a]
Cassava	61.13[cd]	68.29[c]	74.25[c]	8.15[b]

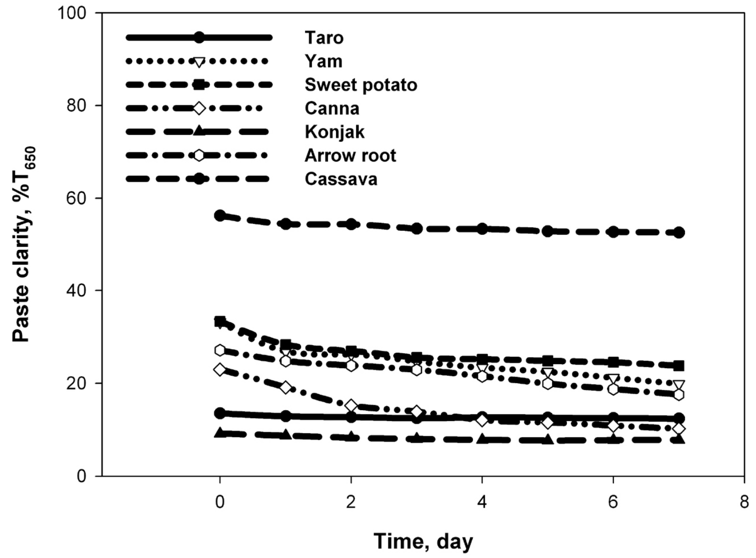
All means present the average of three independent replications. Values followed by the same superscript in each column are not significantly different (p<0.05). To, Tp, and Tc indicate temperature of onset, midpoint and end of gelatinisation, respectively. ΔH indicates enthalpy of gelatinisation (J/g dry starch)

4.3.6 Paste clarity

Paste clarity of the flour and starch samples is presented in Figure 4.4A and B. Cassava had the highest paste clarity compared to the other flours. In addition, the clarity of cassava paste was stable during storage at cold temperatures. The high clarity and stability of cassava paste might be due to its low amount of amylose. According to Craig *et al* (1989), the retrogradation of amylose may cause a rapid opacification, aggregation and phase separation, which in turn may decrease the clarity of paste. This result confirmed a previous study by Achille *et al*. (2007). Other factors that may influence paste clarity are phosphate, protein, and lipid content (Craig *et al*., 1989).

Upon starch extraction, paste clarity of all starches was increased compared to their respective flours (Figure 4.4B.). Cassava and yam starch were the clearest as opposed to konjac starch that was the most opaque paste. Among the starch samples, canna, yam and konjac were the least stable during cooling storage. This might be due to their relatively high amylose content compared to the other starches. Based on their paste clarity, sample that has clearer paste such as cassava and yam could be used for food applications that require more paste clarity such as fruit fillings and jellies (Moorthy, 2004). In the other side, sample that has more opaque pasta for example konjac flour and starch might be used for puddings, sauces, gravies, dressings, and mayonnaise (Craig *et al*., 1989).

A



B

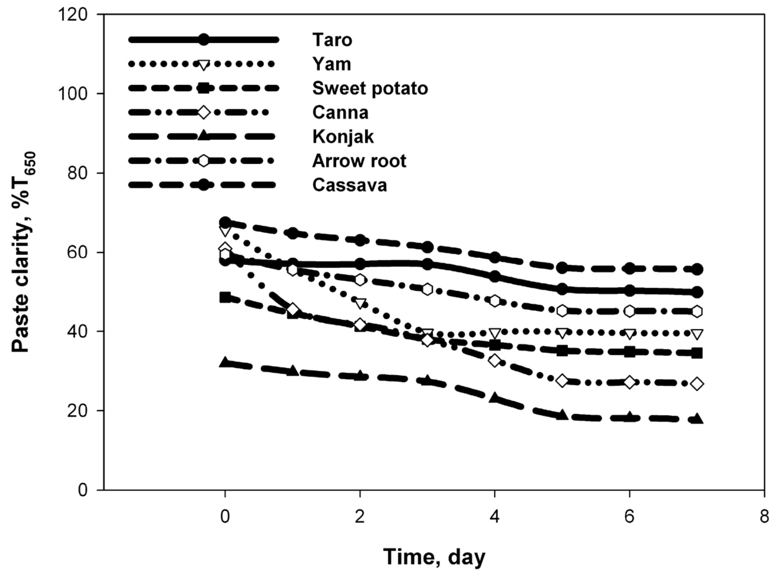


Figure 4.4. Paste clarity of flours (A) and starches (B) isolated from taro, cassava, sweet potato, canna, arrowroot, konjac, and cassava.

4.4 CONCLUSION

This study revealed that flours and starches extracted from tubers and roots collected from Indonesia have some differences in terms of their physicochemical properties. The relatively high starch content of these flours and starches make them potential alternative sources of carbohydrate. These extracted materials also showed potential applications in the food industry. The low digestibility of canna and konjac flour offers health benefits in preventing obesity, hypertension, and other related diseases. In contrast, the high digestibility of the other flours and starches are good for the elderly and young children. In addition, the high resistant starch content of these flours and starches offers processing and textural benefits especially in low-water systems. The low viscosity of these materials is desirable for food applications that require lower viscosity such as soft candy, weaning foods, and others liquid foods. The low retrogradation of flours and starches examined in this study compared to that of wheat flour is important in frozen and cold storage food products. Whereas, the high paste clarity of these samples is important for food products that require a clear paste such as fruit filling, candy, and Turkish delight. Flour and starches that give an opaque paste could be used for salad dressings, sauces, mayonnaises, and puddings. In the future, the possibility of these samples to partially substitute wheat flour to produce composite flours with new properties that are suitable for certain food application needs to be studied.

CHAPTER 5

Physicochemical properties of wheat-canna and wheat-konjac composite flours

5.1 INTRODUCTION

Indonesia has many tropical root and tuber crops that can be used as alternative sources of carbohydrate. These crops include taro (*Colocasia esculenta)*, yam (*Dioscorea alata*), sweet potato (*Ipomoea batatas*), canna (*Canna edulis*), konjac (*Amorphophallus campanulatus)*, arrowroot (*Marantha arundinaceae*), and cassava (*Manihot uttilisima*) (Deshaliman 2003; Aptindo, 2004). Flours and starches isolated from roots and tubers of these plants usually have a higher viscosity compared to that of cereal flours, which allows them to be used as thickening or gelling agents in some food products. In addition, these isolated materials have higher paste clarity, which is important for certain food applications. Compared to cereal flours and starches, these materials also have less starchy flavors (Radley, 1976; Moorthy, 2002). Moreover, these materials also offer health benefits especially in preventing obesity, constipation, cardiovascular disease, diabetes and colon cancer due to the high amount of fiber content (Chen et al., 2003b). The absence of gluten within these materials may help provide nutrition for those who have celiac disease (CD) (Hung and Morita, 2005).

Except for cassava and sweet potato, many of these starchy materials have not been utilized optimally due to the lack of knowledge of suitable processing techniques and product development (Deshaliman, 2003; Nasution, 2003; Aptindo, 2004). Canna and konjac are among these underutilized roots and tubers even though they have been consumed as a source of carbohydrate by local people in rural areas but not as a food ingredient. Flour and starch isolated from canna and konjac rhizomes have unique characteristics that may be important for use in some food applications (Thitipraphunkul et al., 2003; Hung and Morita, 2005). Canna starch has a large particle size, high amylose and phosphate content, as well as a high paste viscosity and clarity (Piyachomkwan et al., 2002; Santacruz et al., 2003; Thitipraphunkul et al., 2003; Srichuwong et al., 2005a). Due to its high paste clarity, canna starch has been used for making transparent noodles (Hung and Morita, 2005). In addition, the high amount of resistant starch of canna flour and starch maybe beneficial in preventing cardiovascular and other related diseases (Srichuwong et al., 2005a). Konjac flour has a high viscosity, which may allow the application of this flour to be used for thickening, a gelling agent and for water binding in food products (Nishinari et al., 1992). Konjac flour also may offer health benefits due to its high dietary fiber content. Dietary fibre has been shown to be beneficial in the digestive system for the prevention of colon cancer and helps in maintaining a moderate level of blood glucose and aids in cholesterol reduction in preventing obesity, constipation, arteriosclerosis and diabetes (Chen et al., 2003b).

Despite the availability of starchy materials derived from roots and tubers as mentioned above, rice and wheat are still the main sources of carbohydrates in Indonesia. The need for wheat in Indonesia is relatively high and nearly all of it is fulfilled by import. Cultivation of wheat in this country has been hampered by the incompatibility between the tropical climate and the growth requirements of this plant (Nasution, 2003). Based on the end products, most imported wheat is used for the production of wet noodles (30%), bread (25%), and instant noodles (20%). The rest is used in the biscuit industry (15%), households (5%), and fried foods (5%) (Aptindo, 2004). With the increase of wheat prices from time to time accompanied by the changes in consumption patterns and peoples preference toward wheat flour-food products, fulfillment of domestic need of wheat by import is a large financial burden. Therefore, to reduce the dependency on wheat, partially substituting wheat flour with other flours and starches derived from underutilized roots and tubers, which are widely available in Indonesia, may provide a solution to this need.

