Utilization of Colored Non-cereal Energy Crops in Food Processing

食品加工への非穀物性カラフル作物の利用特性

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ABSTRACT

Sweet potato is a healthy, cheap and abundantly available food crop in Asia, but despite its nutritional and economic value it still remains underutilized in food processing. In an effort to utilize them for food processing, this study determined the effects of the supplementation of purple sweet potato powder (PSPP) on the quality of specialty bread and fresh pasta. Changes in the quality, color, texture, rupture properties and structures of standard white, 4% PSPP-supplemented, and 0.0125% α-amylase (AM) and 0.025% hemicellulase (HC) treated bread prepared following the no-time bread making method were evaluated. Moreover, the effect of increasing concentrations of supplemented PSPP on color, cooking quality, rupture properties, and acceptability of fresh pasta were also assessed. Results showed that PSPP-supplementation produced darker crust and light purple crumb bread which is attributed to the intrinsic anthocyanin content of PSPP. However, a significantly lower gas retention of dough (GRD), specific loaf volume (SLV) and higher firming rate than the control were also observed which are related to the high damaged starch and hemicellulose content of PSPP causing greater starch-gluten interaction as demonstrated in the dough structure. On the other hand, AM and HC treatments results in improved the bread making quality, and staling rate as evidenced by higher gassing power, GRD, SLV, and lower firming rate, rupture force and energy, and moisture loss during storage which are related to the lower starch-gluten interaction exhibited by the dough and bread structures. For fresh pasta, PSPP contributed acceptable slight to extremely strong purple color which is

related to its natural dark purple color. PSPP-substitution also resulted in slight soft to soft firmness, and moderate elasticity and cohesiveness which are attributed to the improved water holding and absorbing capacities. This study suggests that PSPP is an effective natural colorant and its supplementation gives rise to acceptable baked and noodle products which can potentially increase the utilization of purple sweet potato in the food industry.

ABSTRACT
(Japanese)

甘薯は、アジアにおいて、安く健康に良く多量に利用されている作物である。しかし、その栄養、経済的価値にもかかわらず、まだ食品加工への利用に関しては、低いレベルにとどまっている。本研究では、特殊食パンや生パスタの品質に対する紫甘薯粉末（ＰＳＰＰ）添加の効果について検討を行った。パンにおいては、ノータイム法で製造された標準的食パン、４％ＰＳＰＰ添加、更に０．０１２５％のα－アミラーゼ（ＡＭ）と０．０２５％のヘミセルラーゼ（ＨＣ）で処理された食パンの品質、色相、テクスチャー、破断特性、構造の変化が評価された。更に、生パスタにおいては、色相、クッキング品質、破断特性、製品の受容性に対するＰＳＰＰの添加量の増加効果が評価された。これらの結果から、パンにおいては、ＰＳＰＰ添加によって、より暗いクラストと明るい紫色のクラムの製品が製造され、それは、ＰＳＰＰ中に元々含まれるアントシアニンの効果であった。しかしながら、対照のパンと比べＰＳＰＰ添加のパン生地、パンでは、有意に低いガス保持性（ＧＲＤ）と比容積（ＳＬＶ)、速いパンの硬化（老化）が観察され、それは、生地構造の観察から、強いデンプンとグルテンの相互作用を引き起こすＰＳＰＰ中の高濃度の損傷澱粉とヘミセルロースに関係していた。一方、ＡＭやＨＣで処理されたＰＳＰＰ添加生地やパンは、その製パン性や老化が改善され、その効果は、高い生地のガス発生量、ＧＲＤ、ＳＬＶや貯蔵中の低いパンの老化速度、破断力、破断エネルギー、水分ロスによって裏付けられた。そして、これらの改善は、パン生地やパン中に見られる低いデンプンとグルテンの相互作用構造の効果に関係していた。生パスタにおいて、ＰＳＰＰの添加は、受容生のあるわずかから非常に強い紫色を呈し、これには、ＰＳＰＰ中の濃いナチュラルな紫色が関係していた。また、ＰＳＰＰ添加の生パスタは、わずかにソフトからソフトな硬さ、中程度の弾性と凝集性を示し、それは、生地の水に対する保持性、吸水性の改善に関係していた。これらの研究から、ＰＳＰＰは、効果的なナチュラル色素であり、これにより、食品工業において、紫甘薯の利用性を効果的に向上させることができることが示唆された。

INTRODUCTION

Cereals, and non-cereal energy crops like roots and tubers have received extensive attention for their association with human existence, survival and socio-economic history (Norman *et al.* 1995; Salunkhe and Kadam, 1998; Singh *et al*. 2003). These commodities constitute major part of the diet of humans and animals, as such they served as staple food in many countries as grains, flours and starches (Singh *et al.* 2003). Flours and starches are important raw materials in the food industry because of their effect on the textural properties of many food products (Zaidul *et al*. 2007). They are usually added in food formulations as thickeners, stabilizers, extenders, texture modifiers, adhesives and gelling, bulking and water retention agents (Thomas and Atwell, 1997). Flours and starches from different biological origin will have its unique applications depending on their physicochemical characteristics, nutritional contents and functional properties (Singh *et al.* 2003). Colored root and tuber crops like purple potatoes, sweet potatoes and yams can serve as natural food colorants in many food products like jams, alcoholic and non-alcoholic beverages, confectioneries, breads, and noodles, among others (Steed and Troung, 2008; Li *et al*. 2012; Albishi *et al.* 2013). Besides imparting color to food products, they also contribute in improving the nutritional values and provide potential health benefits which can be attributed to high contents of colored beneficial substances such as carotenoids and anthocyanins (Giusti and Wrolstad, 2003).

Purple potatoes, sweet potatoes and yams were reported to have high antioxidant properties attributed to their inherently high anthocyanin contents (Kano *et al.* 2005; Lachman and Hamouz, 2005; Han *et al*. 2006a; Steed and Troung, 2008; Moriya *et al*. 2015). These commodities were found to have anti-inflammatory, anti-carcinogenic, anti-obesity, anti-diabetic, anti-hypertensive, anti-mutagenic, and anti-plasma properties (Bhandari *et al.* 2003; Suda *et al.* 2003; Han *et al.* 2006b). Moreover, they have also been associated with numerous health benefits related with visual and brain improvement, reduction of cholesterol, prevention of physiological effects of cardiovascular diseases, and hepatoxicity (Bhandari *et al.* 2003; Suda *et al.* 2003; Han *et al.* 2006b; Tsuda, 2012; Mohanraj and Sivasankar, 2014). However, despite their overwhelming functional properties, only few products containing these commodities are available in the market, and their applicability and effects on processed food products like breads and noodles have not yet been fully studied.

The utilization of purple potato, sweet potato and yam for processing of bakery and noodle products may result in changes on their quality and acceptability. Supplementing them in breads and noodles may have great impact on consumers in terms of their beneficial health effects as these commodities are staple foods in many countries around the world (Brennan *et al.* 2004; Nouviaire *et al.* 2008; Abdelghafor *et al*. 2011; Rosell, 2011). In developing countries, baked products are supplemented with locally grown starchy crops in order to improve its nutritional value and reduce costs (Olaoye *et al*. 2006; Olaoye and Ade-Omowaye, 2011). Likewise, fresh pasta supplemented with non-wheat flours became popular due to

its ease of cooking, nutritional qualities and potential health benefits (Silva *et al*. 2013).

However, the supplementation of non-wheat flour from rice, legumes, tuber and root crops for wheat often results in inferior bread making quality, and thus, addition of dough enhancing ingredients like enzymes is necessary (Yamauchi *et al.* 2004a; Caballero *et al.* 2007; Hathorn *et al.* 2008; Mohammed *et al.* 2012). Enzymes such as amylases and hemicellulases improve the quality of bread by hydrolyzing gelatinized starch components and water insoluble hemicelluloses into fermentable simple sugars, respectively, resulting in greater gas production and loaf volume (Gupta *et al*. 2003; Caballero *et al.* 2007; Stojceska and Ainsworth, 2008; Goesaert *et al.* 2009; Schoenlechner *et al.* 2013). On the other hand, low level supplementation of non-wheat flours in noodles results in changes in its cooking qualities, appearance, and texture which are still acceptable to consumers (Li *et al*. 2012; Silva *et al*. 2013)

"Ayamurasaki" is a purple sweet potato variety developed in Japan that has received much attention because of its nutritional value and heat stable anthocyanin content even at baking and steaming temperatures (Oki *et al.* 2002; Bovell-Benjamin, 2007; Kim *et al.* 2012). Its stable anthocyanins have multiple physiological functions such as antioxidative, antimutagenic, hepato-protective, antihypertensive, anti-neuroinflammatory and antihyperglycemic activities (Suda *et al.* 2003; Kang *et al.* 2014). It has also been used as a natural food colorant in beverages, confectionery, bread and noodles (Oki *et al.* 2002; Suda *et al.* 2003; Yang and Gadi, 2008; Choi *et al.* 2011). However, sufficient studies about the use

and effect of “Ayamurasaki” purple sweet potato powder on the qualities of bread and “extra strong flour” fresh pasta, as well as on baking and noodle making properties have not yet been performed.

OBJECTIVES OF THE STUDY

This study utilized the purple sweet potato powder (PSPP) in bread and fresh pasta processing, and determined their effects on bread and noodle making qualities. Specifically this study aimed to:

1) determine the effects of purple sweet potato powder (PSPP) substitution and enzyme treatments on damaged starch, fiber and ethanol-soluble sugar contents in relation to improvement in bread making quality;

2) evaluate how PSPP substitution and enzyme treatments influence the sensory properties, texture, moisture content, and structure of breads and doughs in relation to staling; and

3) evaluate the effect of various amounts of PSPP substituted on the moisture content, cooking quality, color, texture, rupture and sensory properties of "extra strong flour" fresh pasta.

Chapter 1

Review of Literature

1.1 Non-cereal energy crops

Non-cereal energy crops include ground vegetables like tubers (potato yams, arrowroot, etc.), and root crops (sweet potato, taro, cassava, etc.) that are mainly grown as human energy food (Norman *et al.* 1995). They are the third important group of crops next to cereals and pulses providing energy for one fifth of the world population as primary or secondary staple food (Palaniswami and Peter, 2008). They are usually cooked or milled into flours and starches for many different food processing applications (Singh *et al.* 2003; Belitz *et al.* 2004).

1.1.1 Potatoes

With more than 4000 edible varieties, potato (*Solanum tuberosum* L.) is the third most important crop in the world serving as food for more than 1 billion people and has a yearly global production of about 370 million metric tons (Bradshaw and Borniebale, 2010; CIP[1]; FAOSTAT[2]). They are grown as vegetable for direct consumption and traditionally cooked by baking, boiling, or roasting (Alvani *et al.* 2011). Potatoes are superior source of carbohydrates and contain significant amounts of protein, phenolic substances, vitamins and minerals (Jadav and Kadam, 1998; Chung *et al.* 2014).

Today, potatoes are also used as raw material for the processing of frozen or fried products such as chips and French fries, dehydrated products like flours,

starch and starch derivatives, chilled-peeled, and canned potatoes (Jadav and Kadam, 1998; Bradshaw and Ramsay, 2009; Alvani *et al.* 2011; Chung *et al.* 2014). The popular varieties which have white or yellow flesh are commonly used for food processing whereas those with colored flesh are mostly boiled and added in side dishes and salads (Feustel, 1987; Lisinska and Leszczynski, 1989; Gould, 1999).

Potatoes are excellent source of starch which is unique among commercially available starches because of the size of its granule, length of amylose and amylopectin chain, presence of phosphate groups in amylopectin and ability to form visco-elastic gels upon gelatinization and retrogradation (Yusuph *et al.* 2003; Singh *et al.* 2005; Kaur *et al.* 2007; Liu *et al.* 2007a; Noda *et al.* 2007). Because of these unique properties it has been used extensively in many food systems as thickener, colloidal stabilizer, gelling, bulking and water holding agents (Singh *et al.* 2006; Alvani *et al.* 2011).

In America and some European countries, 50 to 60 % of their potato production are used in processing (Bradshaw and Borniebale, 2010). While in Japan, most potatoes are not colored and 80% are produced in Hokkaido, of which 77% is used for processing starch, chips and other potato products, whereas 16% goes to fresh markets (Noda *et al.* 2011).

1.1.2 Yams

About ten of the 600 yam species (*Dioscorea spp.*) are staple food crop for more than 100 million people in tropical and subtropical countries across Asia, Africa, South America, Carribean and Pacific. Yam has a global total production of about 60 million metric tons (Mignouna *et al*. 2003; Egesi *et al.* 2007; Arnau *et*

al. 2010; FAOSTAT[2]). Among its species, the *Dioscorea alata*, *D. cayenensis* and *D. rotundata* are the most cultivated while *D. bulbifera, D. esculenta, D. opposite-japonica, D. nummularia, D. pentaphylla, D. transversa, D. trifida* are considered as minor yams (Lebot, 2009). Yams are considered as survival crops, as they served as a reliable food source during famine or times of scarcity mainly due to their high carbohydrate content (Arnau *et al*. 2010). Its colored species and varieties also contains significant amount of proteins, minerals, vitamins and phytochemicals that have potential health benefits (Lebot, 2009; Arnau *et al*. 2010). Moreover, it is traditionally considered as a medicinal plant due to their pharmacologically active compounds including allantoin, choline, dioscin, dioscorin, mucin, saponin, sapogenin and essential amino acids (Bhandari *et al*. 2003; Behera *et al*. 2009; Li *et al*. 2012). Yams are traditionally consumed as boiled and pounded, grated and steamed into pudding, fried, roasted and baked (Brunnschweiler *et al*. 2006; Lebot, 2009). Today, they serve as ingredients for fabricated foods like chips, flakes, noodles, breads, snacks, and baby food products mainly because of their high starch content (Conlan *et al.* 1998; Salda *et al.* 1998; Huang *et al.* 2006; Lebot, 2009).

1.1.3 Sweet Potatoes

Sweet potato (*Ipomoea batatas*) is the seventh most important crop in the world in terms of human consumption with a total production of about 105 million metric tons (Lebot, 2009; FAOSTAT[2]). It was first domesticated and originated in American continent and is now more cultivated than other root crops in many developing countries in Sub-Saharan Africa, parts of Asia and Pacific Islands (Lu

and Gao, 2011; CIP[1]). As cited by Lebot (2009), FAO reported in 2007 that sweet potatoes are consumed at an average annual per capita of 75, 20, 10, 7, 5 and 2 kg in Oceania, Asia, Africa, Japan, Latin America, and USA, respectively. It is high in carbohydrate, fiber, β-carotene a vitamin A precursor contents (Lebot, 2010), and has significant amounts of vitamins (C, B complex and E) and minerals (potassium, calcium and iron) (Kotecha and Kadam, 1998; Antonio *et al*. 2011; CIP[1]). Moreover its yellow or yellow-orange and deep purple varieties contain stable carotenoid and anthocyanin content, respectively, making them as superior source of natural colorant for the food and cosmetic industry (Bovell-Benjamin, 2007; Teow *et al.* 2007; Lebot, 2009; Rumbaoa *et al.* 2009). Due to its superior nutritional value and its suitability in marginal lands, sweet potato is perceived in Asia as a survival crop during typhoons and natural calamities, and is important in solving food shortages, malnutrition and vitamin A deficiency (Woolfe, 1992; Rasco, 2000; Tan *et al.* 2000). Like other root crops, it is traditionally consumed as boiled, fried, roasted or baked, and it also serves as an ingredient in the processing of animal feeds, flour, starch, dried chips, jam, confectionery, bread, noodles, candy, alcoholic and non-alcoholic beverages, and cosmetic products (Woolfe, 1992; Hathorn *et al.* 2008; Lebot, 2010; Choi *et al.* 2011; Montilla *et al.* 2011; Rosell, 2011).

1.1.4 Other non-cereal energy crops

Cassava (*Manihot esculenta*) is the sixth most important crop and is the main staple food for more than 800 million people generally from tropical countries (Scott *et al*. 2000; Lebot, 2009; Ceballos *et al*. 2010). It has a total global production of 276 million metric tons (FAOSTAT[2]). This important root crop which has likely

originated from the Amazon basin has a long storage life of 36 months in the ground, making it a stable food source when other crops are limited (Olsen and Schaal, 1999; Lebot, 2009). It serves as a superior source of energy which is higher than that of sweet potato, yam and taro (Lebot, 2009). Cassava can provide substantial amount of minerals and vitamins whereas its yellow variety can offer a significant amount of carotenoids (Chavez *et al*. 2000; Lebot, 2009). However, not all cassava varieties are edible due to their high cyanogenic content that may cause toxicity, death and chronic neurological diseases (Du *et al*. 1995; Andersen *et al*. 2000; Dufour, 2007). Cassava is mostly cultivated for starch production rendering it an important source worldwide together with maize, potato and wheat (Ellis *et al.* 1998; Davis *et al.* 2003). Cassava starch is processed into various forms like glucose syrup, fructose syrup, monosodium glutamate, maltose, maltodextrins, ethanol, acid-modified, oxidized, cross-linked, acetylated and cationic starches which are then used as raw material for making confectioneries, processed food, animal feed, pharmaceutical, adhesives, binders, biofuel and biodegradable plastics (Lebot, 2009). Cassava also serve as a superior source of carbohydrate for animal feed, and bio-ethanol production (Ceballos *et al*. 2010). With the development of sweet type cultivars of cassava, it is now consumed directly after boiling. In Africa, it is steamed or boiled, and incorporated in sauces and soups after pounding. In many countries, fresh roots, pellets and paste forms of cassava are processed into various products using various techniques to enhance cooking qualities, and reduce cyanogens (Lebot, 2009).