The objective of this study was to determine the level of substitution of both canna and konjac flours for wheat flour, which would still display physicochemical properties suitable for use in food applications in the place of wheat flour alone. Therefore, the physicochemical properties of these substituted mixtures were examined and compared to unsubstituted wheat flour. The information obtained in this study may be useful in helping to lessen the dependency on wheat flour as the main source of carbohydrate in Indonesia and also the results may be used to broaden the application of canna and konjac flours in the food industry with particular emphasis on biscuit and noodle production.

5.2 MATERIALS AND METHODS

5.2.1 Materials

Matured roots of canna (*Canna edulis* var Ganyong merah), konjac (*Amorphophallus campanulatus* var Mutiara) were collected from Tulung Agung (East Java, Indonesia). Dry chips were prepared by drying the thick chips of these roots in an oven (30C; 40 hours). As a quarantine perquisite, gamma irradiation (25 kGy) was then applied to these materials (Steritect, Dandenong, Victoria). Subsequently, these dried chips were milled and sifted (300-μm sieve) to produce flours. Wheat flours with different protein contents i.e: 11.1% (High protein wheat flour or HPW) and 8.7% (Low protein wheat flour or LPW) were provided by Allied Mills Company, Ballarat, Victoria, Australia. Composite flours were prepared by mixing canna or konjac flours with each of the wheat flours (HPW or LPW) at 0, 25, 50,75, and 100% of canna or konjac flours (on weight basis) in the mixtures.

5.2.2 Proximate analysis of composite flours

Moisture and protein contents of composite flours were determined using AACC (2000) standard method number #44-15A and #46-12, respectively. Amylose content was determined using the method proposed by Hoover & Ratnayake (2005). To avoid the interference of lipids on amylose determination, lipids within the samples were firstly removed with 75% n-propanol for 7 hours in a Soxhlet extractor. In this study, amylose and amylopectin content were expressed relative to Total Starch content. Therefore, amylopectin content was calculated by the formula: % Total starch content - % amylose content. Total starch assay Kit (Megazyme, Ireland) was used to measure the amount of total starch, while a Megazyme resistant starch assay kit (Megazyme, Ireland) was used to measure resistant and non-resistant starch contents. The digestibility was determined based on the ratio of non-resistant starch to total amount of resistant and non-resistant starch (Liu et al., 2006).

5.2.3 Swelling power

Swelling power was determined by heating the composite flour suspensions (0.5%) in a water bath (60, 70, 80 and 90^{o}C; 30 min) with constant stirring to avoid sedimentation. Pellets were obtained after centrifugation (Sorvall) at 1,000-x *g* for 15 min at 20^{o}C. The pellets were weighed and then oven dried until they reached a constant weight. Swelling power (g/g) was expressed as the sedimented fraction and was weighed and its mass related to the mass of dry starch was expressed as swelling power (g/g) (Santacruz et al., 2003).

5.2.4. Color

Color measurements of samples were carried out using a Minolta CM-3600d model spectrophotometer. Each sample was scanned at the different locations to determine $L*$, $a*$, and $b*$ values. The $L*$ value indicates the lightness with 0-100 representing dark to light. The $a*$ value indicates the degree of red-green color. A higher a positive $a*$ value indicates more red. While, the $b*$ values means the degree of yellow-blue color. A higher positive $b*$ value indicates more yellow (Sandhu et al., 2007).

5.2.5 Pasting properties

A starch cell (Physica SmartStarch analyzer-Anton Paar) attached to a CR/CS rheometer (Physica MCR 33011, Anton Paar, GmbH, Germany) was used to determine the pasting properties of composite flour suspensions (7% w/w). Samples were equilibrated at 50°C for 1 min, then heated from 50 to 95°C at 6°C/min, held at 95°C for 5 min, cooled to 50°C at 6°C/min, and held at 50°C for 2 min. The speed was 960 rpm for the first 10s, then 160 rpm for the reminder of the experiment (Jayakordy et al., 2007).

5.2.6 Gel firmness

After rheometer testing, the paste was poured into a plastic container. A few drops of vegetable oil were added onto the surface of the paste to prevent evaporation. The paste was then kept overnight at room temperature. The firmness of gels was tested by force in compression with the TA.XT 2 Texture Analyzer using a 0.5-cm diameter cylinder probe. Texture profile analysis was carried out with a test speed of 1.00 mm/sec. The test strain was set at 50%. Three determination was made per sample.

5.2.7 Thermal properties

The thermal properties including onset (To), peak (Tp), conclusion (Tc) temperature, and gelatinization enthalpy (ΔH) of the composite flours were determined using a Differential scanning calorimetry (DSC-7, Perkin Elmer, Norwalk, CT, USA). Deionized water (11 µl) was added to 3 mg of sample in an aluminum pan (BO160932). The sample was kept overnight at room temperature before analysis. The sample was heated from 20 to 100°C with 10°C/min heating rate. An empty aluminum pan was used as a reference (Ratnayake et al., 2001).

5.2.8 Statistical analysis

A randomized block design was applied in the design of all experiments, with tubers and replications (block) as the main effects. This block structure was repeated at least three times with at least 2 sub samplings. Results were analyzed using a General Linier Model (SAS systems, 1996) with a level of significance preset at $p<0.05$.

5.3 RESULTS AND DISCUSSION

5.3.1 Chemical properties

The chemical composition of wheat-canna composite flours (High protein wheat-canna/ HPWC and Low protein wheat-canna/LPWC) is presented in Table 5.1. From this table, it can be seen that the levels of total starch, amylose and amylopectin in the composite flours did not alter with the different percentage substitution with the canna flour. In contrast, the percentage of protein decreased significantly with the increasing level of canna flour. Wheat flour with a protein content ranging from 8.4 to 10% is suitable for biscuit sponge making, while flour with lower protein content 7.0-8.5% is good to make sweet biscuits (Radley, 1976). Therefore, based on their protein content, substitution of High protein wheat (HPW) flour with 50% of canna flour or replacement of Low protein wheat (LPW) with 25% of canna flour can produce composite flours that are suitable for sweet biscuit production. While, composite flour that is suitable for sponge biscuit making can be obtained by substituting HPW flour with canna flour at 75:25 ratio or by using the LPW flour alone.

As for biscuit making, different types of noodles have differing requirements for protein content (Shiau and Yeh, 2001; Fu, 2008). White salted noodles (WSN) are generally made from wheat flour having 8-11% protein content while Yellow alkaline noodles (YAN) are made from flour with protein content between 9-13%. Instant noodle requires wheat flour with a protein content ranging from 8.5-12.5%, while udon requires flour with 9-9.5% protein content. Therefore, based on protein content, substitution of HPW flour with 25% of canna flour may be used to replace HPW flour in WSN, YAN, instant noodle, and udon making. However, all of the wheat-canna composite flours in this study would not be suitable for Chinese wet noodles production as these require a high protein content (11.0 - 12.5%) (Charles et al., 2007).

Table 5.1. Chemical composition of wheat-canna composite flours

Source	Protein (%)	Total Starch (%)	Amylose (%)	Amylopectin (%)	Moisture (%)
HPWC					
HPWC 100:0	11.10±0.00[a]	91.77±5.77[a]	26.03±1.46[a]	65.74±6.26[a]	13.90±0.00[b]
HPWC 75:25	9.37±0.00[b]	91.40±4.20[a]	26.51±1.43[a]	64.89±4.86[a]	13.17±0.03[d]
HPWC 50:50	7.64±0.01[d]	91.04±2.69[a]	26.99±1.45[a]	64.05±3.53[a]	12.43±0.06[e]
HPWC 25:75	5.92±0.07[g]	90.68±1.50[a]	27.46±1.53[a]	63.22±2.35[a]	11.70±0.09[f]
HPWC 0:100	4.19±0.01[i]	90.32±1.65[a]	27.95±1.66[a]	65.37±1.69[a]	10.96±0.12[g]
LPWC					
LPWC 100:0	8.70±0.00[c]	91.77±5.79 [a]	27.93±1.94[a]	63.84±5.87[a]	14.20±0.00[a]
LPWC 75:25	7.57±0.00[e]	95.47±1.37[a]	26.74±1.70[a]	68.73±1.79[a]	13.39±0.03[c]
LPWC 50:50	6.44±0.01[f]	93.75±1.45[a]	27.13±1.56[a]	66.62±1.54[a]	12.58±0.06[e]
LPWC 25:75	5.32±0.01[h]	92.03±1.54[a]	27.93±1.54[a]	64.10±1.51[a]	11.77±0.09[f]
LPWC 0:100	4.19±0.01[i]	90.32±1.65[a]	27.95±1.66[a]	62,37±1.69[a]	10.96±0.12[g]

All data reported on dry basis and represent the mean of four replicates. Values followed by the same superscript in each column are not significantly different (p<0.05); HPWC: High protein wheat-canna; LPWC: Low protein wheat-canna.

Table 5.2. Chemical composition of wheat-konjac composite flours

Composite flours	Protein (%)	Total Starch (%)	Amylose (%)	Amylopectin (%)	Moisture (%)
HPWK					
HPWK 100:0	11.10 ± 0.00[a]	91.77 ± 5.79[a]	26.03±1.46[ab]	65.74±6.26[ab]	13.90 ± 0.00[b]
HPWK 75:25	9.88 ± 0.01[b]	84.39 ± 4.58[cd]	25.65±1.38[abc]	58.74±5.34[abc]	12.80 ± 0.02[d]
HPWK 50:50	8.67 ± 0.02[c]	77.01 ± 3.38[ef]	25.28±1.45[cd]	51.73±4.48[cd]	11.70 ± 0.04[f]
HPWK 25:75	7.45 ± 0.02[e]	69.64 ± 2.25[g]	24.65±1.63[de]	44.69±3.74[de]	10.60 ± 0.07[g]
HPWK 0:100	6.23 ± 0.03[g]	62.26 ± 1.31[h]	23.96±1.91[e]	38.30±3.20[e]	9.50 ± 0.09[h]
LPWK					
LPWK 100:0	8.70 ± 0.00[c]	97.19 ± 1.32[a]	27.13±1.94[a]	70.06±2.17[a]	14.20 ± 0.00[a]
LPWK 75:25	8.08 ± 0.01[d]	88.46 ± 1.08[bc]	25.94±1.63[bcd]	62.52±1.92[abc]	13.03 ± 0.02[c]
LPWK 50:50	7.47 ± 0.02[e]	77.73 ± 0.99[de]	26.08±1.50[abc]	51.65±2.07[bcd]	11.85 ± 0.04[e]
LPWK 25:75	6.85 ± 0.02[f]	70.99 ± 1.08[fg]	24.78±1.61[d]	46.21±2.54[de]	10.68 ± 0.07[g]
LPWK 0:100	6.23 ± 0.03[g]	62.26 ± 1.31[h]	23.96±1.91[e]	38.30±3.20[e]	9.50 ± 0.09[h]

All data reported on dry basis and represent the mean of three replicates. Values followed by the same superscript in each column are not significantly different (p<0.05); HPWK: High protein wheat-konjac LPWK: Low protein wheat-konjac

Table 5.2 shows the physicochemical properties of wheat-konjac composite flours (High protein wheat-konjac or HPWK and Low protein wheat-konjac or LPWK). The total starch of HPWK and LPWK composite flours was decreased significantly with the increasing amount of konjac flour in the mixture. The percentages of amylose and amylopectin tended to decrease gradually with the increasing amount of konjac flour in the mixture, even though the reduction was not significant. The increasing amount of konjac flour from 0 to 100%, decreased the protein content in all of the wheat-konjac composite flours. Based on the protein requirements for biscuit production, flour that would be suitable for sweet biscuit making can be obtained by substituting HPW flour with 50 and 75% of konjac flour or by replacing LPW flour with 25 or 50% of konjac flour in the mixture. The use of LPW flour in sponge biscuit production can be replaced by substituting HPW flour with 25% or 50% of konjac flour.

In terms of noodle production, the use of HPW and LPW flours in WSN making can be replaced by substituting HPW flour with up to 50% of konjac flour or by substitution of LPW flour with up to 25% of konjac flour. Substitution of HPW flour with 25% of konjac flour might be used to replace the HPW flour in YAN production. Substituting HPW flour with up to 50% of konjac flour can produce flours suitable for instant noodle. This composite flour then can replace LPW flour for instant noodle production. Udon noodles can be made from HPWK composite flour that contains 25% konjac flour in the mixture.

Table 5.3 presents the results for the levels of resistant starch (RS), non-resistant starch (NRS) and digestibility of HPWC and LPWC composite flours. The increasing amount of canna flour in these composite flours increased the percentage of RS significantly ($p<0.05$). As a consequence, the percentage of NRS and digestibility of these mixtures were reduced. The levels of RS, NRS and digestibility of HPWK and LPWK mixtures are shown in Table 5.4. Similar increase of RS and decrease of NRS and digestibility were also observed in these composite flours.

Table 5.3. The content of resistant, non-resistant starch and digestibility of wheat-canna composite flours

Source	Resistant starch (%)	Non resistant starch (%)	Digestibility (%)
HPWC			
HPWC 100:0	1.31 ± 0.16^{e}	87.10 ± 4.32^{b}	98.52 ± 0.18^{a}
HPWC 75:25	15.09 ± 0.84^{d}	72.35 ± 3.34^{c}	82.22 ± 0.50^{b}
HPWC 50:50	28.87 ± 1.76^{c}	57.61 ± 2.39^{d}	65.92 ± 1. 06^{c}
HPWC 25:75	42.65 ± 2.69^{b}	42.86 ± 1.52^{e}	49.62 ± 1.63^{d}
HPWC 0:100	56.43 ± 3.61^{a}	28.11 ± 0.99^{f}	33.32 ± 2.20^{e}
LPWC			
LPWC 100:0	1.31 ± 0.16^{e}	92.68 ± 1.53^{a}	98.30 ± 0.07^{a}
LPWC 75:25	15.31 ± 0.88^{d}	76.54 ± 0.90^{c}	82.05 ± 0.51^{b}
LPWC 50:50	29.02 ± 1.79^{c}	60.39 ± 0.28^{d}	65.81 ± 1.07^{c}
LPWC 25:75	42.72 ± 2.70^{b}	44.25 ± 0.37^{e}	49.56 ± 1.64^{d}
LPWC 0:100	56.43 ± 3.61^{a}	28.11 ± 0.99^{f}	33.32 ± 2.20^{e}

All data reported on dry basis and represent the mean of four replicates. Values followed by the same superscript in each column are not significantly different ($p<0.05$); HPWC: High protein wheat-canna; LPWC: Low protein wheat-canna

Table 5.4. The content of resistant, non-resistant starch and digestibility of wheat-konjac composite flours

Source	Resistant starch (%)	Non-resistant starch (%)	Digestibility (%)
HPWK			
HPWK 100:0	1.31 ± 0.16^{e}	87.10 ± 4.32^{a}	98.52 ± 0.18^{a}
HPWK 75:25	13.91± 0.52^{d}	72.73 ± 3.12^{b}	82.99 ± 0.75^{b}
HPWK 50:50	26.51 ± 0.93^{c}	58.36 ± 2.15^{c}	67.45 ± 1.39^{c}
HPWK 25:75	39.10 ± 1.34^{b}	43.98 ± 1.82^{d}	51.92 ± 2.04^{d}
HPWK 0:100	51.70 ± 1.74^{a}	29.61 ± 2.4 3 ^{d}	36.39 ± 2.68^{e}
LPWK			
LPWK 100:0	1.61 ± 0.05^{e}	92.68 ± 1.53^{a}	98.30 ± 0.07^{a}
LPWK 75:25	14.13 ± 0.46^{d}	76.91 ± 1.75^{b}	82.82 ± 0.72^{b}
LPWK 50:50	26.66 ± 0.89^{c}	61.14 ± 1.97^{c}	67.34 ± 1.37^{c}
LPWK 25:75	39.18 ± 1.32^{b}	45.38 ± 2.20^{d}	51.87 ± 2.03^{d}
LPWK 0:100	51.70 ± 1.75^{a}	29.61 ± 2.43^{e}	36.39 ± 2.68^{e}

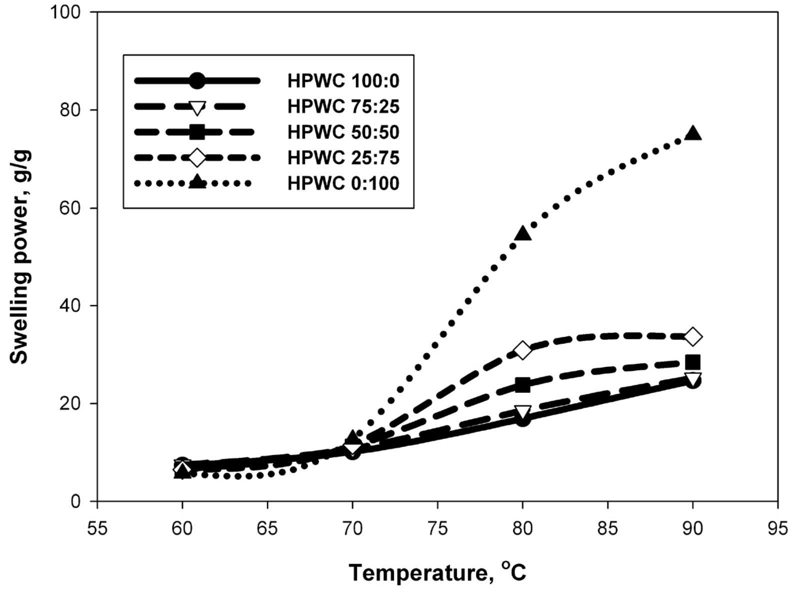
All data reported on dry basis and represent the mean of four replicates. Values followed by the same superscript in each column are not significantly different ($P<0.05$); HPWK: High protein wheat-konjac; LPWK: Low protein wheat-konjac

Thus, substitution of wheat flour with canna or konjac flours may offer health benefits due to the low digestibility of the composite flour which has been shown to be important in the prevention of obesity, diabetes and other related diseases as previously mention in this paper (Chen et al., 2003b; Hung and Morita, 2005). In terms of snack food production, the increase of RS in these mixtures could be used to improve the texture of final products. Flours that contain high amount of RS could produce snack foods with a more expanded, light, and crunchy texture (Taggart, 2004).