Taro (*Colocasia esculenta*) is an ancient root crop which is closely

associated with the diet, culture and tradition of about 500 million people in the tropical countries (Lebot, 2009; Quero-Garcia *et al.* 2010). It has a total global production of 10 million metric tons (FAOSTAT[2]). Taro corms are consumed after roasting, baking, boiling, steaming or frying, whereas the other parts like leaves, petioles and stolons are consumed after steaming or boiling (Masalkar and Keskar, 1998; Lebot, 2009). Taro corm is a significant source of starch, minerals (Ca, P, K and Mg) and vitamins (A, B complex and C), while its leaves are superior source of Ca (IPGRI, 1999; Lebot, 2009). In addition, the yellow, orange, pink, red and purple varieties of taro are superior sources of carotenoids and anthocyanins (IPGRI, 1999; Quero-Garcia *et al*. 2010). Its starchy corm is traditionally processed into 'Poi' naturally fermented paste in Hawaii, 'laplap' a pudding in Vanuatu, 'achicha' powder in Nigeria and 'achu' paste in Ghana (Nwana and Onochie, 1979; Njintang *et al.* 2007; Lebot, 2009). Today taro corms can either be processed industrially into flours, chips, French fries, or as frozen, peeled, pre-cooked and ready-to-use corms (Lebot, 2009).

Cocoyam or Yautia (*Xanthosoma spp.*) is a stem tuber which is similar to taro and is widely cultivated in tropical and sub-tropical countries like Hawaii, USA, Japan, Egypt, Ghana and Nigeria (Iwuoha and Kalu, 1995; Lebot, 2009). It has a total global production of 470 thousands metric tons (FAOSTAT[2]). It is mainly propagated for its corm and cormels which serves as human food, animal feed and industrial input (Iwuoha and Kalu, 1995; Masalkar and Keskar, 1998; Adedeji and Oluwalana, 2014; Oshunsanya, 2016). Cocoyam corms serve as good source of carbohydrates and proteins similar to potatoes but easier to digest (Sefa-Dedeh and

Sackey, 2002; Davies *et al.* 2008; Falade and Okafor, 2013; Oshunsanya, 2016). It is traditionally consumed after boiling, pounding, roasting and frying (Adedeji and Oluwalana, 2014). Moreover, it is processed as soup thickeners, flour for baking, chips, beverage, and porridge (Iwuoha and Kalu, 1995; Falade and Okafor, 2013).

1.2 Functional properties of colored non-cereal energy crops

1.2.1 Colored Potatoes

Potato varieties with colored flesh contain high amounts of carotenoids, flavonoids, folates, polyamines, anthocyanins, and phenolic acids like chlorogenic, neochologenic, ferulic, vanillic, caffeic and p-coumaric which are known to have beneficial health effects and antioxidant properties (Reyes *et al.* 2005; Leo *et al.* 2008; Ieri *et al.* 2011; Burgos *et al.* 2013; Rytel *et al.* 2014; Mane *et al.* 2015). Potato is the third most important source of phenolic compounds like lignin, coumarins, anthocyanins, flavones, tannins, and monohydric and polyhydric phenols after apples and oranges (Talburt *et al*. 1987; Chun *et al.* 2005: Ezekiel *et al.* 2013). Purple- and red-fleshed potatoes contain four times higher the concentration of phenolic acids in white-fleshed potatoes (Ezekiel *et al*. 2013). In addition, purple- and red-fleshed potatoes contain twice of the flavonoid concentration of white-fleshed cultivars (Lewis *et al*. 1998).

Yellow-fleshed potatoes were reported to have high concentrations (50 to 1552 μg/ 100 g dry wt.) of carotenoids such as violaxanthin, lutein, zeaxanthin, neoxanthin, antheraxanthin, β-cryptoxanthin, and β-carotene (Fernandez-Orozco *et al.* 2013; Hejtmankova *et al.* 2013; Kotikova *et al.* 2015). Yellow-fleshed potatoes were also reported to have higher folate content than other cultivars providing 10%

of the folate intake of people in European countries (Goyer and Navarre, 2007; Navarre *et al*. 2009).

On the other hand, red- and purple-fleshed potatoes contains acylated glucosides of pelargonidin, malvidin, petunidin, peonidin, and delphinidin which are strongly related to their ability to scavenge free radicals and mitigate oxidative stress- related diseases (Brown, 2005; Lachman *et al*. 2009; Puchau *et al*. 2010; Burgos *et al.* 2013; Kita *et al.* 2013). Purple-fleshed potatoes remains a good source of anthocyanin and showed high antioxidant activities even after boiling of unpeeled tubers which may contribute significantly to the intake of health promoting compounds (Burgos *et al*. 2013; Lemos *et al.* 2015; Tian *et al.* 2015; Tierno *et al.* 2015). Nutritional and functional value of red- and purple fleshed potatoes can be enhanced by appropriate environmental conditions during tuber development (eg. longer daylight and cooler temperature) and abiotic stresses like wounding, methyl jasmonate treatment and selenium-enrichment making them a better functional food (Reyes *et al.* 2003; Reyes *et al.* 2004; Lachman *et al.* 2008; Lei *et al*. 2014). Moreover, selenium-enriched purple potatoes have increased phenolic and anthocyanin composition and additional physiological functions as antioxidants, anti-cancer, immunity stimulation and inhibiting HIV which are attributed to the activities of selenoproteins, selenomethionine, methylselenocysteine and selenium regulated enzymes (Wong *et al*. 2010; Tara *et al.* 2010; Ramoutar and Brumaghim, 2010; Silva *et al.* 2010; Lei *et al*. 2014).

The total phenolic (TP) and anthocyanin (TA) content of yellow-, red- and purple- fleshed potatoes were reported to have high correlation with their

antioxidant activities (AA) (Lachman *et al.* 2008, Burgos *et al.* 2013; Rytel *et al.* 2014). Red- and purple- fleshed potatoes were analyzed to have radical scavenging activities of 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) and 1,1-diphenyl-2-picrylhydrazyl (DPPH), and ferric reducing ability of plasma (Burgos *et al.* 2013; Kita *et al.* 2013; Tierno *et al.* 2015) which are strongly dependent on the cultivar (Lachman *et al.* 2012). There were contrasting reports on the effects of cooking and thermal processing methods on anthocyanin, carotenoid and antioxidant activities of colored-flesh potatoes (Burgos *et al.* 2013; Kita *et al.* 2013; Tian *et al.* 2015; Tierno *et al.* 2015). However, the most significant cause of phytochemical losses during cooking and thermal processing is the peeling and dicing of potatoes (Rytel *et al.* 2014; Tierno *et al.* 2015). Colored potatoes are also an important source of essential amino acids due to high threonine, cysteine, isoleucine, proline, glycine, and alanine contents (Peksa *et al.* 2013).

Moreover, raw and baked purple-fleshed potatoes have been reported to suppress proliferation and induce apoptosis in the early and advanced colon cancer cell lines which are attributed to its high anthocyanin content (Madiwale *et al.* 2012). In addition, purple-fleshed potatoes reduces the number of colon cancer stem cells and tumor incidence *in vivo* (Charepalli *et al.* 2015).

Purple potato flakes were also described to improve the serum cholesterol metabolism in rats fed with a high cholesterol diet resulting in hypocholesterolemic effect which is attributed to the combined action of anthocyanin and phosphorus (Han *et al*. 2013). In addition, purple potatoes have also been associated with the improved colonic environment of rats caused by increases in cecal short-chain fatty

acids, microflora, and fecal bile acids (Han *et al*. 2008). Moreover, an improved antioxidant potential in rats fed with cholesterol diet was also reported (Han *et al.* 2006a; Han *et al.* 2007).

The presence of valuable carotenoid, anthocyanin and amino acid, and their beneficial health effects and antioxidant activities make red- and purple-fleshed potatoes an important food and raw material in the industry (Peksa *et al.* 2013). Ultimately, interest in these colored varieties is increasing in many countries (Rytel *et al.* 2014).

1.2.2 Colored Yams

Yams were reported to have high concentrations of dioscorin, as major soluble protein accumulating in the vacuoles of the tuber cells (Conlan *et al.* 1998; Chen and Lin, 2007). Dioscorin from *Dioscorea alata* L. has been shown to induce Toll-like receptor 4 (TLR4)-downstream cytokine in bone marrow cells and cytokines in murine macrophages via the TLR4-signaling pathways indicating that it has potential in treating immune diseases and cancers (Fu *et al*. 2006). On the other hand, its mainly mannan-protein mucilage which exhibits high water holding capacity and significantly affects the physicochemical properties of starch was reported to have carbonic anhydrase, trypsin inhibitor, dehydroascorbate reductase, monodehydroascorbate reductase, immunostimulatory, immunomodulatory, antioxidative, and hypolipidaemic activities (Hou and Lin, 1997; Hou *et al*. 2000; Hou *et al*. 2001; Boban *et al*. 2006; Liu, *et al*. 2007b; Shang *et al.* 2007; Yeh *et al*. 2009).

Besides dioscorin and mannan-protein mucilage, purple yam was also accounted for its functional components such as dioscin, mucin, allantoin, choline, phenolic compounds, vitamins and essential amino acids (Bhandari *et al*. 2003; Shewry, 2003; Fang *et al*. 2011). Among its phenolic compounds, the most abundant are the anthocyanins and cathechins which are associated with beneficial health effects like anti-diabetes, blood sugar and lipid reduction, diarrhea prevention, and anti-microbial, antioxidant, antimutagenic and anti-allergic activities (Araghiniknam *et al.* 1996; Miyazawa *et al.* 1996; Kelmanson *et al.* 2000; Bhandari and Kawabata, 2004; Chou *et al*. 2006; Chen *et al.* 2008; Fang *et al*. 2011).

Yam was also reported to have diosgenin, an immunoactive steroidal sapogenin, which enhances the growth of *Lactobaccillus murinus* and *Lactobacillus ruetri* indicating that it is an effective and novel class of prebiotic to lactic acid bacteria (Huang *et al*. 2012). In addition, both the Chinese (*Dioscorea alata* L.) and Japanese yams (*Dioscorea japonica*) were both found useful for alleviating lipopolysaccharide-induced oxidative damage by fibronectin production, that increases the superoxide dismutase activity and decreases lipid oxidation which are attributed to their dietary fiber, polyphenol and flavonoid contents (Hsu *et al*. 2006). On the other hand, the ethanol extracts of *Dioscorea alata* peel were found to have protective effects against *tert*-butylhydroperoxide-induced oxidative stress in mouse liver cells (Hsu *et al*. 2011).

Taiwanese yam (*Dioscorea alata* L. cv. Tainung No. 2) improves the mucosal leucine-aminopeptidase activity of adult Balb/c mice while sucrase activity is reduced. Moreover, feeding up to 50% yam diet resulted in the increase

in fecal excretions of neutral steroid and bile acids, and decrease in fat absorption (Chen *et al*. 2003).

Purple yam (*Dioscorea alata* L.) starch is considered as a B-type starch, and has a round to oval and 10 to 40μm granules (Huang *et al.* 2006; Jayakody *et al*. 2007; Perez *et al*. 2013). Yam starch paste shows low pasting temperature, but high enthalphy of gelatinization, peak viscosity and set back during cooling that may result in high retrogradation which are all attributed to its high amylose content (Freitas *et al*. 2004; Huang *et al.* 2006; Jiang *et al*. 2012; Perez *et al*. 2013). It is an excellent source of dietary fiber and has a low glycemic index whereas its antioxidant potential is similar or higher than butylated hydroxyanisole and α-tocopherol (Mendoza *et al*. 1994; Tecson-Mendoza, 2007).

1.2.3 Colored Sweet Potatoes

Purple-fleshed sweet potatoes (PFSP) have intense and stable color due to the high concentration of anthocyanins that are related with many biological functions such as free-radical scavenging, linoleic acid autoxidation inhibition, anti-carcinogenic, anti-mutagenic, anti-tumor and anti-hypertensive activities (Oki *et al*. 2002; Suda *et* al. 2003; Terahara *et al*. 2004; Rumbaoa *et al*. 2009; Ahmed *et al*. 2010; Troung *et al.* 2012*;* Cipriano *et al*. 2015; Wu *et al*. 2015; Xu *et al*. 2015; Cai *et al*. 2016; Hu *et al.* 2016). Anthocyanin fractions extracted from PFSP suppress hepatic stellate cells by blocking the platelet-derived growth factor receptor and improves liver fibrosis caused by dimethylnitrosamine in rats (Choi *et al*. 2010; Choi *et al*. 2011; Hwang *et al*. 2011a), and thus, it can be used to cure and prevent hepatic fibrosis and liver cirrhosis caused by alcohol consumption, drug

abuse, cholestasis, hepatic viruses, and metabolic and autoimmune diseases (Friedman, 2000; Hsiang *et al*. 2005; Zhang *et al*. 2009; Choi *et al*. 2010). Moreover, anthocyanins from purple sweet potato provide protection against tert-butyl hydroperoxide-induced hepatotoxicity by scavenging reactive oxygen species and regulating the antioxidant enzyme heme oxygenase-1 (Zhang *et al*. 2009; Hwang *et al*. 2011b). Hwang *et al*. (2011c) reported that PFSP-derived anthocyanins also inhibit hepatic lipid accumulation and prevent obesity by activating the adenosine monophosphate-activated protein kinase, acetyl-coenzyme A carboxylase in the liver and HepG2 hepatocytes. Purple sweet potato extract also reduces neuroinflammatory responses in lipopolysaccharide-activated BV-2 microglia cells by inhibiting the over production of nitric oxide, inducible nitric oxide synthase, cyclooxygenase-2 and tumor necrosis factor-alpha (Kang *et al*. 2014).

Oral administration of purple sweet potato color (PSPC) to domoic acid-treated mice inhibits the endoplasmic reticulum stress-induced apoptosis, decreases reactive oxygen species and protein carbonylation, prevents neuron loss, and restores expression of memory-related proteins indicating that it acts through multiple pathways, and may prevent and treat cognitive deficits in excitotoxic and other brain disorders (Lu *et al*. 2012). It can also have neuroprotective effects by suppressing the lipopolysaccharide-induced cyclooxygenase-2 and inducible nitric oxide synthase expression, and decreasing the tumor necrosis factor-alpha, interleukin-1beta and interleukin-6 in the mouse brain (Wang *et al*. 2010). Moreover, PSPC reduces the body weight, urine albumin to creatinine ratio, inflammatory cell infiltration, collagen IV accumulation and kidney NLRP3

inflammasome expression. It also inhibits the activation of I *kappa* B kinase and nuclear translocation of nuclear factor *kappa beta* of rats fed with high fat diet suggesting its beneficial effects on kidney dysfunction and prevention of obesity (Shan *et al*. 2014; Sun *et al.* 2015). PSPC also protects the liver against D-gal-induced hepatocyte apoptosis by reducing oxidative stress, inhibiting activation of caspase-3, enhancing the anti-apoptotic protein Bcl-2 and activating the PI3-kinase/Akt pathway as observed in D-gal-treated mice (Zhang *et al*. 2010). It also attenuates hepatic insulin resistance of high-fat-diet treated mice by suppressing c-Jun-N-terminal kinase 1 and 1 *kappa* B kinase activation and nuclear factor-*kappa* B p65 nuclear translocation caused by oxidative and endoplasmic reticulum stress (Zhang *et al*. 2013).

The major anthocyanidins of purple sweet potato are 3-sophoroside-5-glucoside derivatives of cyanidin and peonidin, and more than 80.7% of them are acylated with *p*-hydroxybenzoic acid, ferulic acid or caffeic acid (Fan *et al*. 2008; Lu *et al.* 2011; Kim *et al.* 2012; Li *et al*. 2013; Liu *et al.* 2013; Tang *et al*. 2015; Xu *et al*. 2015). Moreover, colorless caffeoyl compounds such as 5-caffeoylquinic acid, trans-4,5-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid, 4,5-dicaffeoylquinic acid, and 6-O-caffeoyl-β-D-fructofuranosyl-(2-1)-α-D-glucopyranoside potato were isolated from purple sweet potato adding to its already high antioxidant activities (Zheng and Clifford, 2008; Zhao *et al.* 2014).

A dynamic gastrointestinal system showed that the bio-accessibility and biotransformation of anthocyanins were dependent on the accessions and their stability to intestinal and colonic microbial digestion (Tarko *et al*. 2013; Alminger

et al. 2014; Kubow *et al*. 2016). Nevertheless, an increase in ferric reducing antioxidant power in the intestinal vessel and colonic vessel was observed even after several digestion levels indicating high stability of anthocyanin from purple sweet potato (Kubow *et al*. 2016).