5.3.2 Swelling power

Swelling power of HPWC and LPWC composite flours was summarized in Figure 5.1. The starch granules within these flours started to swell at ~60°C. The swelling power was increased slightly with the increasing temperature to 70°C. A significant increase of swelling power was observed with the increasing temperature from 70 to 90°C. The swelling power of HPWC composite flours that contained 25 or 50% canna flour showed no difference to that of the wheat flour alone at all tested temperatures. HPW flour containing 75% canna flour had a higher swelling power compared to that of HPW flour alone at 80 and 90°C. A similar effect on swelling behavior was also observed in LPWC composite flours. For LPWC composite flours, substitution of LPW flour with an even lower amount of canna flour (50%) increased the swelling power of the composite flours. The increase in swelling power would be beneficial for food applications that require a high swelling power. For example udon and Korean dried salted noodles, which require soft, smooth, and elastic textural properties (Fu, 2008).

A



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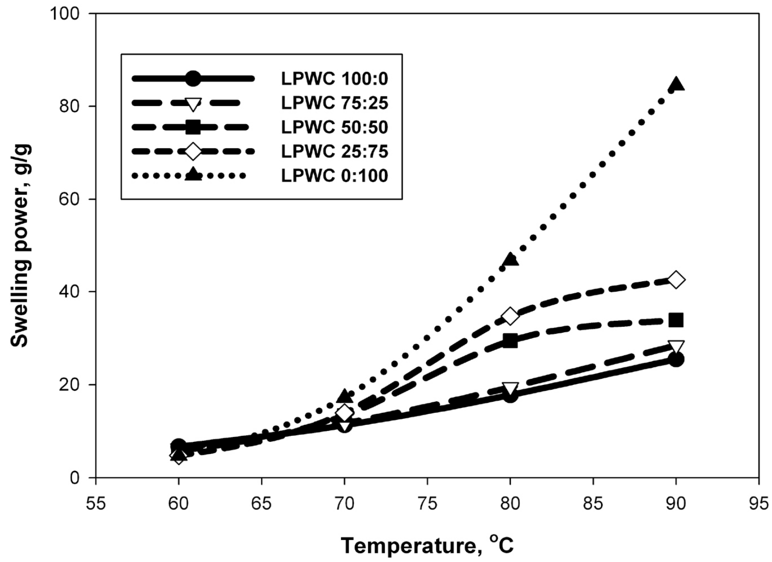
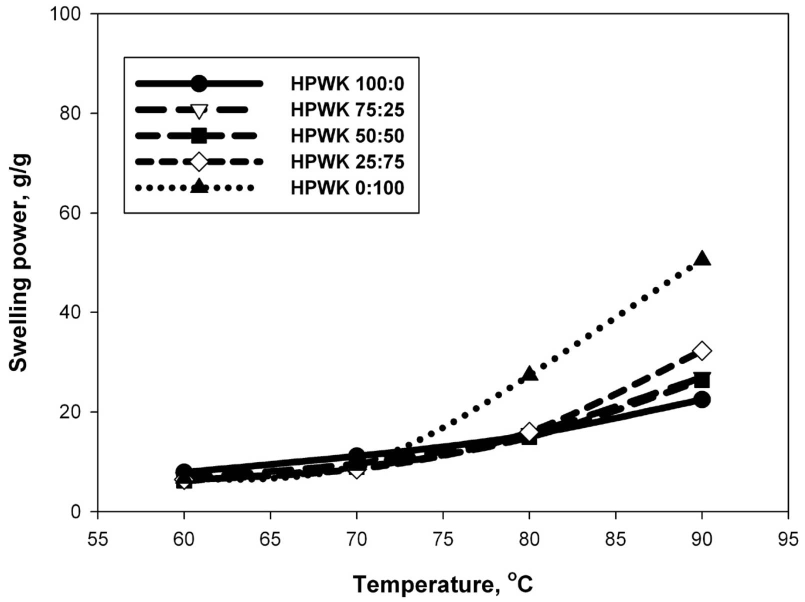


Figure 5.1. Swelling power of HPWC (A) and LPWC (B) composite flours

A



B

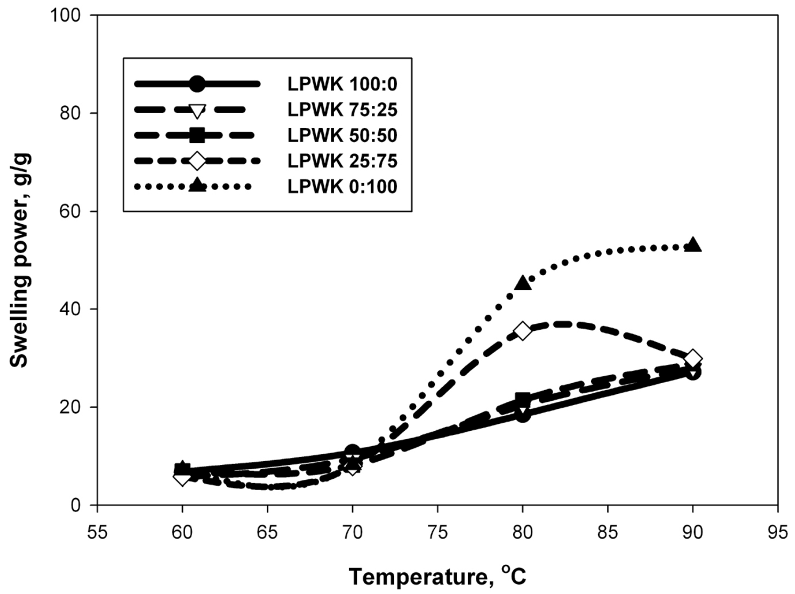


Figure 5.2. Swelling power of HPWK (A) and LPWK (B) composite flour

As can be seen from Figures 5.1 and 5. 2, the 100% canna or konjac flours had a far greater swelling power than the HPW or LPW. Therefore, the expected results of the composite flours were a greater swelling power than what was achieved. The lower than expected results may be due to the influence of several factors such as mixing ratio, chemical composition of flour, starch content and characteristics, as well as interaction between starch granules that are present in the flours (Liu and Lelievre, 1992; Ortega-Ojeda and Eliasson, 2001; Chen et al., 2003b; Ortega-Ojeda et al., 2004). Interaction between starch granules could be attributed to the difference in their granule size. Such interaction was observed in canna-rice starch mixture (Puncha-arnon et al., 2008). Rice starches, that were smaller in size compared to that of canna starches, surrounded granules of canna starch and restricted the swelling power of canna flour.

5.3.3 Color characteristics

The results of the analysis for color of the HPWC and LPWC composite flours are presented in Table 5.5. Wheat flours (HPW and LPW) were whiter, more yellow and less red compared to canna flour. The difference in color characteristics between wheat and canna flour could be attributed to the difference in protein content of these flours. Protein content of flours was negatively related with the $L*$ value but positively correlated with $a*$ and $b*$ values (Jamin and Flores, 1998; Sandhu et al., 2007). In addition, the difference of colored pigment that is present in wheat and canna flours might also contribute to this difference (Singh et al., 2003). Substitution of wheat flours with 25% canna flour in the HPWC and LPWC flour mixtures did not cause a significant reduction in terms of the lightness. However, after this point, the lightness decreased significantly with the presence of 50-75% of canna flour in the mixtures. In contrast, redness and yellowness of composite flours was increased significantly with the increasing canna flour in the mixtures.

Table 5.5. The color and gel hardness of wheat-canna composite flours

Source	*L**	*a**	*b**	Gel Firmness (g)
HPWC				
HPWC 100:0	67.21±1.79^{ab}	-0.21±0.02^{g}	8.58±0.20^{g}	20.03±1.12^{abc}
HPWC 75:25	63.49±1.90^{bc}	1.45±0.07^{e}	11.69±0.23^{ef}	17.93±3.31^{bc}
HPWC 50:50	55.93±1.75^{d}	2.34±0.09^{c}	13.06±0.46^{d}	17.25±0.88^{c}
HPWC 25:75	59.88±2.14^{cd}	3.02±0.16^{b}	16.06±0.65^{b}	8.79±0.84^{d}
HPWC 0:100	59.54±1.90^{cd}	3.65±0.17^{a}	17.96±0.60^{a}	1.74±0.39^{e}
LPWC				
LPWC 100:0	72.17±2.81^{a}	-0.82±0.13^{h}	7.69±0.49^{g}	23.17±2.30^{a}
LPWC 75:25	69.86±2.04^{a}	0.95±0.06^{f}	10.51±0.21^{f}	21.42±2.97^{b}
LPWC 50:50	59.39±2.08^{d}	1.86±0.17^{d}	11.97±0.49^{de}	18.16±2.07^{bc}
LPWC 25:75	58.93±3.05^{d}	2.72±0.12^{b}	14.64±0.86^{c}	9.89±1.64^{d}
LPWC 0:100	56.48±2.96^{d}	3.57±0.26^{a}	16.89±0.77^{ab}	1.74±0.39^{e}

All data reported on dry basis and represent the mean of four replicates. Values followed by the same superscript in each column are not significantly different (p<0.05); HPWC: High protein wheat-canna; LPWC: Low protein wheat-canna.

Table 5.6. The color and gel firmness of wheat-konjac composite flours

Source	*L**	*a**	*b**	Gel firmness (g)
HPWK				
HPWK 100:0	72.99 ± 1.27^{a}	-0.40 ± 0.06^{g}	9.09 ± 0.17^{de}	20.03 ± 1.12^{b}
HPWK 75:25	63.79 ± 2.83^{b}	1.51 ± 0.19^{e}	9.50 ± 0.61^{cde}	15.36 ± 1.79^{c}
HPWK 50:50	59.29 ± 1.20^{c}	2.08 ± 0.09^{cd}	10.00 ± 0.27^{bc}	8.61 ± 0.70^{d}
HPWK 25:75	58.99 ± 1.30^{c}	2.33 ± 0.31^{bc}	10.44 ± 0.56^{ab}	1.77 ± 0.28^{e}
HPWK 0:100	59.40 ± 1.28^{c}	2.71 ± 0.08^{a}	11.04 ± 0.36^{a}	1.68 ± 0.39^{e}
LPWK				
LPWK 100:0	73.83 ± 1.57^{a}	-0.71 ± 0.05^{g}	7.47 ± 0.27^{f}	23.17 ± 2.30^{a}
LPWK 75:25	71.85 ± 2.13^{a}	1.12 ± 0.07^{f}	8.86 ± 0.34^{e}	18.07 ± 1.13^{bc}
LPWK 50:50	65.72 ± 2.83^{b}	1.85 ± 0.16^{de}	9.90 ± 0.27^{bcd}	10.88 ± 1.11^{d}
LPWK 25:75	64.67 ± 1.59^{b}	2.37 ± 0.07^{abc}	11.10 ± 0.24^{a}	2.32 ± 0.22^{e}
LPWK 0:100	59.34 ± 0.88^{c}	2.66 ± 0.18^{ab}	11.23 ± 0.30^{a}	1.68 ± 0.39^{e}

All data reported on dry basis and represent the mean of four replicates. Values followed by the same superscript in each column are not significantly different (P<0.05); HPWK: High protein wheat-konjac; LPWK: Low protein wheat-konjac

The change of color of wheat-konjac composite flours was presented in Table 5.6. Similar to results obtained from wheat-canna mixtures, konjac flour was darker, less yellow, and redder compared to wheat flours. Substitution of wheat flours with konjac flour reduced the whiteness, but increased the redness and yellowness of the mixtures.

5.3.4 Pasting properties

Pasting properties of HPWC and LPWC composite flours are presented in Table 5.7 and Figure 5.3. Wheat flours had a higher peak, holding strength, breakdown, setback, and final viscosity compared to those of canna flour. The LPW flour has a higher peak, breakdown, holding strength, setback from peak, setback from trough and final viscosity values compared to that of HPW flour. This difference could be partially due to the difference in their protein contents (Table 5.1). Proteins may form complexes with granule surfaces preventing the release of exudates and lowering the viscosity (Olkku and Rha, 1978). A lowering effect of the protein content of the wheat flour on peak viscosity of wheat-sweet potato starch, wheat-cassava starch and wheat-yam starch has been reported previously (Zaidul et al., 2007). The viscosity of canna flour reported in this study was lowered more than reported elsewhere (Srichuwong et al., 2005a). This discrepancy might be caused by degradation of starch molecules by the irradiation (MacArther and D'Appolonia, 1984) or by the activity of amylolytic enzymes (Radley, 1976).

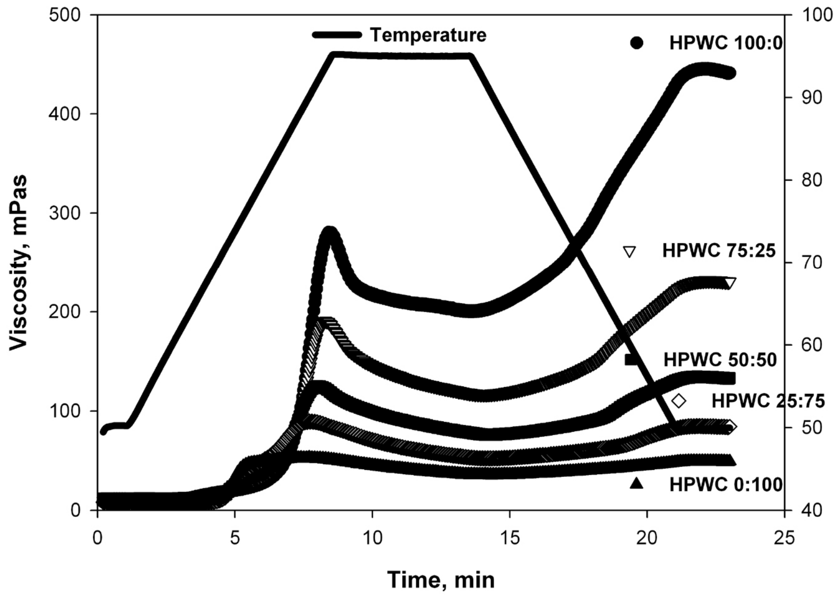
In general, viscosities (peak, breakdown, setback from peak, setback from trough and final viscosities) of HPWC and LPWC composite flours decreased significantly with the presence of canna flour at 25% and 50% (Table 5.7). After this point, viscosities tended to decrease gradually with the increase of the canna flour in the mixture. The high setback and final viscosities of the wheat flour pastes indicated their weak resistance against retrogradation. Substitution of wheat flour with canna flour might be used to decrease retrogradation tendency of wheat flours indicated by the lower setback viscosities of these mixtures compared to that of the wheat flour alone (Leon et al., 2006; Zaidul et al., 2007). In addition, substitution of wheat flour with 50% of canna flour in LPWC composite flour increased the heat stability of this mixture indicated by the lowered value of its breakdown viscosity. Whereas, in HPWC composite flours, substitution of wheat flour with canna flour did not improve the heat stability of wheat flours (Table 5.7) (Leon et al., 2006; Zaidul et al., 2007).

Table 5.7. Pasting characteristics of wheat-canna composite flours

Sample	Pasting characteristics							
	Peak Time (sec)	Past Temp (ºC)	Peak vis (cP)	H strength (cP)	B down (cP)	SFP (cP)	SFT (cP)	Final vis (cP)
HPWC								
HPWC 100:0	507.00±6.00^{a}	66.32±5.94^{b}	282.68±37.48^{b}	199.95±20.41^{b}	82.73±18.10^{bc}	158.58±18.37^{b}	241.30±30.84^{b}	441.25±50.05^{b}
HPWC 75:25	500.50±5.74^{ab}	64.35±3.26^{b}	191.60±52.21^{cd}	116.22±23.71^{c}	75.39±2.76^{bcd}	38.73±13.60^{cd}	114.11±17.37^{d}	230.33±40.86^{d}
HPWC 50:50	484.00±2.83^{cd}	66.00±1.10^{b}	125.43±6.86^{def}	75.16±1.28^{d}	50.26±6.39^{cde}	7.85±3.20^{e}	58.11±4.36^{e}	133.28±4.91^{e}
HPWC 25:75	465.38±4.19^{ef}	66.63±0.68^{b}	90.37±9.64^{ef}	51.72±1.82^{de}	38.65±8.86^{de}	-6.09±7.89^{e}	32.56±0.69^{ef}	84.28±1.84^{ef}
HPWC 0:100	456.95±10.09^{f}	65.27±1.24^{b}	53.36±6.28^{f}	34.92±2.61^{e}	18.44±4.60^{e}	-3.87±4.88^{e}	14.57±1.28^{f}	49.48±3.73^{f}
LPWC								
LPWC 100:0	509.00±2.00^{a}	74.06±0.78^{a}	428.13±40.48^{a}	293.85±24.03^{a}	134.28±16.70^{a}	223.68±15.88^{a}	357.95±30.74^{a}	651.80±54.19^{a}
LPWC 75:25	501.00±3.46^{ab}	64.85±1.83^{b}	267.23±65.41^{bc}	163.88±32.20^{b}	103.35±33.45^{ab}	58.90±8.53^{c}	162.25±27.38^{c}	326.13±59.56^{c}
LPWC 50:50	490.50±3.00^{bc}	65.56±0.89^{b}	140.23±18.47^{de}	84.07±10.12^{cd}	56.15±9.01^{cde}	15.65±4.43^{de}	71.80±6.84^{e}	155.88±16.97^{de}
LPWC 25:75	474.00±0.00^{de}	66.16±0.89^{b}	80.61±5.92^{ef}	51.34±0.80^{de}	29.27±5.18^{e}	2.97±1.80^{e}	32.24±3.97^{ef}	83.58±4.59^{ef}
LPWC 0:100	456.95±10.09^{f}	65.27±1.24^{b}	53.36±6.28^{f}	34.92±2.61^{e}	18.44±4.60^{e}	-3.87±4.88^{e}	14.57±1.28^{f}	49.48±3.73^{f}