On the other hand the yellow and orange- fleshed sweet potatoes have been regarded to reduce the vitamin A malnutrition and food insecurity due to the high β-carotene and other carotenoid that are retained even after boiling (van Jaarsveld *et al*. 2006; Laurie *et al*. 2015; Tang *et al*. 2015). Both varieties, contain *cis*- and *trans*- *α- and β*-carotene, whereas the orange-fleshed sweet potatoes contain higher total carotenoid content than the yellow-fleshed (Liu *et al*. 2009). The total phenolic content of these varieties was highly correlated with the oxygen radical absorbance capacity and free radical scavenging activities, whereas the β-carotene content was poorly correlated (Teow *et al.* 2007).

1.3 Food processing applications of purple non-cereal energy crops

1.3.1 Purple Potatoes

Purple- and red-fleshed potatoes show similar hues to red cabbage extracts and FD&C Red #40, respectively, at around pH 3 (Reyes and Cisneros-Zevallos, 2007), thus, they can be a superior source of natural colorant and antioxidants for the food and non-food industry (Lachman and Hamouz, 2005; Andre *et al*. 2007; Reyes and Cisneros-Zevallos, 2007). Cooking methods like boiling, baking, steaming and microwave retains high concentration of anthocyanin in colored-flesh potatoes (Lemos *et al.* 2015). Thus, these methods can be used in developing colored-flesh-potato-based products (Burmeister *et al*. 2011; Lachman *et al.* 2012;

Burgos *et al*. 2013). Moreover, purple-potato based extruded products have significantly higher total phenolics and flavonoid contents, and ORAC antioxidant activity than the raw formulations (Nayak *et al*. 2011). Although frying may cause degradation of anthocyanin and polyphenols, the pelargonidin and malvidin derivatives can still remain stable which may result in a bright intensive colored potato crisps with good antioxidant activity (Kita *et al*. 2013). Colored-potato extracts can also be used as natural antioxidant that suppress lipid oxidation of oils and fats in processed food products (Ur-Rehman *et al.* 2004; Schieber and Saldana, 2009; Albishi *et al*. 2013). Because of the low-cost, as well as the higher nutritional, antioxidant and health promoting properties, these sweet potatoes have great potential in the nutraceutical industry (Jansen and Flamme, 2006; Lachman *et al*. 2009; Puertolas *et al*. 2013; Durham *et al.* 2015).

1.3.2 Purple Yams

Purple yam tubers have been traditionally consumed as boiled, steamed or fried, but they are also used in soups, herbal medicine, and sometimes processed into powder (Fang *et al*. 2011). Several methods like air-, freeze-, far-infrared radiation-assisted freeze drying and vacuum frying have been applied to preserve its color, flavor and taste, and prolong shelf stability (Hsu *et al*. 2003; Falade *et al*. 2007; Lin *et al*. 2007; Fang *et al*. 2011). Freeze drying of yam chips was reported for higher retention of total phenolics and DPPH radical scavenging activity while deep frying provide good storage stability (Liu and Lin, 2009).

Yam tubers are processed into flours to extend its supply, and reduce storage losses and transportation cost (Iwuoha, 2004). Purple yam tubers are non-traditional

source of flours and starch that can be used as food ingredient and are now increasingly used in the processing of breads, cakes, confectioneries and noodles (Mali *et al*. 2003; Iwuoha, 2004; Krishnan *et al.* 2010). Substitution of not more than 25% yam flour in wheat bread has been acceptable to consumers due to very minimal to non-traceable cracks observed (Amandikwa *et al*. 2015). Likewise, salted noodles substituted with about 15% of purple yam have gained consumer acceptability because of the produced pleasant purple-red color (Li *et al*. 2012).

Gutierrez *et al*. (2015) reported that the native starch of dark purple cush-cush yam (*Dioscorea trifida*) and its sodium trimetaphosphate-modified starch plasticized with glycerol produce edible and biodegradable films that can be used as food coatings or primary packaging (Alves *et al*. 1999). On the other hand, extruded yam starch gels demonstrate gel strength with high cold thickening capacity which can be used for the processing of instant creams and puddings (Alves *et al*. 1999; Mali *et al*. 2002).

In West Africa, yam is used in the preparation of their staple food called '*foutou*' or pounded yam which appear as a dough-like paste. This pounded yam is enjoyed by West Africans because of its good textural quality, numerous health benefits and functional properties (Brunnschweiler *et al*. 2006; Otegbayo *et al*. 2006; Akissoe *et al*. 2011).

Moreover, yam can also be a substitute for pork backfat particularly in the production of Chinese sausage which can be advantageous because of the significant reduction in crude fat, as well as increase in moisture content, water holding capacity and water activity. Hence, substitution of only up to 5% yam has

no significant effect on the color, hardness, flavor, juiciness and overall acceptability (Tan *et al*. 2007). Nevertheless, Chinese yam is also a good source of oligosaccharides that have good hydroxyl radical scavenging activity and can serve as a functional food ingredient (Chen *et al*. 2015).

1.3.3 Purple Sweet Potatoes

Despite the well-published reports on the health benefits of sweet potato, it still remains as an underutilized crop in terms of food processing (Woolfe, 1992; Cipriano *et al*. 2015; Kusumayanti *et al*. 2015). In an effort to increase its utilization, various sweet potato-based products have been developed which includes natural food colorants, dehydrated flakes, chips casserole, pudding, pies, cakes, patties, breads, noodles, jams, confectionary, soups, beverages and baby food (Yamakawa and Yoshimoto, 2002; Suda *et al*. 2003; Steed and Troung, 2008; Qiao *et al*. 2012; Cipriano *et al*. 2015; Kusumayanti *et al*. 2015). However, the most common cooking methods can damage a significant amount of bioactive substances associated with sweet potatoes such as phenolics, carotenoids, and anthocyanin (Kim *et al*. 2015; Tang *et al.* 2015). In this regard, the use of more adequate cooking procedures like high hydrostatic pressure and high temperature short time processing can be explored to retain their antioxidant capacities and health promoting effects (Wang *et al*. 2012; Kim *et al*. 2015; Tang *et al.* 2015).

Purple-fleshed sweet potato flour can be used as a natural food colorant to enhance the color, flavor, nutrients and marketability of food products (Cevallos-Casals and Cisneros-Zevallos, 2004; Fan *et al.* 2008; Ahmed *et al*. 2010). The demand for natural colorants is now high due to some legislative and health

concerns on the utilization of synthetic dyes like FD&C red 40 and FD&C red 2 (Fabre *et al*. 1993; Cevallos-Casals and Cisneros-Zevallos, 2004). These natural food colors can be spray dried and encapsulated with ascorbic acid and maltodextrin or β-cyclodextrin to protect the natural colorant from oxidation, and enhance its antioxidant activities (Cai and Corke, 2000; Desai and Park, 2005; Ahmed *et al*. 2010; Peng *et al.* 2013). Likewise, they can also be used as thickener in soups and gravy, and as a functional ingredient in snacks and baked products (Van hal, 2000). Moreover, purple-fleshed sweet potato powder added in pork sausages as a substitute for nitrites improves the color, texture, sensory characteristics and acceptability (Jin *et al*. 2012). Anthocyanins can also be isolated from fermented purple sweet potato which may provide purer extracts that are more stable at low pH, and can be used as natural colorant in the food industry (Fan *et al*. 2008). Purple sweet potato anthocyanins have higher stability at pH 3-4 and can be used as good natural colorant to produce red-colored beverages particularly apple and pear juices (Li *et al*. 2013).

With its antioxidant properties, and beneficial health effects, purple sweet potato and its extracts can also be used as a drug or functional food ingredient (Wang *et al*. 2012; Tang *et al.* 2015; Wu *et al*. 2015). Its use as an ingredient for food and pharmaceutical processing has been demonstrated by the stable biological activities of its anthocyanin content even after steam cooking and baking. (Kim *et al*. 2012).

1.4 Integration of this chapter to this research

Previous researches provided information on the physicochemical characteristics, detailed functional properties and potential beneficial health effects of purple potato, yam, and sweet potato. It has been demonstrated that these commodities have high concentrations of bioactive compounds in the form of carotenoids, polyphenols, anthocyanins and other phytochemicals that have antioxidant, anti-tumor, anti-hypertensive, anti-carcinogenic, anti-inflammatory properties and other beneficial health effects (Kita *et al.* 2013; Rytel *et al.* 2014 Mane *et al.* 2015 Cai *et al*. 2016; Hu *et al.* 2016).

Conflicting results on the effects of boiling, steaming, frying and other thermal processing techniques on the stability and retention of different bioactive compounds have been reported. In general, wet heating techniques like boiling and steaming results in greater bioactive compound loss than dry heating, like roasting and baking. The reason for this is the solubility of bioactive compounds in water which affects its retention during thermal processing (Kim *et al.* 2012). In addition, the peeling and dicing of tuber and root crops resulted in greater phytochemical losses during thermal processing (Rytel *et al.* 2014; Tierno *et al.* 2015). Nevertheless, even after some phytochemical losses due to the thermal processing of purple potato, yam and sweet potato, they still show potent antioxidant capacities and functional properties (Kita *et al*. 2013 Kim *et al*. 2015; Tang *et al.* 2015). Ultimately, non-thermal processing that use high pressure and pulse electric field along with other alternative techniques like microwave heating, radio-frequency processing, ohmic heating, combined microwave vacuum drying, and infrared

heating can be explored to retain the phytochemical composition, antioxidant capacities and health promoting effects of colored tubers and root crops (Wang *et al*. 2012; Sun, 2014; Kim *et al.* 2015).

However, despite the voluminous reports about the beneficial health effects and potential food processing applications of colored tuber and root crops, their utilization in food processing is still minimal and only a few products from these commodities are available in the market. Therefore, in order to take advantage of the beneficial health effects of these commodities, supplementing or substituting them in staple food products like bread and noodle products among others can be explored. Studies on extraction, isolation and processing techniques of important bio-active components of colored tubers and root crops can serve as guide to retain phytochemical composition, functional properties, antioxidant capacities and health promoting effects in processed food products.

Chapter 2

Effect of Purple Sweet Potato Powder Substitution and Enzymatic Treatments on Bread Making Quality

2.1 Introduction

Sweet potato is the sixth most important food crop in the world; more than 105 million metric tons is produced yearly (CIP[3)]). About 95% of its total production is from developing countries, with Asia as the largest producing region (Lu and Gao, 2011). Sweet potato is a good source of carbohydrates, dietary fiber, minerals and vitamins (Antonio *et al*. 2001). It is also a superior source of natural phytochemicals, such as phenolic acids, tocopherol, β-carotene and anthocyanin (Teow *et al*. 2007; Rumbaoa *et al.* 2009), which are responsible for the stable yellow, orange and purple colors of sweet potato varieties, making them a better alternative than synthetic colorants (Bovell-Benjamin, 2007). Furthermore, the stability of anthocyanin in purple-fleshed sweet potato has been confirmed at steaming and baking temperatures of 121°C and 200°C, respectively (Kim *et al.* 2012). Thus, purple sweet potato can be used as a natural colorant in beverages, confectioneries, and staple foods like bakery and noodle products (Hathorn *et al*. 2008; Montilla *et al*. 2011; Rosell, 2011).

Specialty breads substituted with non-wheat flour have been attracting attention because of their added nutrients, flavor, and color not typically observed

in plain wheat bread (Meuser *et al.* 1994; Brown, 1996; Brown, 1998; Dewettinck *et al.* 2008; Hathorn *et al.* 2008). However, the addition of non-wheat flour from rice, chickpea, potato, and sweet potato has resulted in inferior bread making quality due to the lack of gliadin and glutenin proteins, and the presence of damaged starch and fibers that weaken the gluten (Yamauchi *et al.* 2004a; Yamauchi *et al.* 2004b; Hathorn *et al.* 2008; Mohammed *et al.* 2012). Thus, the addition of dough enhancing ingredients or enzymes to improve bread making quality is necessary.

Enzymes such as amylases and hemicellulases have become important in baking because they improve the quality of bread (Caballero *et al.* 2007). Previous studies reported that α-amylase and β-amylase catalyze the hydrolysis of amylose and amylopectin to fermentable sugars; the gas production resulting from the yeast-fermented sugars produces greater loaf volume (Macgregor *et al.* 2001; Gupta *et al*. 2003; Goesaert *et al.* 2009). On the other hand, hemicellulases such as xylanase have been reported to impart a slacker, softer and more viscous dough, which results in a greater bread volume because of their ability to degrade water insoluble hemicelluloses into water soluble forms and simple sugars (Jiang *et al.* 2005; Stojceska and Ainsworth, 2008; Schoenlechner *et al.* 2013).

In this study, the effect of purple sweet potato powder (PSPP) substitution and enzyme treatments using α-amylase and hemicellulase on bread making quality were examined. Furthermore, damaged starch, fiber, and ethanol-soluble sugar were analyzed in order to evaluate the relationship between these parameters and bread making quality.

2.2 Materials and Methods

2.2.1 Flour samples and enzymes used

The commercial hard wheat flour (Camellia) and purple sweet potato powder (PSPP: Ayamurasaki Powder) used in this study were manufactured by Nisshin Flour Milling Co., Ltd. (Tokyo, Japan) and Kumamoto Flour Milling Co., Ltd. (Kumamoto, Japan), respectively. Two commercial enzymes were used: α-amylase (Sumizyme AS) containing 1500 α-amylase U/g, and hemicellulase (Sumizyme SNX) containing 14,000 xylanase U/g, both manufactured by Shin Nihon Chemical Co., Ltd. (Anjo, Japan).

2.2.2 Dough preparation and bread making

The bread-making tests were carried out using the no-time method and following the standard wheat bread formulation as the control, which is prepared from 200 g of wheat flour, 10 g of sugar (Nippon Beet Sugar Mfg. Co. Ltd., Tokyo, Japan), 10 g of shortening (Snowlight, Kaneka Corp., Osaka, Japan), 4 g of wet yeast (regular yeast, Nippon Beet Sugar Mfg. Co. Ltd.), 4 g of NaCl purified salt (The Salt Industry Center of Japan, Tokyo, Japan), 20 mg of ascorbic acid (Wako Pure Chemical Industries, Ltd., Osaka, Japan), and a suitable amount of water, as presented by Yamauchi *et al.* (2001). For the PSPP-substituted bread making treatments, 4 percent of the original wheat flour content of the control was replaced with PSPP, which is the minimum concentration that results in crumb color change. The bread treated with α-amylase and hemicellulase contained the optimum amount of 0.025 g and 0.05 g, respectively, which were determined from preliminary testing of the enzymes (data not shown). The optimal water absorption of each test was

determined using a Farinograph at 500 BU according to the method used by the AACC (1991). The dough was mixed to just beyond the peak development, as indicated by the electric power curve of the mixing motor. Pieces of mixed dough (100 g and 20 g) were weighed, rounded, and incubated for 20 min (bench time) at 30°C and 75% relative humidity (RH) in a fermentation cabinet. Samples (100 g) were molded and rolled using a molding machine with 0.79 and 0.47 cm upper and lower roller clearance, respectively. The rolled doughs were panned in baking pan with W 4.5cm x L 10cm and W 6cm x L 13cm bottom and opening areas, respectively, and 5 cm height. The doughs were then proofed for 70 min at 38°C and 85% RH, and then baked at 180°C for 25 min. Meanwhile, 20 g samples were used for the analysis of gassing power (GP) and gas retention of dough (GRD).

2.2.3 Dough properties and bread quality evaluation

GRD was evaluated by measuring the maximum expansion volume of 20 g of dough proofed at 38°C and 85% RH in a cylinder subjected to 0 to 100 kPa as presented by Yamauchi *et al*. (2000). GP was measured at 30°C for 1, 2, and 3 h using a Fermograph II (ATTO Co. Ltd., Tokyo, Japan). The specific loaf volume (SLV) of bread cooled at room temperature for 1 h after baking was measured by the rapeseed-replacement method. Images of bread and bread crumb were recorded by a digital camera and a scanner, respectively. Color of the bread crust and crumb were determined using a colorimeter (CR-400; Konica Minolta Sensing, Inc., Tokyo, Japan). The moisture content of the bread crumb was measured based on the AOAC official method (AOAC, 2000).

2.2.4 Soluble sugar analysis

Ethanol (80%)-soluble fractions of the breads were extracted to measure the sugar content and composition. The total saccharide content was determined by the phenol–sulfuric acid method as reported by Dubois *et al*. (1956). On the other hand, for the HPLC analysis of glucose, fructose, sucrose and maltose contents, 1 ml of the extract was diluted with an equal volume of acetonitrile, and filtered through a 0.45 μm membrane filter (Millipore Japan Co. Ltd., Tokyo, Japan). HPLC analyses of soluble sugars were performed using a Shodex Asahipak NH2P-50 4E (4.6 mm ID x 250 mm) column and RI-930 Intelligent RI detector (JASCO Corporation, Tokyo, Japan).

2.2.5 Fiber and damaged starch analysis

Dough samples (100 g) after final proofing at 38^{o}C and 85% RH for 70 min were divided into 90 g and 10 g portions, frozen at -40^{o}C for 30 min using a blast freezer and stored in a freezer at -30^{o}C until used for analysis of dough fiber and damaged starch (DS) content.