Each mean presents an average of four independent observations; *Peak T, peak time; Past T, pasting temperature; Peak vis, peak viscosity; H strength, holding strength; B down, breakdown; SFP, setback from peak; SFT, set back from through; Final vis, final viscosity. Values followed by the same superscript in each column are not significantly different (p<0.05); HPWC: High protein wheat-canna; LPWC: Low protein wheat-canna

A



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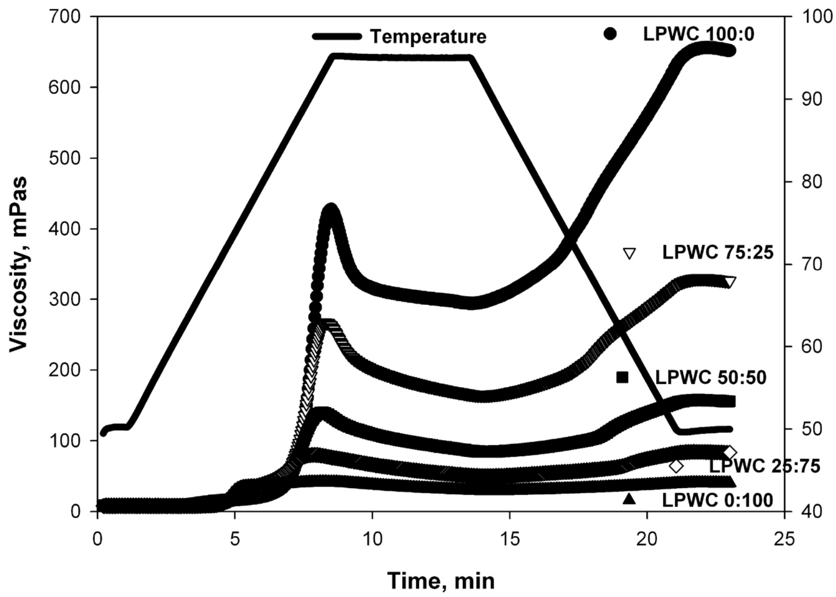


Figure 5.3. Pasting properties of HPWC (A) and LPWC (B) composite flours

Table 5.8 and Figure 5.4 present the pasting properties of HPWK and LPWK composite flours. For HPWK mixtures, the overall viscosity decreased significantly ($P<0.05$) with the presence of 25 and 50% of konjac flour in the mixtures. Afterwards, the increase of konjac flour did not cause any significant decrease. The same trend was observed in LPWK composite flours. As opposed to the individual konjac flour paste, the high setback and final viscosity of the individual wheat flour paste indicated its high retrogradation tendency. Setback viscosity of the mixture tended to decrease significantly with the increasing amount of konjac flour up to 50% in the mixture. Thus, substitution of wheat flour with konjac flour may be used to reduce the retrogradation tendency of wheat flours. Similar effects to the konjac flour in reducing retrogradation have been observed in maize and potato starches (Khanna and Tester, 2006).

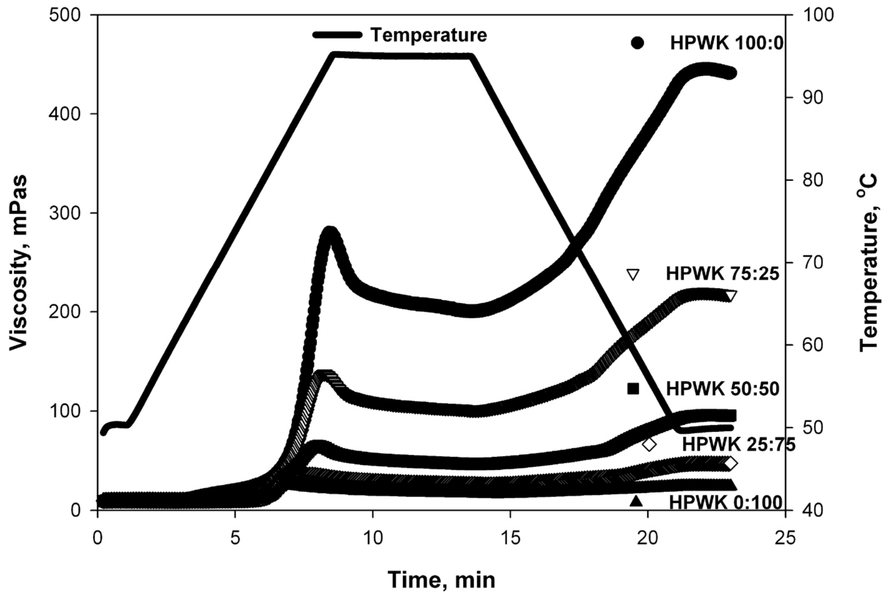
Retrogradation occurred due to the formation and subsequent aggregation double helix of amylose and amylopectin. The early stage of retrogradation involves the loss of amylose network, development of amylose aggregates and the assembly of amylose aggregates. Meanwhile, amylopectin retrogradation occurs more slowly. Therefore, amylose is proposed to be responsible for the short-term (less than one day) retrogradation while amylopectin contributes to the long term of retrogradation (Bao, 2004). The interaction of konjac or other hydrocolloids with amylose and amylopectin could reduce retrogradation (Funami et al., 2004; Khanna and Tester, 2006). Konjac might act as a physical barrier that prevents amylose and amylopectin chain association, which is a perquisite for retrogradation to occur as mentioned above (Khanna and Tester, 2006). In addition, hydrocolloids might also act as a water binder and limit the availability of water for amylose and amylopectin, which subsequently prevents the crystallization. Substitution of wheat flour with konjac flour also increased the shear stability of the composite flour indicated by the decrease of their breakdown viscosity (Leon et al., 2006; Zaidul et al., 2007).

Table 5.8. Pasting characteristics of wheat-konjac composite flours

Source	Pasting characteristics							
	Peak Time (sec)	Past Temp (ºC)	Peak vis (cP)	H strength (cP)	B down (cP)	SFP (cP)	SFT (cP)	Final vis (cP)
HPWK								
HPWK 100:0	507.00±6.00^{a}	66.32±5.94^{b}	282.68±37.48^{b}	199.95±20.41^{b}	82.73±18.10^{b}	158.58±18.37^{b}	241.30±30.84^{b}	441.25±50.05^{b}
HPWK 75:25	494.50±3.00^{a}	68.86±3.46^{ab}	138.38±21.88^{c}	100.42±1.76^{c}	37.95±10.43^{cd}	78.93±7.85^{c}	116.88±14.35^{c}	217.30±25.82^{c}
HPWK 50:50	483.00±3.46^{a}	68.61±1.61^{ab}	65.17±4.57^{de}	46.00±2.14^{de}	19.17±2.44^{de}	30.45±2.12^{de}	49.62±1.06^{de}	95.62±2.70^{de}
HPWK 25:75	462.00±4.90^{a}	69.79±0.92^{ab}	36.45±2.49^{de}	25.52±1.15^{ef}	10.94±1.34^{e}	10.88±0.41^{ef}	21.81±1.66^{ef}	47.33±2.80^{ef}
HPWK 0:100	411.07±5.74^{a}	64.72±3.25^{b}	31.25±3.89^{de}	17.69±2.49^{f}	13.56±1.40^{e}	-4.62±1.15^{f}	8.93±1.16^{f}	26.63±3.29^{f}
LPWK								
LPWK 100:0	509.00±2.00^{a}	74.16±0.78^{ab}	428.13±40.48^{a}	293.85±24.03^{a}	134.28±16.70^{a}	223.68±15.88^{a}	357.95±30.74^{a}	651.80±54.19^{a}
LPWK 75:25	499.50±3.00^{a}	71.90±0.77^{ab}	167.18±5.41^{c}	122.00±2.91^{c}	45.18±3.63^{c}	98.40±3.65^{c}	143.58±6.90^{c}	265.58±7.96^{c}
LPWK 50:50	472.13±36.19^{a}	71.61±0.29^{ab}	73.28±6.89^{d}	52.01±2.95^{d}	21.27±5.34^{de}	38.38±0.68^{d}	59.65±5.97^{d}	111.65±7.56^{d}
LPWK 25:75	468.00±6.93^{a}	76.03±6.77^{a}	35.98±3.24^{de}	23.84±1.75^{ef}	12.14±1.59^{e}	14.30±3.43^{ef}	26.44 ±1.89^{def}	50.28±1.42^{ef}
LPWK 0:100	411.07±5.74^{a}	65.80±3.42^{b}	26.64±6.89^{e}	16.85±2.64^{f}	9.79±5.94^{e}	-1.13±5.11^{f}	8.66±1.09^{f}	25.51±3.49^{f}