The dough samples were dried at 105^{o}C and ground prior to fiber analysis. The neutral detergent fiber (NDF), an estimation of cellulose, hemicellulose and lignin content, and the acid detergent fiber (ADF), equivalent to the amount of cellulose and lignin, were analyzed using AOAC official methods (AOAC, 2000). Subsequently, crude hemicellulose content was estimated as the difference between NDF and ADF.

On the other hand, before DS analysis, water soluble sugars were removed by mixing 100 mg of dough with 8 ml of distilled water in a vortex mixer for 1 min

and centrifuging at 2,200 ×g for 10 min at 20°C. Mixing and centrifugation were repeated twice, and the resulting precipitate was used for DS analysis using the Megazyme assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland) based on the method of Gibson *et al.* (1991).

2.2.6 Statistical analysis

All data except for water absorption, SLV and color values of breads were measured in triplicate. The SLV and color values of breads were measured 4 and 10 times, respectively. Bread making and physicochemical properties of dough and bread substituted with PSPP, and treated with α-amylase and hemicellulase were statistically analyzed using SPSS for Windows (ver. 17.0). ANOVA and Tukey's multiple range test were performed to compare means at a 5% confidence level. Pearson's bivariate test was used to evaluate the correlation of parameters.

2.3 Results

2.3.1 Bread making quality of dough

The bread making quality of the control dough and doughs substituted with purple sweet potato powder (PSPP) and treated with α-amylase (AM) and hemicellulase (HC) is presented in **Table 2.1**. Results showed that the addition of PSPP significantly lowered GRD compared with the control and the enzyme treatments ($p<0.05$), whereas the doughs with PSPP+AM and PSPP+HC showed similar GRD to the control. On the other hand, the PSPP+AM+HC dough had a significantly higher GRD among the bread making treatments ($p<0.05$). The tendency for GP to increase during the incubation of each dough varied among bread making treatments. After 1 hour of incubation, the dough with PSPP had the

Table 2.1. Bread making qualities[1)] of dough supplemented with PSPP

Bread Making Treatments	Water absorption (%)	GRD (ml)	GP (ml)			SLV (ml/g)
			1h	2h	3h	
Control	68	95±4b	24.4±0.6ab	58.1±0.3a	90.9±0.4a	4.70±0.22b
+ PSPP	69	85±0a	23.7±0.5a	57.3±1.0a	91.7±1.3ab	4.09±0.17a
+ PSPP +AM	69	98±3b	24.7±0.3b	58.5±0.3a	92.1±0.3ab	4.65±0.18b
+ PSPP +HC	69	102±5b	24.6±0.1b	58.3±0.5a	93.2±0.6b	4.67±0.20b
+ PSPP +AM+HC	69	109±2c	26.5±0.2c	62.8±0.3b	99.5±0.4c	4.73±0.12b

Abbreviations: GRD, gas retention of dough; GP, gassing power of dough; SLV, specific loaf volume; PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value, except for water absorption is the mean ± SD. The values followed by different letters within column are significantly different (p<0.05).

lowest GP. However, with increasing incubation time, the GP of the PSPP dough approached that of the control and the doughs with PSPP+AM and PSPP+HC. On the other hand, the dough with PSPP+AM+HC showed significantly higher GP than other treatments throughout all incubation periods ($p<0.05$).

In terms of SLV, the PSPP bread was significantly lower than all other breads ($p<0.05$).

2.3.2 Bread crust and crumb properties

Table 2.2 summarizes the color and moisture content of breads; the results showed that the control bread crust had higher L*, a* and b* values than those of other treatments except for PSPP. Similarly, L* and b* values of the control crumb were significantly higher than all bread crumbs containing PSPP. On the other hand, the a* value of the control crumb was significantly lower than the bread crumb of other treatments ($p<0.05$).

The bread and bread crumb images are shown in **Fig. 2.1.** The PSPP bread with or without enzymes showed a darker external color compared to the control. Similarly, the crumbs of PSPP breads had light purple color and differed from the white crumb of the control. The bread with PSPP alone appeared to be smaller than the control, whereas the breads with PSPP and enzyme treatments were either the same size or larger than the control.

2.3.3 Soluble sugar content of bread

Table 2.3 shows the soluble sugar contents of breads. Significant differences in all treatments were observed among the means of glucose and fructose contents ($p<0.05$). The bread with PSPP+AM+HC showed the highest

Table 2.2. Color and moisture content of bread crusts and crumbs [1)]

Bread Making Treatments	Bread crust color			Bread crumb color			Moisture Content of crumb [2)]
	L*	a*	b*	L*	a*	b*	
Control	44.42±0.95 c	15.84±0.15 c	28.23±0.92 d	73.32±0.74 c	-4.33±0.06a	9.69±0.36 b	40.7±0.5
+ PSPP	43.30±2.03bc	15.33±0.30bc	25.71±1.67cd	65.13±0.81 b	7.08±0.19b	0.72±0.17 a	41.3±0.8
+ PSPP +AM	40.42±1.94ab	14.84±0.06ab	23.07±1.69bc	62.27±1.56 a	7.01±0.47b	0.69±0.14 a	40.6±0.5
+ PSPP +HC	38.56±1.48 a	14.54±0.41 a	20.99±1.61ab	63.53±1.43 a	6.83±0.23b	0.87±0.19 a	39.9±0.8
+ PSPP +AM+HC	37.70±2.14 a	14.38±0.53 a	19.67±2.44 a	64.96±0.66ab	6.56±0.17b	0.87±0.22 a	40.0±1.3

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase; L*, level of lightness or darkness; a*, level of redness or greeness; b*, level of yellowness or blueness

[1)]Each value is the mean ± SD. The values followed by different letters within column are significantly different (p <0.05).

[2)]Moisture content of crumb stored 1 day after baking.

Control +PSPP +PSPP+AM +PSPP+HC +PSPP+AM+HC

Fig. 2.1. Photograph and scanned images of breads
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

glucose and fructose contents: 8.11 ± 0.14 mg/g bread and 12.61 ± 0.10 mg/g bread, respectively, whereas the control had the lowest (p<0.05). Moreover, the control contained the lowest sucrose content of 0.28 ± 0.05 mg/g bread among all treatments. In terms of maltose, the control had a significantly lower content of 17.75 ± 0.21 mg/g bread than all other treatments. Bread with PSPP had 23.66 ± 0.14 mg/g bread, which is higher than the control but lower than the enzyme-treated breads. Breads with PSPP+AM and PSPP+HC had 35.07 ± 0.45and 35.56 ± 0.58 mg/g bread, respectively. The highest maltose content was observed in the PSPP+AM+HC bread at 41.81±0.11 mg/g bread.

For total sugars, the PSPP bread had higher content than the control. Enzyme treatment of the PSPP bread further increased the total sugar content. The PSPP+AM+HC bread had a higher total sugar content than the PSPP+HC bread but was not significantly different from PSPP+AM at p<0.05.

2.3.4 Fiber and starch damage contents of dough

Table 2.4 shows the fiber composition and damaged starch content of doughs from different treatments. Results showed that the neutral detergent fiber (NDF) and crude hemicellulose (NDF-ADF) contents of PSPP and PSPP+AM doughs were significantly higher than the control, PSPP+HC and PSPP+AM+HC doughs. Meanwhile, the ADF content of the doughs from all treatments did not significantly differ.

The dough treated with PSPP+AM+HC had the lowest DS at 2.54 ± 0.03%. The DS of PSPP+AM and PSPP+HC doughs was significantly lower than the control and PSPP doughs. The control had a lower DS of 3.96 ± 0.03% than the

Table 2.3. Soluble sugar content of breads[1)]

Bread Making Treatments	Glucose (mg/g bread)	Fructose (mg/g bread)	Sucrose (mg/g bread)	Maltose (mg/g bread)	Total Sugar (mg/g bread)
Control	5.01±0.11a	8.79±0.06 a	0.28±0.05 a	17.75±0.21 a	48.02±1.02 a
+ PSPP	6.13±0.13 b	9.79±0.18 b	0.46±0.05 b	23.66±0.14 b	62.35±0.80 b
+PSPP+AM	6.82±0.11c	10.87±0.07 c	0.57±0.07 b	35.07±0.45 c	73.26±3.23cd
+PSPP+HC	7.28±0.15d	11.84±0.25d	0.49±0.04 b	35.56±0.58 c	68.90±0.70 c
+PSPP+AM+HC	8.11±0.14e	12.61±0.10e	0.61±0.06 b	41.81±0.11 d	77.02±1.13 d

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within column are significantly different (p <0.05).

PSPP dough (4.13 ± 0.19%), but was significantly higher than the enzyme-treated doughs (p<0.05).

2.4 Discussion

2.4.1 Bread making quality of dough

The low GRD and SLV of bread with PSPP can be attributed to the lack of gluten protein and relatively higher fiber and damaged starch contents (**Tables 2.1**, **2.4** and **Fig. 2.1**). These properties of PSPP disrupt formation of the gluten network, resulting in a weaker gluten network for bread containing sweet potato flour (Hathorn *et al.* 2008). The improved GRD and SLV of the PSPP+AM bread in comparison with the PSPP bread can be explained by the α-amylase hydrolysis of damaged and gelatinized starch to maltose and dextrin, as evidenced by the increased maltose content of the PSPP+AM bread **(Table 2.3)**. These results agree with the report of Kim *et al*. (2006) wherein SLV decreased when the bread was substituted with polished wheat flour high in fiber and damaged starch contents; SLV increased upon the addition of α-amylase. A similar observation was reported by Patel *et al*. (2012) on the improvement in specific volume of chemically leavened bread treated with fungal α-amylase.

Likewise, hemicellulase catalyzes the degradation of polysaccharides including glucans, galactans, mannans, pentosans and xylans, into mono-sugars and short chain saccharides such as glucose, galactose, mannose, arabinose, xylose, xylobiose and xylotriose, which do not disturb the gluten network formation (Jiang *et al.* 2005). This catalytic activity may have caused the higher GRD and SLV of the bread with PSPP+HC compared to the PSPP bread. The same improvement in

Table 2.4. Fiber and damaged starch content of doughs[1)]

Bread Making Treatments	NDF (%)	ADF (%)	NDF-ADF[2)] (%)	DS (%)
Control	0.94±0.08 ab	0.28±0.10	0.66±0.04 bc	3.96±0.03 c
+ PSPP	1.15±0.03 c	0.36±0.02	0.78±0.02 c	4.13±0.19 d
+PSPP+AM	1.09±0.03bc	0.30±0.08	0.79±0.06 c	2.87±0.14 b
+PSPP+HC	0.81±0.07 a	0.32±0.12	0.50±0.07 a	2.98±0.04 b
+PSPP+AM+HC	0.94±0.05 ab	0.30±0.07	0.64±0.05 b	2.54±0.03 a

Abbreviations: NDF, neutral detergent fiber; ADF, acid detergent fiber; DS, damaged starch; PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within column are significantly different (p <0.05).

[2)]NDF-ADF: crude hemicellulose content

SLV after adding xylanase, a kind of hemicellulase enzyme, to whole wheat and millet/wheat composite breads was observed by Shah *et al.* (2006) and Schoenlechner *et al.* (2013), respectively.

A significant increase in GRD of PSPP+AM+HC over other treatments, including the control, was due to the decreased content of damaged starch and hemicellulose by the combined catalytic activity of α-amylase and hemicellulase (**Tables 2.1** and **2.4)**. The increase in mono-sugars from the α-amylase and hemicellulase hydrolytic activities, as reported by Goesaert *et al.* (2009) and Jiang *et al.* (2005), respectively, promotes yeast fermentation and may have resulted in significant improvement in GP of the PSPP+AM+HC dough in all incubation periods (**Tables 2.1** and **2.3**).

Ultimately, the GP of doughs at all incubation periods was significantly correlated ($p<0.05$) with GRD; the Pearson's correlation coefficients ranged from 0.749- 0.817. This suggests that an increase in GP results in an increase in GRD. Similarly, GRD and SLV were significantly correlated ($r = 0.772$).

2.4.2 Bread color and appearance

The addition of PSPP resulted in a darker bread crust compared with the control. Likewise, individual and combined treatments of α-amylase and hemicellulase also resulted in a darker color compared with the control and PSPP, evidenced by the lower L* values and images (**Table 2.2** and **Fig. 2.1**, respectively). Similarly, the addition of enzymes decreased the values of redness and yellowness, indicated by the lower a* and b* values shown in **Table 2.2**. These color changes can be attributed to the increased concentration of reducing sugars, i.e., glucose,

fructose, and maltose (**Table 2.3**), which promote the Maillard reaction, resulting in the intensification of bread flavor and browning (Goesaert *et al*. 2009).

The darker bread crumb color with PSPP addition can be attributed to the natural dark purple color of the anthocyanin pigments (Kano *et al*. 2005; Montilla *et al.* 2011; Ray *et al.* 2011). Similarly, the purple color of PSPP also influences the change in crumb color from white to light purple, as verified by the increase in redness and the decrease in yellowness.

2.4.3 Bread soluble sugar content

Higher glucose, fructose and total sugar contents of the PSPP bread compared with the control can be associated with the inherent sugar content of purple sweet potato powder (Antonio *et al*. 2011). On the other hand, the additional glucose, fructose and total sugar contents in the breads treated with enzymes may have resulted from the catalytic activity of α-amylase and hemicellulase (Caballero *et al.* 2007; Goesaert *et al*. 2009). In addition, the invertase enzyme of yeast may have catalyzed the conversion of sucrose in PSPP to glucose and fructose (Caballero *et al.* 2007). Moreover, sucrose, which is the most abundant sugar in raw sweet potato, contributed to the increase in sugar content of the PSPP bread with or without enzymes (Antonio *et al.* 2011).

On the other hand, the high maltose content of the PSPP bread could be caused by the catalytic activity of β-amylase, which is naturally present in wheat flour and sweet potato and results in hydrolysis of damaged or gelatinized starch to maltose and glucose (Lu and Gao, 2011). Moreover, the high maltose content observed in the PSPP+AM and PSPP+AM+HC breads may have been caused by

the catalytic activity of α-amylase, which hydrolyzes gelatinized starch to maltose and dextrins (Goesaert *et al.* 2009). Likewise, the high maltose content of the PSPP+HC bread can be attributed to the amylase activity of the crude hemicellulase used in this study.

2.4.4 Fiber and damaged starch contents of dough

The total fiber content of the control bread originated from the wheat flour used for baking. The high NDF and crude hemicellulose (NDF-ADF) contents of doughs from PSPP and PSPP+AM treatments (**Table 2.4**) can be attributed to the inherent fiber content of sweet potato, which generally contains about 3% dietary fiber (Antonio *et al.* 2011). On the other hand, the xylanase activity of the hemicellulase used, which catalyzes the hydrolysis of hemicelluloses like xylan, arabinoxylan to xylobiose and xylose (Jiang *et al.* 2005), may have resulted in the low NDF and crude hemicellulose (NDF-ADF) contents of PSPP+HC and PSPP+AM+HC doughs.

The DS content of the control dough can be associated with the DS contained in the wheat flour after milling. The higher DS of the PSPP dough compared with the control was brought about by the high level of damaged starch of 54% (data not shown) contained in PSPP, which is an indication of damage caused by heat treatment during preparation.

In contrast, the lower DS of the PSPP+AM and PSPP+HC doughs compared with PSPP and control in **Table 2.4** seems to be the result of the amylase activity. Moreover, the combined activity of crude α-amylase and hemicellulase in the PSSP+AM+HC dough produced a significantly lower DS than PSPP+AM and

PSPP+HC doughs (**Table 2.4**). The α-amylases in these crude enzymes catalyze the degradation of damaged and gelatinized starch to soluble sugars, as verified by the increase in glucose, maltose and total sugar contents of breads, which were inversely correlated with DS (correlation coefficients of -0.850, -0.938 and -0.826, respectively, at $p<0.05$).

Finally, the NDF of the dough was inversely correlated with SLV (r = -0.695) and GRD (r = -0.657) at $p<0.05$. Similarly, the DS of dough was inversely correlated with SLV (r = -0.634), GRD (r = -0.845) and GP at all incubation periods (r = -0.762 to -0.689). These findings indicate that the decrease in fiber and damaged starch contents improves GP, GRD and SLV of the bread treated with α-amylase and hemicellulase.

2.5 Conclusion

Substitution with PSPP in bread results in light purple color, attributable to the intrinsic anthocyanin content. However, this also results in low GRD and SLV, making the bread inferior to pure wheat bread, and is related to the lack of gluten protein as well as high damaged starch and fiber contents of PSPP.

On the other hand, the addition of α-amylase and hemicellulase to the PSPP dough improved the GRD, GP and SLV of the resultant bread. These improvements were mainly brought about by the degradation of damaged starch and hemicellulose into mono-, di- and oligo-saccharides, which do not interfere with formation of the gluten network during bread dough development. Thus, PSPP substitution and enzyme treatments result in bread with light purple color and of acceptable quality. However, direct effects of α-amylase and xylanase in the

crude hemicellulase on gluten-starch and gluten-pentosan interaction were not investigated in this study.