Each mean presents an average of three independent observations; *Peak T, peak time; Past T, pasting temperature; Peak vis, peak viscosity; H strength, holding strength; B down, breakdown; SFP, setback from peak; SFT, set back from through; Final vis, final viscosity. Values followed by the same superscript in each column are not significantly different (p<0.05); HPWK: High protein wheat-konjac; LPWK: Low protein wheat-konjac

A



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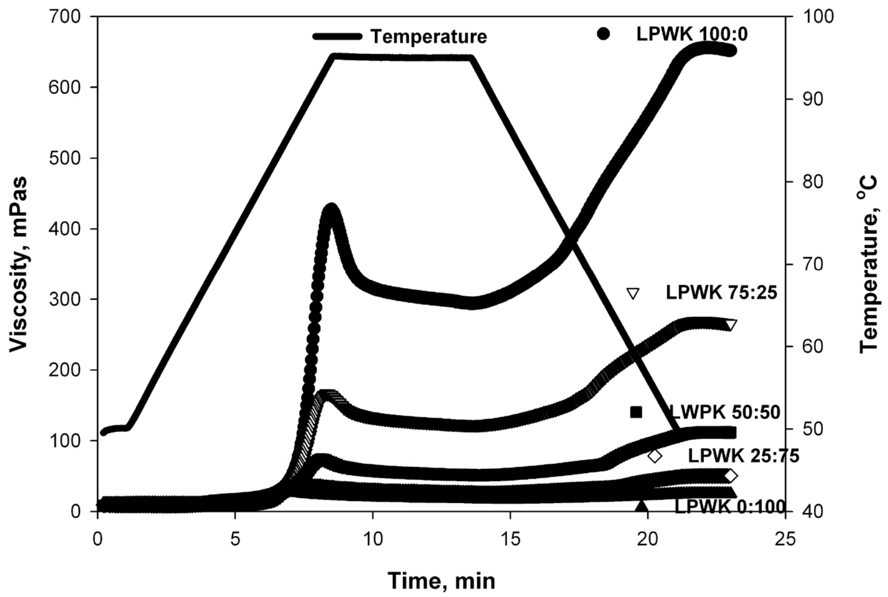

Figure 5.4. Pasting properties of HPWK (A) and LPWK (B) composite flours

Based on the pasting properties of HPWC and LPWC as well as the HPWK and LPWK composite flours as discussed above, partial replacement of wheat flours with canna or konjac flours might offer advantages for some food applications. Due to their low retrogradation tendency, these composite flours might be advantageously used in frozen products, for examples frozen pie fillings or cold-storage foods such as canned sauces and gravies (Cornell, 2004). In addition, in bread making, the low retrogradation tendency of these composite flours could reduce the bread staling, which in turn the self-storage of this product could be enhanced (Radley, 1976; Taggart, 2004).

The low viscosity of these composite flours might bring advantages in the confectionary industry especially in the processing of gumdrops, which would allow better evaporation and pouring (Radley, 1976). Having a low viscosity value, these composite flours could be incorporated into certain food products in higher concentrations without becoming too viscous (Cornell, 2004). The low viscosity of these flours is also beneficial for infant nutrition since infant cannot tolerate a solid diet due to their digestive system and eating skills not being fully developed (Walker and Rolls, 1999; Muyonga et al., 2001). There is an inverse relationship between viscosity and energy density of infant food. The low viscosity value might eliminate the need for dilution and increase the energy intake of infants (Walker and Rolls, 1999). While the lower breakdown of these composite flours might produce a less cohesive paste which would be beneficial during food processing (Moorthy, 2004). In addition, the increase of heat stability of these composite flours is important for food products prepared by heat-moisture or steam pressure for example canned foods (Moorthy, 2004).

In this study, viscosity of the composite flours was lower than the expected results. This fact in agreement with results obtained from the swelling power experiment. It also confirmed the presence of interactions between canna and wheat granules or with other components such as the leached amylose and amylopectin as has been discussed previously.

5.3.5 Thermal properties

The gelatinization temperature and enthalpy for the HPWC and LPWC are presented in Table 5.9. Each individual wheat and canna flour has a single endothermic peak. Despite having different protein contents, HPW and LPW flours used in this study have similar gelatinization temperatures and enthalpy. A similar onset (57.0ºC) and peak (62.3ºC) temperature as well as enthalpy value (5.3 J/g dry starch) of wheat flour has been reported previously (Zaidul et al., 2007). Gelatinization temperature and enthalpy of the canna flour was higher than that of wheat flour, which indicates the higher stability of canna flour compared to that of wheat flour (Srichuwong et al., 2005b).

The X-ray diffraction patterns reflect the packing of amylopectin side chains. Based on their diffraction patterns, native starches can be categorized into A, B, and C type starches (Jane et al., 1997). The A type starch has a closely packaged double helices, and formed from short chain amylopectin. This type is the characteristic of cereal starches. In contrast, the B type starch has a less dense packaging and formed from long chain amylopectin. Root starches, amylomaize starches, and retrograded starches belong to B-type starches. While, C type starch is a combination between the A and B-type starches (Cui, 2005). Canna starch is considered a B-type starch and therefore has a high proportion of longer chain of amylopectin (Srichuwong et al., 2005a) as opposed to the wheat starch which has been reported to have a low amount of long chain amylopectin (Blazek and Copeland, 2008). The higher gelatinization temperature and enthalpy of canna flour compared to that of wheat flours could be attributed to the higher amount of long chain amylopectin in canna starch. Yuan et al (1993) reported that there is a positive correlation between the proportion of longer chains of amylopectin with the increase of enthalpy and temperature of gelatinization. Compared to the short chain of amylopectin, the long chain amylopectin is more stable to heat and requires more energy to initiate gelatinization. As a consequence, a higher gelatinization temperature is required (Hoover and Ratnayake, 2002).

Table 5.9. Thermal properties of wheat-canna composite flours

Sample	Gelatinisation characteristics				
	To (ºC)	Tp1 (ºC)	Tp2 (ºC)	Tc (ºC)	ΔH (J/g dry starch)
HPWC					
HPWC 100:0	57.82±1.45^{b}	63.94±1.10^{b}	-	70.30±1.48^{b}	5.60±0.93^{d}
HPWC 75:25	58.02±3.36^{b}	63.44±2.37^{b}	71.84±1.23^{a}	75.25±1.43^{a}	8.27±1.08^{cd}
HPWC 50:50	57.80±2.33^{b}	65.08±3.27^{b}	72.43±0.76^{a}	77.64±1.77^{a}	10.51±0.95^{abc}
HPWC 25:75	58.09±1.38^{b}	64.75±2.05^{b}	71.97±0.66^{a}	76.90±1.09^{a}	11.58±1.02^{ab}
HPWC 0:100	68.62±2.72^{a}	72.54±1.18^{a}	-	77.70±1.84^{a}	13.03±1.84^{a}
LPWC					
LPWC 100:0	60.58±1.80^{b}	64.06±1.36^{b}	-	69.64±2.53^{b}	5.73±0.85^{d}
LPWC 75:25	60.97±1.39^{b}	63.64±0.69^{b}	71.83±1.40^{a}	77.98±1.01^{a}	8.77±1.40^{bc}
LPWC 50:50	59.38±1.78^{b}	65.83±0.89^{b}	72.49±0.81^{a}	77.32±1.77^{a}	10.11±0.91^{abc}
LPWC25:75	61.50±1.76^{b}	63.47±2.06^{b}	72.16±0.55^{a}	78.03±1.45^{a}	11.92±1.79^{a}
LPWC 0:100	68.54±2.23^{a}	73.53±0.81^{a}	-	77.58±1.52^{a}	13.04±1.21^{a}

All means present the average of three independent replications. Values followed by the same superscript in each column are not significantly different (p<0.05). To, Tp, and Tc indicate temperature of onset, midpoint and end of gelatinization, respectively. Enthalpy of gelatinization ΔH (J/g dry starch)**;** HPWC: High protein wheat-canna; LPWC: Low protein wheat-canna.