Chapter 3

Texture and Structure of Bread Supplemented with Purple Sweet Potato Powder and Treated with Enzymes

3.1 Introduction

Bread is one of the most widely consumed foods worldwide, and is a staple food in many developed and developing countries (Abdelghafor *et al*. 2011; Rosell, 2011). In developing countries, the wheat flour of baked products is supplemented with locally grown starchy crops in order to improve its nutritional value and reduce costs related to wheat imports (Olaoye *et al*. 2006; Olaoye and Ade-Omowaye, 2011). Moreover, many studies have focused on non-wheat flour supplementation with the goal of developing specialty breads with added nutritional value, flavor and color (Hathorn *et al*. 2008). Sweet potato is an abundantly available, inexpensive food crop in developing countries, and is of significant socio-economic importance because of its high nutrient, carotenoid and anthocyanin contents (Antonio *et al*. 2011; Ray and Tomlins, 2010; Lu and Gao, 2011). However, despite its abundance, low cost and high nutrient content sweet potato remains an underutilized food resource (Hathorn *et al*. 2008). To enhance utilization, sweet potato supplementation to baked products has been explored in many developing countries, and has been commercialized on a limited scale in Peru and Japan (Woolfe, 1992). However, lower bread quality is an issue due to the lack of gluten protein, and high fiber and damage starch content of non-wheat flour (Hathorn *et*

al. 2008). Thus, the use of enzymes, e.g., α-amylase and hemicellulase, has been explored to improve loaf volume, crumb texture and staling properties of bread, important considerations for both bakers and consumers (Scanlon and Zghal 2001; Jiang *et al.* 2005; Caballero *et al*. 2007; Rozylo and Laskowski, 2011; Wang *et al.* 2013). Loaf volume and texture dictates the quality and acceptability of bread, whereas staling serves as a measure of freshness and can be associated with changes in crumb moisture, hydration capacity and firmness during storage (Brady and Mayer, 1985; Greene and Bovell-Benjamin, 2004; Lai and Lin, 2006; Gomes-Ruffi *et al.* 2012).

In Japan, many sweet potato cultivars with white, yellow, orange and purple flesh are available. Although the yellow-fleshed variety is the most common, purple sweet potato has received much attention because of its nutritional value and heat stable color, attributed to its anthocyanin content (Terahara *et al.* 2000; Oki *et al.* 2002; Kim *et al.* 2012; Bovell-Benjamin, 2007). In this regard, purple sweet potato has been employed as a natural food colorant in noodles, jam, chips, confectionery, juice, alcoholic drinks and bread (Oki *et al.* 2002; Choi *et al.* 2011). However, despite its use in bread making, its effect on the texture, structure and staling of bread has not yet been fully explored.

Therefore, this study evaluated the effect of purple sweet potato powder (PSPP) supplementation and α-amylase (AM) and hemicellulase (HC) treatment on the texture and structure of doughs and breads. Changes in crumb hardness, cohesiveness and moisture were also determined to evaluate the effect of PSPP supplementation and enzyme treatment on bread staling.

3.2 Materials and Methods

3.2.1 Bread making treatments

Bread making tests were performed following the no-time method and a standard wheat bread formulation was employed as the control following the method of Yamauchi *et al.* (2001). Control bread was prepared from 200 g of Camellia wheat flour (Nisshin Flour Milling Co., Ltd., Tokyo, Japan), 10 g of sugar (Nippon Beet Sugar Mfg. Co., Ltd., Tokyo, Japan), 10 g of shortening (Snowlight; Kaneka Corp., Osaka, Japan), 4 g of wet yeast (Regular yeast; Nippon Beet Sugar Mfg. Co. Ltd.), 4 g of NaCl purified salt (The Salt Industry Center of Japan, Tokyo, Japan), and 20 mg of L-ascorbic acid (Wako Pure Chemical Industries, Ltd., Osaka, Japan). A suitable amount of water was added based on the optimal water absorption of dough at 500 BU and determined using Farinograph analysis as presented by AACC (1991). For the PSPP-added treatments, 4 percent of the original wheat flour content of the control was replaced with PSPP (Kumamoto Flour Milling Co., Ltd., Kumamoto, Japan). PSPP was prepared by heat-treating the raw purple sweet potato variety, Ayamurasaki, resulting in almost completely gelatinized starch. The amount of added PSPP, 4%, was determined as the minimum concentration that resulted in a clear crumb color change according to a previous report (Santiago *et al.* 2015a). For the enzyme treatment, optimum amounts of 0.025 g AM and 0.05 g HC (Shinnihon Chemical Co., Ltd., Anjo, Japan) were added to the formulation. AM and HC are crude products for food processing applications, each of which contain some other enzymes. Optimum amounts of these enzymes were determined according to a previous report (Santiago *et al.*

2015a).

3.2.2 Bread making and evaluation

The dough was mixed to just beyond peak development, as indicated by the electric power curve of the mixing motor. Pieces of dough (100 g and 20 g) were weighed, rounded, and incubated for 20 min (bench time) at 30°C and 75 % relative humidity (RH) in a fermentation cabinet, panned and proofed for 70 min at 38°C and 85 % RH.

Gas retention of dough (GRD) and gassing power (GP) of 20 g proofed dough were evaluated by measuring the maximum expansion volume at 0 to 100 kPa, and gas production at 30°C for 1, 2, and 3 h using a Fermograph II (ATTO Co., Ltd., Tokyo, Japan), respectively. Meanwhile, the 100 g proofed dough was baked at 180°C for 25 min and specific loaf volume (SLV) of the bread was measured by the rapeseed displacement method 1 h after baking in accordance with Yamauchi *et al*. (2000). Photographs of bread and scanned images of bread crumbs were recorded using a digital camera and scanner.

3.2.3 Texture and rupture properties measurements

Textural properties of bread crumb during storage were analyzed using the method as presented by Yamauchi *et al*. (2001). Loaves were stored in a polyethylene bag at 20°C and 70% RH for 3 days. At each storage day, 3 loaves were cut into 2 cm-thick slices and a square of crumb (3x3 cm) was cut from the center of the slices using an ultrasonic cutter (USC-3305; Yamaden Co., Ltd., Tokyo, Japan). Textural properties were measured by compressing the whole crumb twice from 2-cm to 1-cm thickness at a speed of 1 mm/s using a special cube plunger (6

cm length x 6 cm width x 2 cm height), up to strain of 0.5 with a creep meter (RE2-33005C; Yamaden Co., Ltd.). From the resulting stress-strain curve the texture profile specifically hardness, cohesiveness, springiness, gumminess and chewiness of breads were calculated. Moreover, the firmness rate was calculated based on changes in bread hardness during storage.

Rupture force (RF), rupture deformation (RD) and rupture energy (RE) were measured using the same size of crumb sample as for the textural analysis. Crumb samples were placed in the center of a 5 x 5 cm measuring table with a 1.5 x 1.0 cm square hole in the center of the table, and then ruptured at a speed of 5 mm/s up to 1.5 strain using the No. 64 wedge plunger of the creep meter (RE2-33005C; Yamaden Co., Ltd.).

3.2.4 Amylose content and enthalpy change for retrogradation of bread

Using the same sample as in the textural analysis, bread crumbs were air-dried after 99.5% ethanol and acetone treatment. Dried bread crumbs were ground, stored in polyethylene bags and used for determinations of amylose content and enthalpy change for retrogradation. Amylose content of bread crumbs was analyzed using a Megazyme assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland) based on the method of Gibson *et al.* (1996). On the other hand, the enthalpy change for retrogradation of starch was determined using a differential scanning calorimeter (DSC) (Micro DSC II, Setaram, Inc., Caluire, France). A sample of 200 mg dry weight basis (dwb) was weighed in a DSC pan and distilled water was added to give a suspension of 30% dwb. The pan was sealed and allowed to stand overnight at 20°C. The scanning temperature range was set at 30 to 95°C

and the heating rate was 1.5°C /min. Water (400 mg) was used as a reference.

3.2.5 Moisture content and soluble sugar analysis

Changes in the moisture content (MC) of bread stored for 3 days were determined using 2 x 3 x 3 cm bread crumbs according to the AOAC official method (AOAC, 2000).

Water-soluble fractions of the breads were extracted for determinations of sugar content and composition. Total and reducing saccharide contents were determined using the phenol–sulfuric acid and dinitrosalicylic acid methods as reported by Dubois *et al*. (1956) and Luchsinger and Cornesky (1962), respectively. Glucose, fructose, and maltose contents were analyzed using 1 ml of the water extract, diluted with an equal volume of acetonitrile and filtered through a 0.45-μm membrane filter (Millipore Japan Co., Ltd., Tokyo, Japan). HPLC analyses of soluble sugars were performed using a Shodex Asahipak NH2P-50 4E (4.6 mm ID x 250 mm) column and RI-930 Intelligent RI detector (JASCO Corporation, Tokyo, Japan).

3.2.6 Scanning electron microscopy

Pieces of dough just after mixing and proofing were blast frozen at -40°C for 30 min and stored at -30°C until used for analysis. Dough samples were cut into 1 cm-thick slices using an ultrasonic cutter and blast frozen at -40°C for 30 min. A representative portion of the frozen sample was cut and viewed using a scanning electron microscope (JCM-6000; JEOL Ltd., Akishima, Japan). On the other hand, for the elution treatment, dough samples were washed with deionized distilled water in a sonicator for 10 min and blast frozen as described above. Likewise,

representative samples were cut and viewed using a scanning electron microscope (SEM).

For bread just after baking, loaves were cut into 1 cm-thick slices and a square of crumb (2 x 2 cm) was cut from the center of the slices using an ultrasonic cutter. The sample was blast frozen, crushed with a hammer, and a representative sample was observed using SEM. For the elution treatment, 1 x 2 x 2 cm bread samples were washed with deionized distilled water in a sonicator for 10 min, blast frozen, crushed, and representative samples were viewed by SEM. All bread dough samples were scanned to observe the bread structures at 500x magnification.

3.2.7 Sensory evaluation

Quantitative descriptive analysis of PSPP and PSPP+AM+HC bread stored for 24 h for the following sensory properties: purple color (1-no purple to 9-extremely purple), sweet potato flavor (1-not perceivable to 9-extremely strong), sweet potato taste (1-not perceivable to 9-extremely strong), hardness (1-extremely soft to 9-extremely hard), elasticity (1-extremely low to 9-extremely high), cohesiveness (1-extremely low to 9-extremely high) and overall acceptability (1-disliked extremely to 9-liked extremely) a were evaluated and compared with the control.

3.2.8 Statistical analysis

All data except for water absorption, SLV, physical and sensory properties of bread were measured in triplicate. The SLV physical and sensory properties of bread were performed 4, 12 and 12 times, respectively. All data were statistically analyzed using SPSS for Windows (ver. 17.0). ANOVA and Tukey's multiple range

test were performed to compare means at a 5% significance level. Pearson's bivariate test was used to evaluate the correlation of parameters.

3.3 Results

3.3.1 Bread making quality

The bread making qualities of doughs supplemented with PSPP, treated with AM and HC and control are shown in **Table 3.1**. Results showed that the PSPP dough has significantly lower GRD than the control and PSPP+AM+HC. On the other hand, the PSPP+AM+HC dough showed improved GRD, but did not significantly differ from the control. **Table 3.1** also shows that the GP of PSPP+AM+HC dough was significantly higher than the doughs of PSPP and control at all incubation periods ($p<0.05$). In terms of SLV, PSPP bread had the lowest value, not significantly different from the control, whereas the PSPP+AM+HC bread had a significantly higher SLV than the control and PSPP bread ($p<0.05$). The difference in loaf volume is illustrated in **Fig. 3.1**, wherein the PSPP bread was smaller than the control. On the other hand, the PSPP+AM+HC bread appeared larger than the control and PSPP. In regards to bread crumb color, PSPP and PSPP+AM+HC had a light purple appearance, while the control was white (**Fig. 3.1**).

3.3.2 Textural properties, amylose content and enthalpy change for retrogradation of breads during storage

Figure 3.2 and **Table 3.2** shows the typical stress-time plots and textural properties of bread just after baking, respectively. **Figure 3.2** shows that PSPP bread had a clearly higher peak than the control and PSPP+AM+HC. Correspondingly,

Table 3.1. Bread making quality of bread dough[1)]

Bread Making Treatments	Water absorption (%)	GRD (ml)	GP (ml)			SLV (ml/g)
			1h	2h	3h	
Control	68	100.0±0.00 b	26.12±0.15 b	59.52±0.34 a	90.92±0.65 a	4.95±0.07 a
+PSPP	69	90.0±0.00 a	25.65±0.09 a	59.44±0.26 a	91.94±0.46 a	4.82±0.04 a
+PSPP+AM+HC	69	103.3±2.9 b	26.40±0.10 c	60.99±0.02 b	95.12±0.07 b	5.28±0.16 b

Abbreviations: GRD, gas retention of dough; GP, gassing power of dough; SLV, specific loaf volume; PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value except of water absorption for bread making is the mean ± SD. The values followed by different letters within columns are significantly different (p <0.05).

Control +PSPP +PSPP+AM+HC

Fig. 3.1. Photograph and scanned images of bread and bread crumbs
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, Hemicellulase

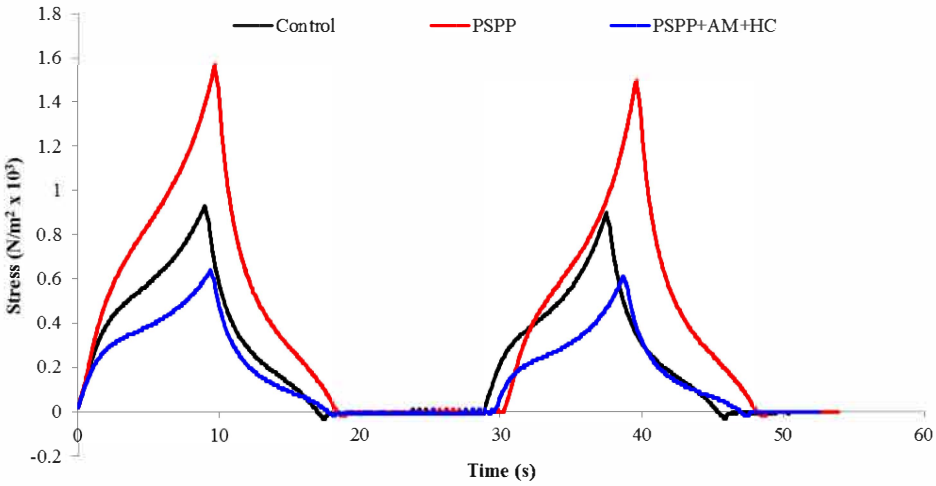

Fig. 3.2. Stress-strain curves of breads
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

Table 3.2. Texture properties of breads with PSPP[1)]

Bread Making Treatments	Hardness N/m^2	Cohesiveness (-)	Springiness (-)	Gumminess N/m^2	Chewiness (-)
Control	1063.89±51.35 a	0.84±0.006 b	0.96±0.002 a	897.78±45.00 a	866.66±52.63 a
+PSPP	1480.56±69.71 b	0.85±0.005 b	0.97±0.004 a	1252.57±55.66 b	1209.98±56.06 b
+PSPP+AM+HC	1056.94±49.85 a	0.82±0.001 a	0.97±0.004 a	861.46±40.98 a	832.16±41.54 a

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

1)Each value is the mean ± SD. The values followed by different letters within columns are significantly different ($p<0.05$).

PSPP bread had significantly higher hardness, gumminess and chewiness than the control and PSPP+AM+HC breads, as shown in **Table 3.2** (p<0.05). On the other hand, cohesiveness of PSPP+AM+HC bread was significantly lower than the control and PSPP bread (p<0.05).

Moreover, **Fig. 3.3** illustrates the increase in hardness, gumminess and chewiness, and decrease in cohesiveness and springiness of breads during storage. It was observed that the bread treatments showed significantly different hardness, cohesiveness, gumminess and chewiness after 3 days of storage, with PSPP+AM+HC revealed to have the lowest values (p<0.05). On the other hand, the PSPP bread had the highest hardness, gumminess and chewiness after 3 days storage (p<0.05).

Table 3.3 shows that the PSPP bread had a significantly higher firming rate at 2625.0±105.5 N/m^2 per day than the control at 2185.0±95.7 N/m^2 per day (p<0.05). On the other hand, PSPP+AM+HC bread had the lowest firming rate at 1993.2±74.8 N/m^2 per day (p<0.05). Likewise, PSPP+AM+HC had the lowest amylose content (p<0.05) among the bread treatments, which did not change during storage (data not shown). In addition, bread treatments showed significantly different enthalpy change for retrogradation just after baking, with PSPP+AM+HC as the lowest value (p<0.05). In **Fig. 3.4**, the enthalpy change for retrogradation increased during bread storage. However, a significantly lower change of retrogradation enthalpy was observed for PSPP+AM+HC after 3 days of storage.

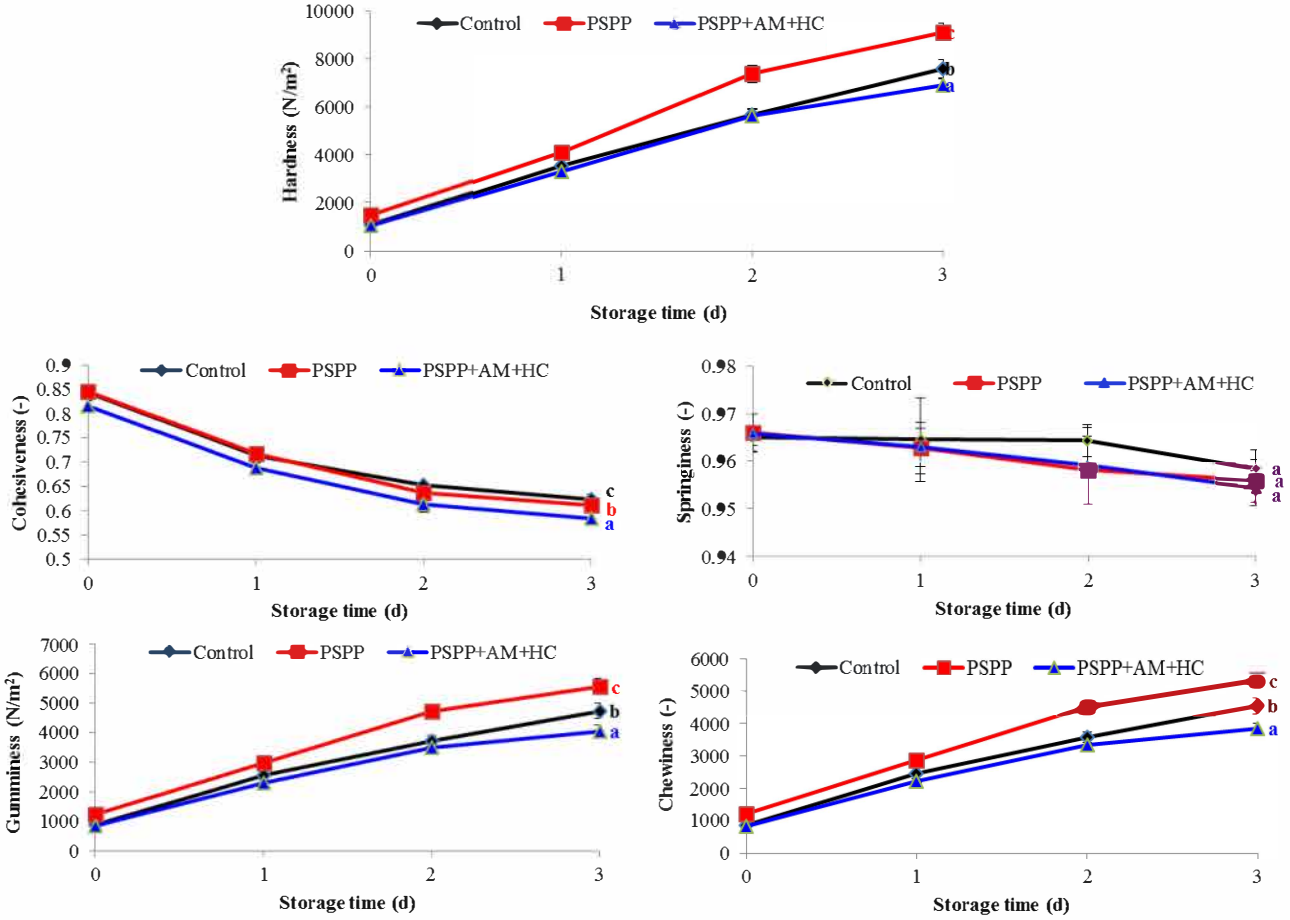

Fig. 3.3. Changes in texture properties of breads during storage[1)]

[1)]The vertical bar is the standard deviation of each value. The data points followed by different letters are significantly different (p<0.05).
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

Table 3.3. Firming rate, enthalpy of retrogradation, and amylose content of bread[1)]

Bread Making Treatments	Firming rate (N/m^2 per day)	Enthalpy of Retrogradation[2)] (J/g)	Amylose Content[2)] (%)
Control	2185±95.73 b	1.23±0.02 c	31.81±0.37 b
+PSPP	2624.99±105.50 c	1.13±0.02 b	31.88±1.07 b
+PSPP+AM+HC	1993.19±74.75 a	1.04±0.02 a	28.94±0.62 a

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase
1)Each value is the mean ± SD. The values followed by different letters within columns are significantly different ($p<0.05$).
2)Enthalpy of retrogradation and amylose content of breads just after baking

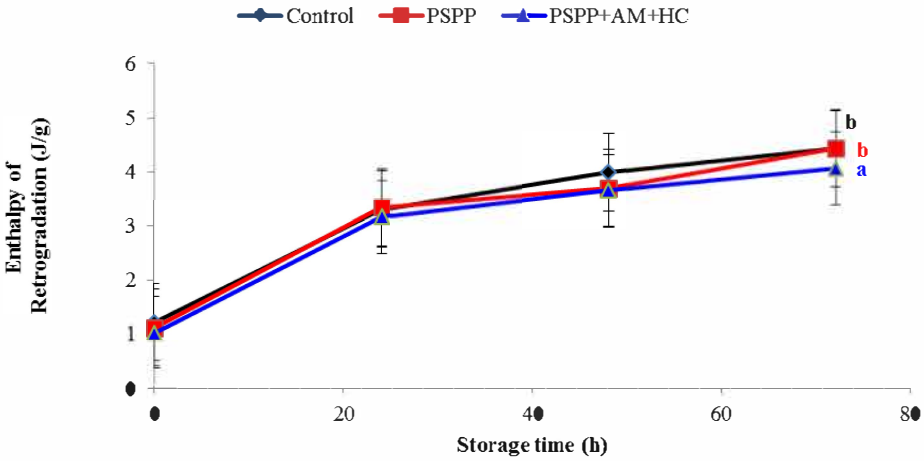

Fig. 3.4. Changes in enthalpy of retrogradation of breads during storage[1)]
[1)]The vertical bar is the standard deviation of each value. The data points followed by different letters are significantly different ($p<0.05$).
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

3.3.3 Rupture properties of breads

Table 3.4 presents the rupture properties of bread crumbs for each treatment. Results showed that after 1 day of storage, the rupture force (RF) of bread crumbs for each treatment differed significantly, with the PSPP bread showing the highest value and PSPP +AM+HC exhibiting the lowest ($p<0.05$). Decreases in RF,

RD and RE were observed during storage. After 3 days of storage, PSPP+AM+HC had significantly lower RF than the control and PSPP (p<0.05). Similarly, the RE of PSPP+AM+HC was significantly lower than the other bread treatments under all incubation periods (p<0.05).

3.3.4 Moisture and soluble sugar content of bread

Table 3.5 shows the decrease in moisture content of bread during storage. **Table 3.5** showed that the moisture loss of PSPP+AM+HC after 3 days of storage was significantly lower than the control and PSPP (p<0.05). On the other hand, **Table 3.6** shows that the PSPP bread had significantly higher water-soluble glucose, maltose, reducing and total saccharide content compared with the control (p<0.05). Moreover, PSPP+AM+HC had the highest water-soluble glucose, fructose, maltose, reducing and total sugar contents (p<0.05). In terms of fructose content, PSPP+AM+HC had the highest content at 11.81±0.12 mg/g bread, which was significantly higher than that of the control (11.35±0.15 mg/g bread).

3.3.5 Dough and bread crumb structure

Figures 3.5, 3.6 and **3.7** show images of the dough just after mixing, proofing, and baking, respectively. **Figure 3.5a**, **c** and **e** show the evenly scattered large and small starch granules of the non-eluted control, PSPP and PSPP+AM+HC doughs, respectively. However, no noticeable differences can be observed among non-eluted dough treatments just after mixing. On the other hand, **Fig. 3.5b**, **d**, and **f** show the eluted control, PSPP and PSPP+AM+HC doughs, respectively, and clearly illustrate the gluten network and crosslinking with starch granules. The interaction of gelatinized starch with the gluten network was observed in the PSPP

Table 3.4. Rupture properties of breads[1)]

Bread Making Treatments	RF (N)		RD (mm)		RE (J)	
	1d	3d	1d	3d	1d	3d
Control	3.66±0.05 b	3.05±0.23 b	21.46±0.19 a	15.67±0.54 a	0.030±0.001 b	0.029±0.002 b
+PSPP	3.83±0.05 c	2.95±0.10 b	21.54±0.10 a	15.75±0.59 a	0.031±0.001 b	0.030±0.001 b
+PSPP+AM+HC	3.30±0.08 a	2.39±0.15 a	21.54±0.46 a	15.29±0.43 a	0.028±0.001 a	0.025±0.001 a

Abbreviations: RF, rupture force; RD, rupture deformation; RE, rupture energy; PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within columns are significantly different (p <0.05).

Table 3.5. Changes in moisture content of breads during storage[1)]

Bread Making Treatments	Moisture Content of Crumb (%)				Difference in moisture content of crumb (%)
	Day 0	Day 1	Day 2	Day 3	Day 3-Day 0
Control	43.14±0.42 a	40.43±0.61ab	38.68±0.73 ab	36.87±0.13 a	6.27±0.29 b
+PSPP	43.58±0.18 a	40.47±0.50 b	39.23±0.33 b	37.28±0.12 b	6.30±0.08 b
+PSPP+AM+HC	43.14±0.24 a	39.66±0.45 a	38.15±0.57 a	37.40±0.28 b	5.74±0.17 a

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within columns are significantly different (p <0.05).

Table 3.6. Saccharide content in water soluble fraction of breads[1)]

Bread Making Treatments	Glucose (mg/g bread)	Fructose (mg/g bread)	Maltose (mg/g bread)	Reducing Saccharide (mg/g bread)	Total Saccharide (mg/g bread)
Control	5.91±0.09 a	11.35±0.15 a	24.21±0.71 a	35.42±0.70 a	70.12±1.08 a
+PSPP	7.01±0.09 b	11.59±0.24 ab	29.22±1.39 b	45.83±0.56 b	82.54±1.24 b
+PSPP+AM+HC	7.57±0.03 c	11.81±0.12 b	42.21±0.65 c	64.03±0.28 c	115.93±0.67 c

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within columns are significantly different (p <0.05).

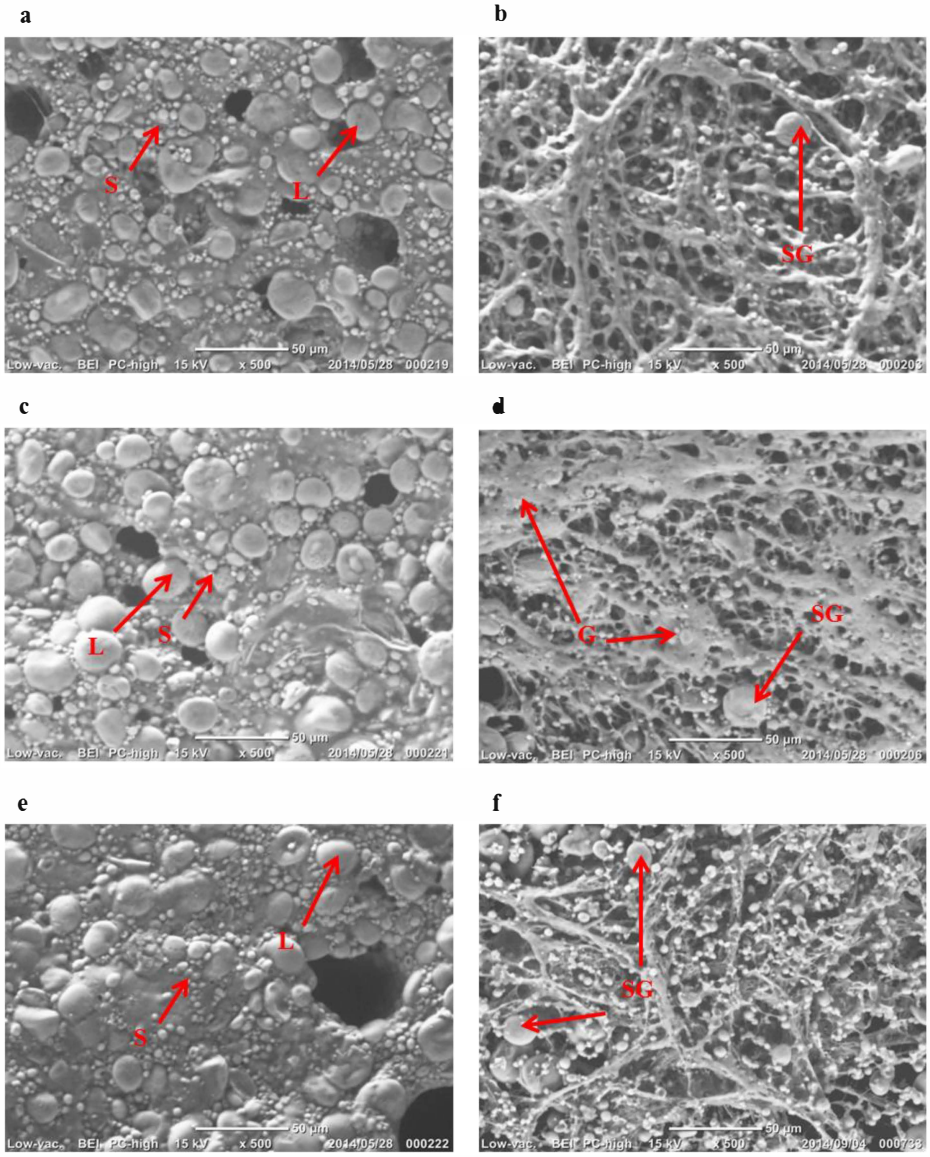

Fig. 3.5. Electron microscope photographs of dough just after mixing
a) Control without elution, b) Control with elution, c) +PSPP without elution, d) +PSPP with elution, e) +PSPP+AM+HC without elution, f) +PSPP+AM+HC with elution
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase; L, large type starch granules; S, small type starch granules; SG, starch and gluten crosslinks; G, gelatinized starch

dough (shown in **Fig. 3.5d**), which was not present in the control and PSPP+AM+HC. The areas of SG (starch and gluten crosslinks) are thought to show starch particles that are tightly cross-linked or adhered to the gluten network since

this dough sample has already undergone elution treatment to sufficiently remove the starch granules.

Similarly, **Fig. 3.6a**, **c** and **e** show the evenly scattered large and small starch granules of the non-eluted control, PSPP and PSPP+AM+HC doughs, respectively, just after proofing. More swollen starch granules were observed in PSPP+AM+HC (**Fig. 3.6e)** than the other bread treatments**.** **Figure 3.6b**, **d**, and **f** show the gluten network of the eluted control, PSPP and PSPP+AM+HC doughs, respectively, just after proofing. It can be observed in **Fig. 3.6d** that the PSPP dough formed a greater number of swollen starch granule-gluten network crosslinks compared with control and PSPP+AM+HC. Moreover, partial interaction of gelatinized starch with the gluten network is observed in PSPP dough in **Fig. 3.6d**, which was not present in control and PSPP+AM+HC. On the other hand, lesser starch-gluten crosslinks, smaller pores and greater porosity were observed in PSPP+AM+HC (**Fig. 3.6f)** compared to the control and PSPP dough.