Table 5.10. Thermal properties of wheat-konjac composite flours

Sample	Gelatinisation characteristic				
	To (ºC)	Tp1 (ºC)	Tp2 (ºC)	Tc (ºC)	ΔH (J/g dry starch)
HPWK					
HPWK 100:0	57.73±1.58^{bc}	63.96±0.52^{b}	-	69.13±0.72^{b}	5.04±1.61^{d}
HPWK 75:25	56.74±1.12^{c}	64.23±1.30^{b}	69.08±1.55^{a}	76.91±1.34^{a}	9.73±0.99^{c}
HPWK 50:50	58.19±3.02^{bc}	64.36±2.31^{b}	70.52±0.64^{a}	76.64±1.08^{a}	11.81±1.47^{bc}
HPWK 25:75	57.72±1.18^{bc}	64.24±1.22^{b}	70.10±1.18^{a}	78.29±0.92^{a}	13.04±1.31^{b}
HPWK 0:100	64.89±1.30^{a}	69.88±1.70^{a}	-	77.47±1.04^{a}	16.63±1.06^{a}
LPWK					
LPWK 100:0	60.58±1.80^{bc}	64.06±1.36^{b}	-	69.64±2.53^{b}	5.73±0.85^{d}
LPWK 75:25	60.99±1.93^{ab}	63.90±1.10^{b}	69.92±1.61^{a}	78.76±1.08^{a}	11.13±0.99^{bc}
LPWK 50:50	60.83±1.08^{abc}	64.80±1.25^{b}	69.29±1.41^{a}	77.89±2.27^{a}	12.41±1.21^{bc}
LPWK 25:75	59.37±2.07^{bc}	64.62±1.70^{b}	69.05±1.29^{a}	77.71±1.30^{a}	12.91±0.98^{b}
LPWK 0:100	64.89±1.30^{a}	69.13±1.13^{a}	-	77.47±1.04^{a}	13.63±1.01^{b}

All means present the average of four independent replications. Values followed by the same superscript in each column are not significantly different (p<0.05). To, Tp, and Tc indicate temperature of onset, midpoint and end of gelatinization, respectively. ΔH indicates Enthalpy of gelatinization (J/g dry starch); HPWK: High protein wheat-konjac; LPWK: Low protein wheat-konjac

In contrast to the individual wheat or canna flours that have a single endothermic peak, the presence of canna flour at 25, 50, and 75% in the composite flours led to the presence of two endothermic peaks (Table 5.9). The lower Tp (midpoint temperature) corresponded to the gelatinization of the wheat flour while the higher Tp corresponded to the gelatinization of the canna flour. The To (onset temperature) of these composites was similar to temperatures observed for the wheat flours, while their Tc (end temperature) was close to that of canna flour. The presence of these two endothermic peaks indicated that wheat and canna starches present in the composite flours were gelatinized independently. Similar phenomena have been reported from mixtures of canna-potato starch (Puncha-arnon et al., 2008), potato-waxy maize and waxy maize-barley starches (Ortega-Ojeda et al., 2001) as well as yam-cassava-maize starch blend (Karam et al., 2006). A similar gelatinization phenomenon was observed from HPWK and LPWK composite flours (Table 5.10). Starches within the konjac flour have a higher stability compared to that of starches in wheat flour. This fact was reflected by the higher gelatinisation temperature and enthalpy values of konjac flour compared to those of the wheat flours.

The presence of canna or konjac flour in their respective composite flours has increased the gelatinisation temperature range (Tc–To) of the composite flours compared to that of individual flours. In other words, partial substitution of wheat flour with canna or konjac flour has increased the heterogeneity of starch crystallites within the composite flours, which also means that higher heat energy is required to fully gelatinize the starches. Thus, this change has many implications on sample preparation, food processing, and the increase of production costs.

5.4 CONCLUSION

From the results shown in this study there is an indication that the substitution of wheat flour for flour from these tubers may be beneficial in the production of various food products. Substitution of wheat flour with canna or konjac flour may bring health benefits by increasing the amount of resistant starch and decreasing the digestibility. This substitution could also improve the textural properties of snack foods. Substitution of wheat flour with canna flour might improve the pasting behavior of wheat flour by reducing the retrogradation tendency, which is required for many food productions such as frozen foods and cold-storage foods. This low retrogradation tendency is also important to improve the self-storage of bread products by reducing the occurrence of bread staling. The increase of canna or konjac flours in the composite flours decreased wheat flour viscosity, which is suitable for the production of weaning food, confectionary (soft candy and gum drops), and other liquid foods. In addition, there is a possibility of wheat-canna and wheat-konjac composite flours to be applied for sweet biscuit or sponge biscuit making. Investigation on more specific properties, such as baking property, of these composite flours should be undertaken in the future to fully investigate their specific application.

CHAPTER 6

Summary of Results

Based on their physicochemical properties, the main extracts namely flour, starch, and mucilage of tubers and roots commercially available on the Australian market have a potential to be used in the food industry. Taro starch and flour have a small particle size, thus suitable for applications where improved binding and reduced breakability is required. Taro starch has a high viscosity, which allows its application for food products that require a high thickening power. On the other hand, sweet potato starch with its low viscosity is beneficial for food applications that require low viscosity such as weaning food and confectionary (soft candy and gumdrops). In general, flours have lower viscosity than starch. The presence of other components such as protein and lipids, which may interfere with the pasting process, could be the cause of this phenomenon. Compared to that of taro and sweet potato, yam flour and starch have higher stability towards heat and mechanical treatments. Thus, yam flour and starch would be useful for food applications that involve these treatments in the processing process such as mayonnaise and confectionary.

In terms of paste clarity, sweet potato flour and starch have better clarity compared to that of yam and taro. Therefore, sweet potato flour and starch are preferable to be used for food products that require clearer paste such as fruit filling and jelly. In contrast, flours and starches of taro and yam are suitable for more opaque food products such as mayonnaises, sauces, gravies, and dressings. These flours and starches are potential to be used as functional foods since the low digestibility and the high amount of resistant starch of these may be beneficial to reduce the incidence of obesity, hypertension, and cardiovascular diseases. The absence of gluten in these flours and starches allows them to be used as alternative sources of carbohydrate for people suffering from celiac disease. In addition, mucilage present in these materials may have antioxidative and ACE inhibitory activities. The mucilage extracted from these tubers and root showed apparent shear thinning behaviour. The Power Law, Hershel Buckley and Casson models successfully fit concentration dependant flow behaviour of all mucilage samples.

Similarly, roots and tubers collected from Indonesia also showed a potential to yield flours and starches that could be applied in many food processes. Due to their low digestibility, canna and konjac flours may offer health benefits in prevention of obesity, hypertension, and other related diseases. Additionally, the high digestibility of others flours and starches is important for weaning foods. Amongst tested samples, taro starch and flour have the smallest particle size. Such fine particles are important for snack food production to improve binding and reduce breakability. Overall, all flours and starches extracted from starchy materials collected from Indonesia have low viscosity. This low viscosity could be due to the activity of α-amylase, storage time, and gamma irradiation. Having low viscosity values, these extracted materials could also be suitable for weaning food, soft candy, and others liquid foods. In addition, these flours and starches have a low retrogradation tendency, which is important for frozen and cold-storage food. This property could also prevent bread staling, which in turn could produce bread with better quality and storage stability. Having a high paste clarity, cassava flour and starch could be potentially used for food products that require a clear paste such as pie and fruit fillings, candy, and Turkish delight. Other flours and starches that give an opaque paste could be used for salad dressing, sauces, and mayonnaise.

Substitution of wheat flour with canna and konjac flours could produce composite flours which are beneficial in the production of various food products. This substitution may bring health benefit by increasing the amount of resistant starch and decreasing the digestibility of wheat flour. Retrogradation tendency of wheat flour is also reduced through this substitution. As a consequence, the cold storage stability of wheat flour was improved. In addition, substitution of wheat flour with canna or konjac flour also lowered the viscosity of wheat flour. As mention above, this low viscosity is suitable for the production of confectionary i.e. soft candy and gumdrops, weaning food, and other liquid foods. This substitution also could be used to avoid the use of chemical modification to produce starch with low viscosity. Based on DSC analysis, it was proposed that wheat and canna or konjac granules that present in the composite flours were gelatinized independently which was indicated by the presence of two endothermic peaks.

From this study, we found that flours and starches isolated from roots and tubers commercially available on the Australian market as well as from Indonesia have physicochemical properties which could be utilized for some food applications. However, since most of food processing also involves other ingredients during the production process, further research is needed to optimize the use of these materials in the presence of other ingredients to obtain food products with acceptable quality. The future research direction should also consider the low viscosity of flours and starches extracted from roots and tubers from Indonesia. At this stage, it was predicted that the low viscosity of these materials were due to the radiation, activity of amylolytic enzyme, and the storage time. A study is needed to fully understand the possible cause of this low viscosity.

The demand for functional foods has increased in recent years due to consumer awareness of the healthy foods. Our study has demonstrated that there are possibilities to develop functional foods from these flours, starches, and mucilage. Despite their potential applications in food industry, information regarding the physicochemical and functional properties of mucilage is still rare and not fully understood. Therefore, further research should be conducted to understand their properties. Analysis using differential scanning calorimetry on wheat-canna and wheat-konjac composite flours revealed that canna and konjac flours were immiscible with wheat flour. In the future, there is a need to expand upon this study in order to obtain a composite flour which comparable with non-substituted wheat flour.

CHAPTER 7

List of References

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