Figure 3.7a, c and **e** show images of non-eluted bread just after baking, wherein the swollen starch granules can be respectively observed in control and PSPP bread, while for PSPP+AM+HC the starch granules were ruptured and undistinguishable. Moreover, **Fig. 3.7b**, **d**, and **f** show the gluten networks for each bread treatment. It was observed that the control **(Fig. 3.7b)** had a compact, close gluten network, whereas PSPP+AM+HC (**Fig. 3.7f)** had a more open network. On the other hand, a likely weak gluten network with more gelatinized starch-gluten interaction was observed in PSPP, as shown in **Fig. 3.7d**. It seems that this weak gluten network in the PSPP bread was caused by the residual gelatinized starch of

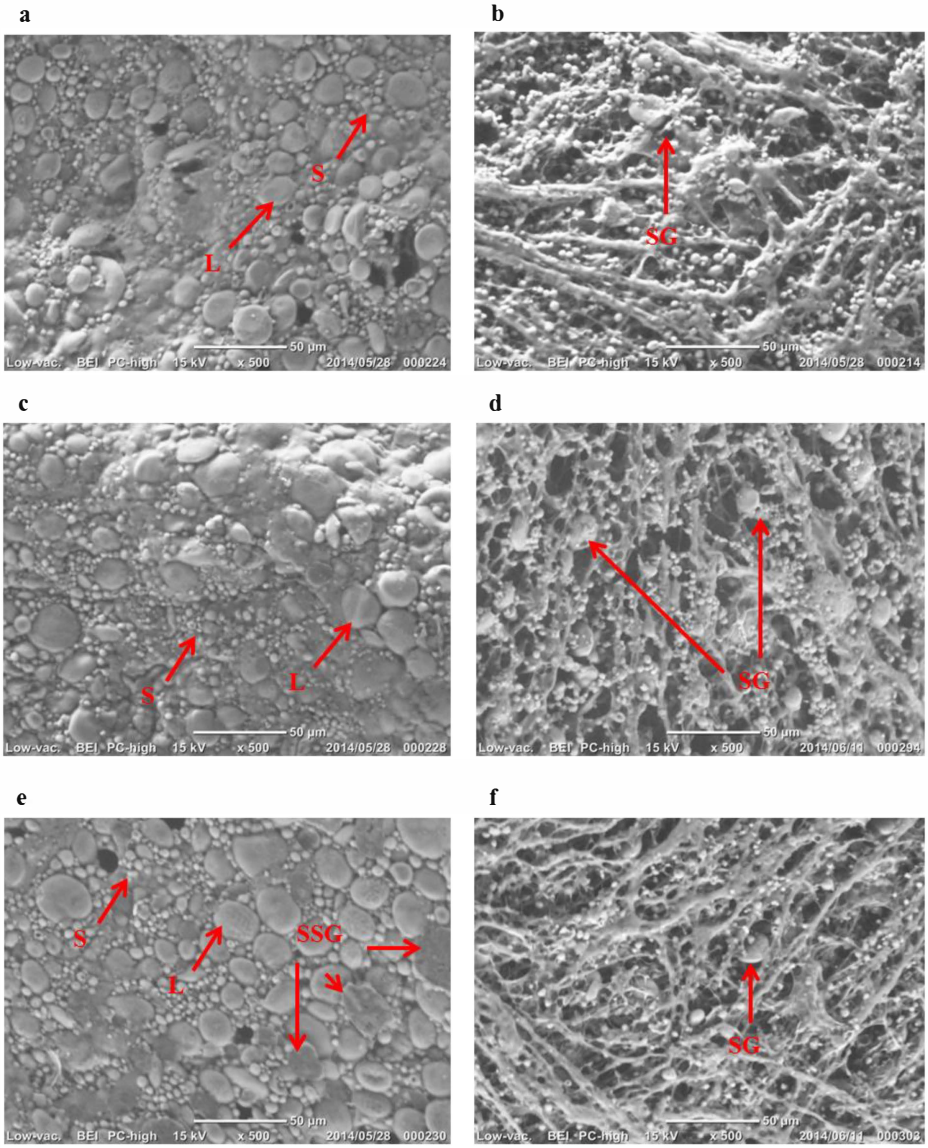

Fig. 3.6. Electron microscope photographs of dough just after proofing
a) Control without elution, b) Control with elution, c) +PSPP without elution, d) +PSPP with elution, e) +PSPP+AM+HC without elution, f) +PSPP+AM+HC with elution
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase; L, large type starch granules; S, small type starch granules; SG, starch and gluten crosslinks; SSG, swollen starch granules; G, gelatinized starch

PSPP not completely decomposed by the intrinsic enzymes of wheat flour, which then cross-linked or adhered to the gluten network during the baking process.

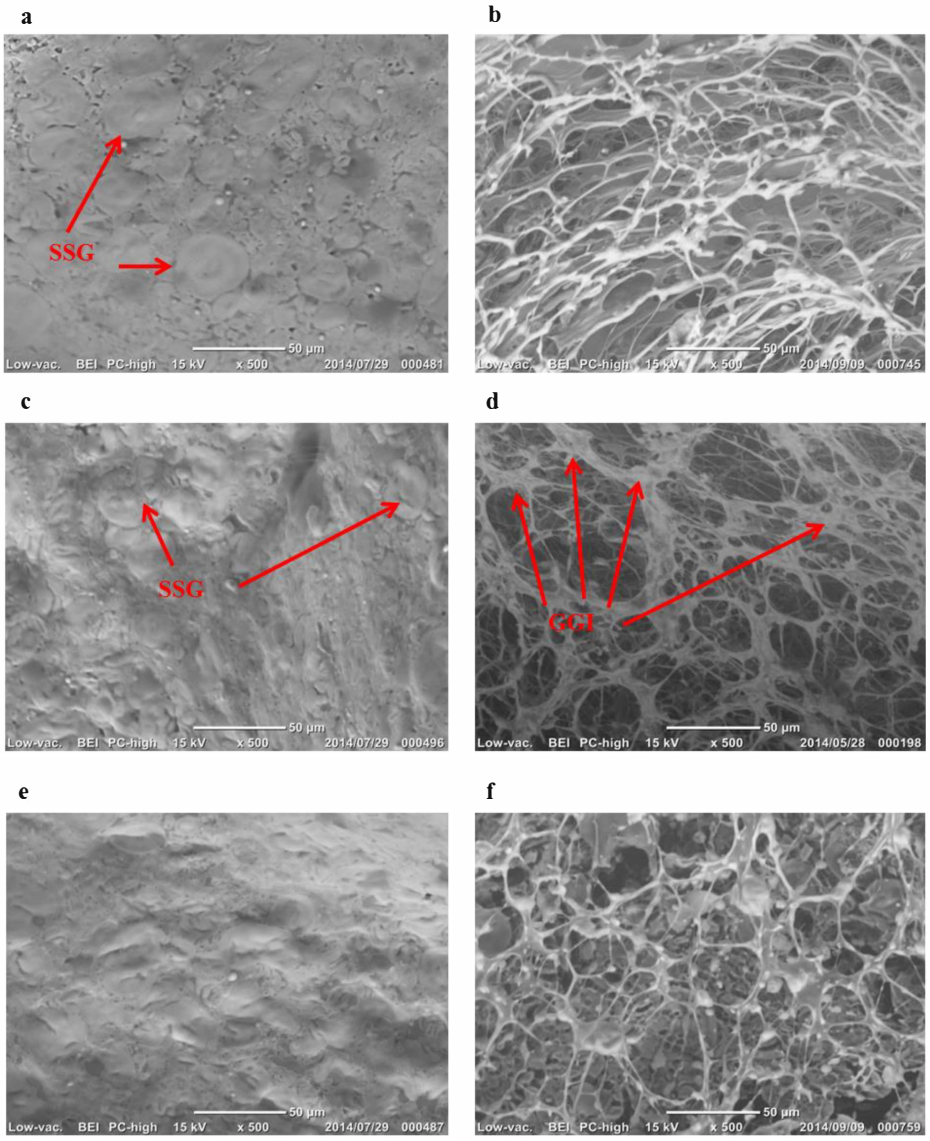

Fig. 3.7. Electron microscope photographs of bread crumb just after baking
a) Control without elution, b) Control with elution, c) +PSPP without elution, d) +PSPP with elution, e) +PSPP+AM+HC without elution, f) +PSPP+AM+HC with elution
Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase; SSG, swollen starch granules; GGI, gelatinized starch and gluten interaction

3.3.6 Sensory properties of breads

Table 3.7 shows the quantitative descriptive evaluation of bread supplemented with PSPP and treated with enzymes in terms of purple color, sweet potato aroma, sweet potato flavor, hardness, elasticity, cohesiveness and overall

Table 3.7. Sensory properties of PSPP substituted bread[1)]

Bread Making Treatments	Color	Sweet potato aroma	Sweet potato flavor	Hardness	Elasticity	Cohesiveness	Overall acceptability
Control	1.00±0.00 a	1.23±0.25 a	1.56±0.28 a	5.18±0.34 b	5.05±0.31 a	5.33±0.41 a	6.69±0.36 a
+PSPP	5.44±0.46 b	4.61±0.27 b	4.96±0.46 b	5.97±0.28 c	5.36±0.24 a	5.73±0.32 a	6.56±0.65 a
+PSPP+AM+HC	5.29±0.18 b	4.50±0.38 b	5.00±0.60 b	3.25±0.14 a	5.12±0.37 a	4.92±0.26 a	8.08±0.23 b

Abbreviations: PSPP, purple sweet potato powder; AM, α-amylase; HC, hemicellulase

[1)]Each value is the mean ± SD. The values followed by different letters within columns are significantly different ($p<0.05$). Quantitative descriptive analysis scale: purple color, 1-no purple to 9-extremely purple; sweet potato aroma, 1-not perceivable to 9-extremely strong; sweet potato flavor, 1-not perceivable to 9-extremely strong; hardness, 1-extremely soft to 9-extremely hard; elasticity, 1-extremely low to 9-extremely high; cohesiveness, 1-extremely low to 9-extremely high; overall acceptability, 1-disliked extremely to 9-liked extremely

acceptability. Results showed that purple color was significantly perceived in PSPP supplemented bread. Sweet potato aroma and flavor were perceived significantly higher in PSPP and PSPP+AM+HC breads than the control. PSPP- supplemented bread was perceived as significantly hardest whereas PSPP+AM+HC was the softest among bread treatments. While the control was judged significantly softer than PSPP bread but harder than PSPP+AM+HC bread. Ultimately, overall acceptability of PSPP+AM+HC bread was significantly higher than the control and PSPP bread.

3.4 Discussion

3.4.1 Bread making quality

The significantly lower GRD of the dough with PSPP compared to control and PSPP+AM+HC can be attributed to the absence of gluten protein, and high fiber and damaged starch content, resulting in a weaker gluten network (Hathorn *et al.* 2008). Decreased GRD was also observed by Murayama *et al*. (2015) after the addition of potato flour to wheat bread. On the other hand, the improvement in GRD, GP, and SLV of PSPP+AM+HC bread can be attributed to the activities of AM and HC, which resulted in the formation of fermentable sugars that were used by yeast for increased gas production (Goesaert *et al*. 2009). The same improvement in SLV was reported by Kim *et al.* (2006) and Schoenlechner *et al.* (2013) after adding AM to polished flour supplemented wheat bread and HC in millet/wheat composite bread, respectively. Moreover, as previously reported, the general improvements in the bread making qualities of the dough with PSPP+AM+HC can be mainly explained by the hydrolytic activity of AM and HC, which resulted in the

decomposition of damaged starch, including the gelatinized starch of PSPP and hemicellulose such as insoluble pentosans into low molecular weight substances (Santiago *et al*. 2015a).

3.4.2 Changes in textural properties during bread storage

The significantly higher hardness, gumminess, chewiness and firming rate (**Tables 3.2** and **3.3**) of PSPP bread can be attributed to the 54% damaged starch content of PSPP (data not shown), which forms cross-links with the protein network during baking and increases in number and strength during storage, causing crumb hardening (Martin *et al.* 1991). The same increase in firming rate was observed by Yamauchi *et al.* (2004a) for bread supplemented with intact and fermented potato pulps of high decomposed starch and fiber contents. On the other hand, the significantly lower firming rate of PSPP+AM+HC bread corroborates with its significantly lower amylose content and enthalpy change for retrogradation (**Table 3.3)** and can be related with the anti-staling property of AM and HC (p<0.05). The same lower firming rate of wheat bread with AM and HC was reported by Caballero *et al.* (2007). The activity of AM results in the degradation of mainly damaged starch of wheat flour and gelatinized starch of PSPP into low molecular weight dextrins, oligo-saccharides, maltose and glucose, decreasing the amount of available starch for retrogradation and retarding the retrogradation of gelatinized starch gel in bread (Duran *et al.* 2001; Palacios *et al.* 2004; Goesaert *et al.* 2009; Gomes-Ruff *et al.* 2012). Moreover, these saccharide products of AM hydrolysis interfere with starch-protein interactions, resulting in few, weak crosslinks, thus reducing the firming rate (**Table 3.3**) (Martin *et al.* 1991; Martin and Hoseney,

1991). The weaker starch-protein interaction may have also resulted in significantly lower cohesiveness of bread with PSPP+AM+HC compared to control and PSPP breads (**Table 3.2**). A similar decrease in the cohesiveness of wheat dough resulting from AM addition was reported by Armero and Collar (1997). Likewise, lower hardness and cohesiveness of wheat bread crumb treated with fungal AM compared to the control was reported by Blaszczak *et al*. (2004).

3.4.3 Rupture properties of breads

The significantly higher RF of PSPP bread crumb after 1 day of storage compared with the control and PSPP+AM+HC ($p<0.05$) can be related to its harder texture (**Table 3.2** and **Fig. 3.3**), resulting from its low porosity and the high interaction between gelatinized starch and the gluten network (Martin *et al*. 1991). The same increase in RF was observed by Yamauchi *et al*. (2004b) after supplementing wheat bread with 50% rice flour. On the other hand, the lower RF of bread crumb with PSPP+AM+HC than the control and PSPP can be related to its softer texture (**Table 3.2** and **Fig. 3.3**), which resulted from its high porosity, lesser interaction of gelatinized starch with gluten and the anti-staling effect of AM and HC (Martin and Hoseney, 1991; Duran *et al.* 2001; Caballero *et al.* 2007). The decrease in RF, RD and RE during storage was caused by starch retrogradation (**Fig. 3.4**), making the crumb brittle. The significantly lower RF of PSPP+AM+HC after 3 days of storage compared to the control and PSPP can be attributed to the collective effect of a softer and brittle bread crumb. Similarly, the significantly lower RE of PSPP+AM+HC compared to the other treatments at all incubation periods can be attributed to its softer texture, and lower firming rate and enthalpy

change for retrogradation (**Figs. 3.3, 3.4** and **Tables 3.3, 3.4**).

3.4.4 Moisture and soluble sugar content of bread

The significantly lower moisture content loss of PSPP+AM+HC compared to control and PSPP may have caused its lower firming rate (**Table 3.3**), which conforms to the report of Rogers *et al.* (1988) showing that moisture loss results in higher firming rate. On the other hand, the significantly higher water soluble glucose, maltose, reducing and total saccharide content of PSPP bread (**Table 3.6)** compared to the control may have been affected by the intrinsic sugar content of sweet potato powder and the hydrolytic enzyme products of wheat flour and yeast (Lu and Gao, 2011). Moreover, the significantly higher water-soluble glucose, fructose, maltose, reducing and total sugar contents (**Table 3.6**) of PSPP+AM+HC may be due to the products of AM and HC hydrolytic activities. These higher water-soluble sugar contents may have prevented the loss of water during storage, resulting in the lower firming rate of PSPP+AM+HC (**Tables 3.3, 3.5** and **Fig. 3.3)**. Similar observations were reported by Martin and Hoseney (1991), i.e., lower firmness of bread with higher maltose content after 5 days of storage. Moreover, Duran *et al.* (2001) reported that sugars and oligosaccharides reduce the retrogradation rate by inhibiting hydrogen bonding among starch chains, which causes a decrease in crumb firmness and staling rate. Furthermore, Yamauchi *et al.* (2014) related the higher moisture and saccharide content of Yudane bread as a reflection of increased water absorption and decomposition of starch, resulting in a softer texture and slower staling.

3.4.5 Dough and bread crumb structure

The large and small starch granules detected in all dough treatments just after mixing and proofing were also observed by Blaszczak *et al*. (2004) in the microstructure of wheat dough. The interaction of gelatinized starch with the gluten network observed in **Figs. 3.5d** and **3.6d** for PSPP dough may have caused the lower SLV and high firming rate of the resulting bread (**Tables 3.1** and **3.3**).

For dough just after proofing, the greater number of swollen starch granules observed in PSPP+AM+HC (**Fig. 3.6e)** can be related to the hydration and swelling pressure caused by AM, as reported by Blaszczak *et al*. (2004). In addition, the lower number of starch-gluten crosslinks, smaller pores and greater porosity of PSPP+AM+HC dough (**Fig. 3.6f)** compared to the control and PSPP may have caused its significantly higher SLV and lower firming rate, as shown in **Tables 3.1** and **3.3**. On the other hand, the greater swollen starch granule-gluten network crosslinks can be related to the larger and reduced number of pores (**Fig. 3.6d**) caused by PSPP supplementation, which may have resulted in the lower SLV and higher firming rate (**Tables 3.1** and **3.3**).

Ultimately, for bread just after baking, the greater starch granule rupture of PSPP+AM+HC may have been caused by the greater susceptibility of amylose to the action of AM, as also reported by Blaszczak *et al*. (2004). Moreover, the more open network of PSPP+AM+HC (**Fig. 3.7f)** compared to the compact, close gluten network of the control **(Fig. 3.7b)** may have resulted in the significantly higher SLV and GRD (**Table 3.1**). The same result was observed by Blaszczak *et al*. (2004) in wheat bread supplemented with fungal and bacterial AM. On the other hand, the

greater gelatinized starch-gluten interaction observed in PSPP bread (**Fig. 3.7d)** may have caused the lower SLV and GRD (**Table 3.1**).

3.4.6 Sensory Properties of Breads

PSPP-supplementation significantly affected the perceived purple color from no purple color in the control to moderately purple in PSPP and PSPP+AM+HC bread which can be attributed to the natural dark purple color of Ayamurasaki sweet potato powder (Kano *et al*. 2005; Montilla *et al.* 2011; Ray *et al.* 201). Moreover, sweet potato aroma and flavor was not perceived in the control but it was moderately perceived in PSPP and PSPP+AM+HC breads. All bread treatments were evaluated to have moderate elasticity and cohesiveness (**Table 3.7**).

In terms of hardness, PSPP bread was evaluated slightly hard while the control was perceived as neither hard nor soft. On the other hand, the enzyme treated PSPP-supplemented bread was perceived to have soft crumb. This may be is the main reason for significantly higher overall acceptability of PSPP+AM+HC than the control and PSPP-supplemented bread. The judges like the control and PSPP bread while the PSPP+AM+HC was liked very much (**Table 3.7**).

3.5 Conclusion

Our results demonstrated that PSPP supplementation results in bread with a higher firming rate, which can be attributed to the high damaged starch content of PSPP causing greater starch-gluten interaction, as shown by its dough structure. However, moisture loss and rupture force of PSPP bread was the same as the control, which can be attributed to the high water holding capacity of sugars in PSPP. In terms of sensory properties, PSPP supplementation resulted in slightly hard bread

perceived to have moderate purple color, sweet potato aroma and flavor.

On the other hand, treatment with AM and HC resulted in bread with lower firming rate, enthalpy change for retrogradation, amylose content, rupture force and energy, and moisture loss during storage. These improvements are related to the anti-staling properties of AM and HC, resulting in lower starch-gluten interaction, as shown by the dough and bread structures. Moreover, the sugar and dextrin products of AM and HC hydrolysis prevents moisture loss and starch retrogradation, resulting in lower firming rate and rupture properties. Ultimately, enzyme treatment resulted in softer bread than the control and PSPP which liked very much by the judges. These enhanced textural properties, enthalpy change for retrogradation and structure indicate a more acceptable bread, potentially leading to the increased utilization of purple sweet potato in the baking industry.

Chapter 4

Noodle Qualities of Fresh Pasta Supplemented with Various Amounts of Purple Sweet Potato Powder

4.1 Introduction

Pasta is generally a simple dough product made of durum wheat semolina and water, which is obtained by extrusion or lamination and successive drying (Alexander, 2000; Carini *et al.* 2009). Fresh pasta, on the other hand, is usually made of common wheat flour and is not subjected to drying, but it is pasteurized and stored at temperatures <4 ^{o}C (Carini *et al.* 2010). Pasta, including fresh pasta, is one of the most consumed food product in the world due to its ease of cooking and nutritional qualities (Brennan *et al.* 2004; Nouviaire *et al.* 2008). In addition, durum wheat semolina pasta, common wheat flour fresh pasta and starch noodles are considered healthy and an ideal food to be enriched with nutrients (Silva *et al*. 2013).

Sweet potato is an abundantly available, inexpensive food crop in developing countries, however, it still remains an underutilized food resource (Hathorn *et al*. 2008). It is of significant socio-economic importance because of its high nutrient, and superior carotenoid and anthocyanin contents, which are responsible for the stable yellow, orange and purple colors of sweet potato varieties (Yang and Gadi, 2008; Antonio *et al*. 2011; Lu and Gao, 2011). Their superior biochemical and nutritional composition makes them a better alternative than

synthetic food colorants, and give them high potential as value-added and functional food products in the human food systems (Suda *et al.* 2003; Bovell-Benjamin, 2007). “Ayamurasaki” is a purple sweet potato variety that has received much attention because of its nutritional value and heat stable anthocyanin content (Oki *et al.* 2002; Bovell-Benjamin, 2007). The stability of anthocyanin in purple-fleshed sweet potato has been confirmed at steaming and baking temperatures (Kim *et al.* 2012). In this regard, “Ayamurasaki” has been used as a natural food colorant in beverages, confectionery, bread and noodles (Oki *et al.* 2002; Suda *et al.* 2003; Yang and Gadi, 2008; Choi *et al.* 2011). However, sufficient studies about the use of “Ayamurasaki” purple sweet potato powder for pasta processing and its effect on noodle quality have not yet been performed.

“Yumehiryu” is the wheat flour milled from “Yumechikara” that has low ash content, bright color and high protein content, and produces extra strong dough making it suitable for fresh pasta processing (Ito *et al.* 2012). In this study, the effect of purple sweet potato powder (PSPP) supplementation on the moisture content, cooking quality, color, texture, rupture and sensory properties of “Yumehiryu” fresh pasta was evaluated.

4.2 Materials and Methods

4.2.1 Fresh pasta treatments and preparation

Fresh pasta was prepared using the following formulation as the control: 200g Yumehiryu wheat flour based on 13.5% moisture (Nisshin Flour Milling Co., Ltd., Tokyo, Japan), 3g salt (The Salt Industry Center of Japan, Tokyo, Japan), 3g olive oil (J-Oil Mills, Inc., Tokyo, Japan) and 65g water. For the supplemented

treatments, 2.5, 5.0, 7.5, 10% of the original wheat flour was replaced with purple sweet potato powder (PSPP) (Kumamoto Flour Milling Co., Ltd., Kumamoto, Japan). All ingredients were mixed using a food processor (MK-K80P-W, Panasonic Corporation, Osaka, Japan) for 1 min at high speed and extruded through dice no.15 using a pasta machine (SIRIOMATIC TR-5, Imperia Corporation, Italy). The extruded fresh pasta were cut into approximately 20cm strips using kitchen scissors and stored for 2 hrs at 20 ℃ in a polyethylene bag. Raw fresh pasta strips were boiled for 3 and 7 min in 3L boiling water, and cooled in a water bath at 20 ℃ for 3min. Excess water on the surface of the fresh pasta was wiped using tissue paper.

4.2.2 Moisture content and cooking quality of fresh pasta

Moisture content of the raw and boiled fresh pastas was determined based on the AOAC official method (AOAC, 2000). After removing the excess water, the boiled fresh pastas (B) were weighed and then dried in an air oven at 135°C for 3hrs to determine the remaining dry matter (R). The cooking weight gain (CWG) and cooking dry matter loss (CDML) were determined as percentage of initial dry matter, dry matter of raw fresh pastas, (I) by using the following equations ① and ②, respectively.

$$\mathrm{CWG}(\%) = \frac{B - R}{I} \times 100 \quad \text{----------} ①$$

$$\mathrm{CDML}(\%) = \frac{I - R}{I} \times 100 \quad \text{----------} ②$$

4.2.3 Texture properties of fresh pasta

Texture profile of raw and boiled fresh pastas were determined using a creep meter (model RE2-33005C, YAMADEN Co., LTD., Tokyo, Japan) fitted with a 2N load cell. 5-cm long fresh pastas were compressed twice up to 70% strain rate of the original thickness using cylindrical plunger of a 3-mm diameter (Type No.4) in a flat sample stage (Type No.1) at a speed of 0.5mm/s. Hardness, elasticity, cohesiveness, gumminess, chewiness and thickness of the fresh pastas were calculated from the resulting stress-strain curves.

4.2.4 Rupture properties of fresh pasta

Rupture properties of raw and boiled fresh pastas were measured using a creep meter (model RE2-33005C) fitted with a 2000 g load cell as presented by Ito *et al.* (2012). Rupture test was determined using a wedge plunger (Type No.49). The 5-cm-long pasta strips were placed in the center of the sample stage (Type No.1) and ruptured crosswise at a speed of 5mm/s up to 0.9 strain. Rupture force (RF), rupture deformation (RD) and rupture energy (RE) were calculated based from the force-deformation curves.

4.2.5 Color measurements and images of raw and boiled noodles

Color of the raw and boiled noodles were determined using a colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan) using the Commission International Del'Eclairage (CIE) L^*(brightness) a^* (red-green) b^*(yellow-blue) color system. The images of three noodles arranged side-by-side with 1cm intervals were recorded with a scanner (model GT-S630, Seiko Epson Corporation, Suwa, Japan).

4.2.6 Sensory Evaluation

Quantitative descriptive analysis of 3 min boiled PSPP-supplemented fresh pasta in terms of purple color (1-no purple to 9-extremely purple), sweet potato flavor (1-not perceivable to 9-extremely strong), sweet potato taste (1-not perceivable to 9-extremely strong), hardness (1-extremely soft to 9-extremely hard), elasticity (1-extremely low to 9-extremely high), cohesiveness (1-extremely low to 9-extremely high) and overall acceptability (1-disliked extremely to 9-liked extremely) were evaluated and compared with the control.

4.2.7 Statistical analysis

Statistical analysis was performed using SPSS for Windows (ver. 17.0). ANOVA and Tukey's multiple range tests were used to compare means at a 5% significance level. Pearson's bivariate test was used to evaluate the correlation of parameters. All data except for MC, CWG, CDML, color properties and sensory evaluation were measured eight times. MC, CWG and CDML were performed in 3 times and color properties were measured 10 times, whereas sensory evaluation was carried out with 18 judges.

4.3 Results

4.3.1 Moisture content and cooking properties of fresh pasta

The moisture content, and cooking properties of raw and boiled fresh pastas supplemented with PSPP are presented in **Fig. 4.1** and **4.2**, respectively. **Fig. 4.1** shows that the moisture content of raw fresh pasta supplemented with 5.0, 7.5 and 10% PSPP were significantly higher than the control ($p<0.05$). Similarly, after boiling for 3 min, all PSPP supplemented fresh pasta had significantly higher

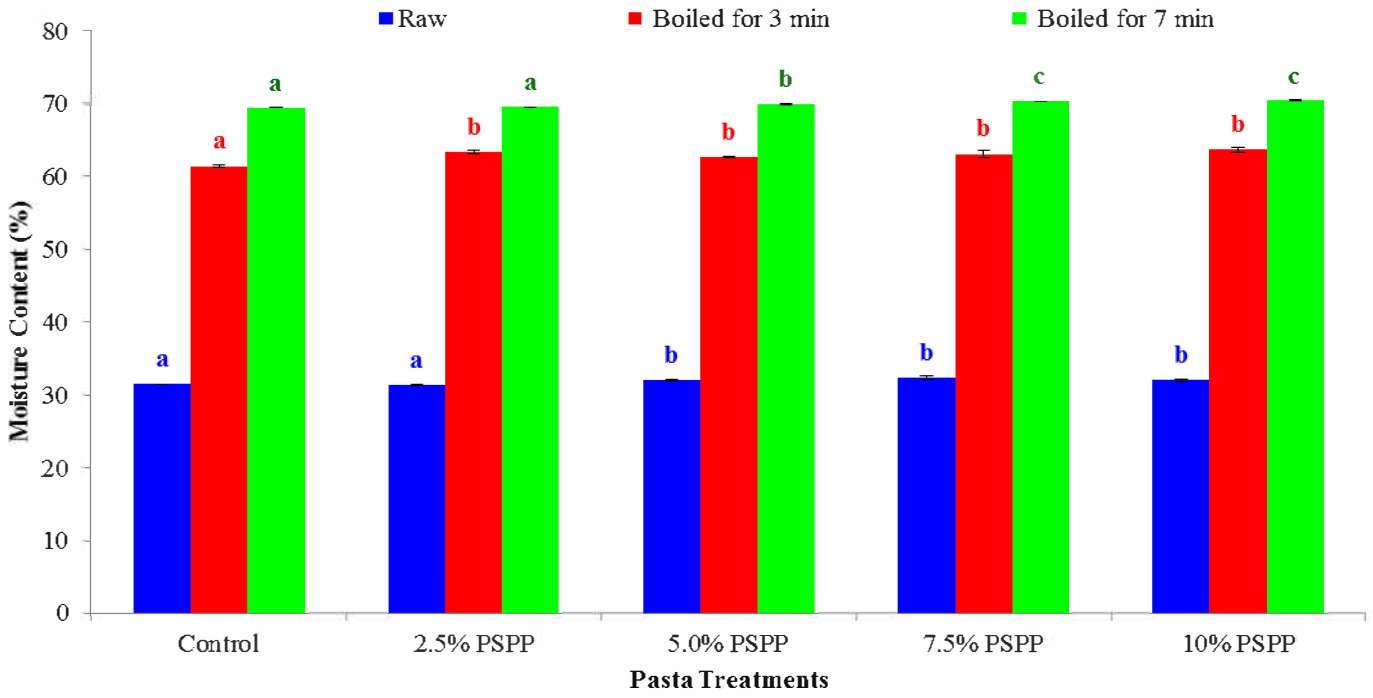

Fig. 4.1. Moisture content of raw and boiled fresh pastas[1]

[1]Vertical bars indicate the standard deviation of each mean value. The data points followed by different letters within series are significantly different (p<0.05).

Abbreviations: PSPP, purple sweet potato powder

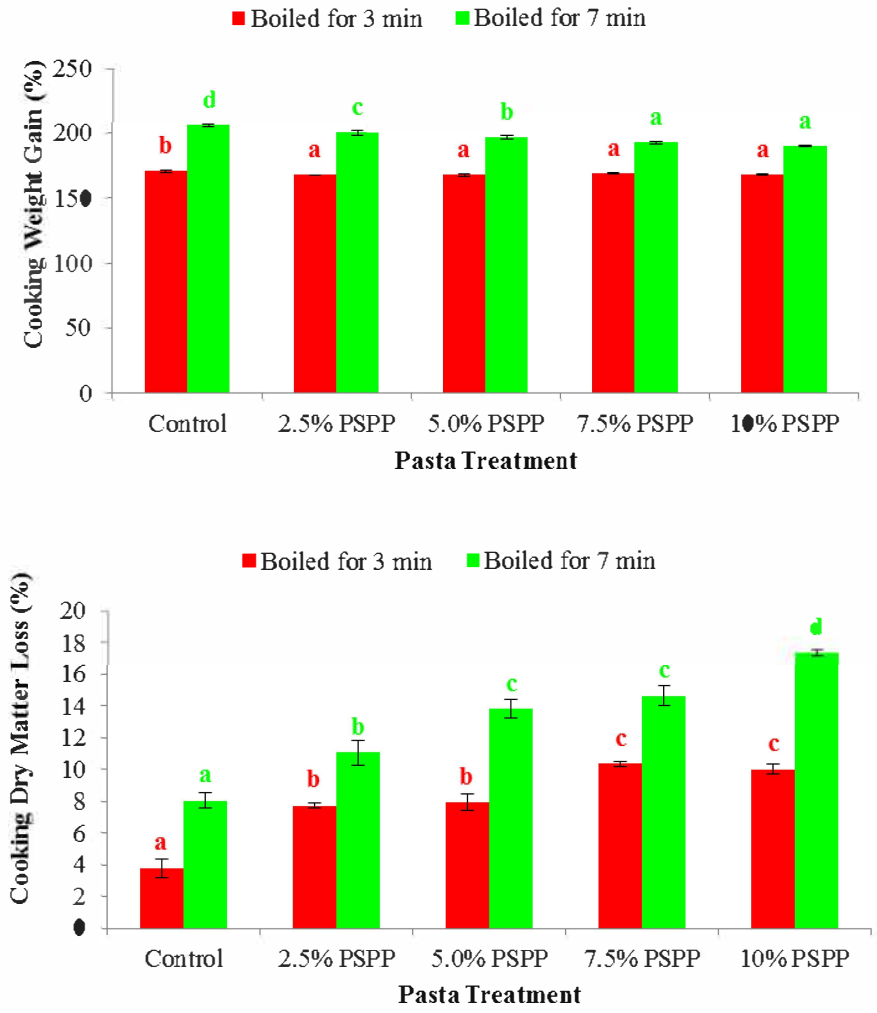

Fig. 4.2. Cooking properties of fresh pastas[1]
[1]Vertical bars indicate the standard deviation of each mean value.
The data points followed by different letters within series are significantly different (p<0.05).
Abbreviations: PSPP, purple sweet potato powder

moisture content than the control (p<0.05). Moreover, after boiling for 7 min, fresh pasta supplemented with 5.0, 7.5 and 10% PSPP also resulted to be significantly higher than the control (p<0.05). In terms of cooking properties, **Fig. 4.2** shows that the cooking weight gain (CWG) of all PSPP supplemented fresh pasta after boiling for 3 and 7 min were significantly lower than the control (p<0.05). On the other hand, the cooking dry matter loss (CDML) of all PSPP supplemented fresh pasta

after boiling for 3 and 7 min were significantly higher than the control (p<0.05).

4.3.2 Texture properties of fresh pasta

Table 4.1 shows the texture properties of fresh pastas supplemented with PSPP. Results showed that the hardness, gumminess and chewiness of all PSPP-supplemented raw and boiled fresh pastas were significantly lower than the control. Similarly, the cohesiveness of all PSPP-supplemented raw fresh pasta was significantly lower than the control (p<0.05). For fresh pastas boiled for 3 and 7 min, the cohesiveness of 10% PSPP was significantly lower than the control and other treatments. Moreover, **Table 4.1** shows that the elasticity of all PSPP-supplemented raw fresh pasta were significantly higher than the control (p<0.05), while the thickness of raw fresh pasta supplemented with more than 5.0% PSPP was significantly higher than the control (p<0.05). Similarly, the thickness of all boiled PSPP-supplemented fresh pasta were significantly higher than the control (p<0.05). For the effect of boiling on texture, results showed that the hardness, gumminess and chewiness of all boiled fresh pastas were significantly lower than the raw fresh pastas (p<0.05). On the other hand, the elasticity and cohesiveness of boiled fresh pastas were significantly higher than the raw fresh pastas (p<0.05). Furthermore, elasticity and cohesiveness of fresh pastas boiled for 7 min were significantly higher than the fresh pastas boiled for 3 min in all treatments (p<0.05). **Table 4.1** also shows that the boiled fresh pastas were significantly thicker than the raw fresh pastas (p<0.05). Ultimately, the fresh pastas boiled for 7 min were significantly thicker than the fresh pastas boiled for 3 min (p<0.05).

Table 4.1. Texture properties of fresh pastas supplemented with PSPP[1)]

Pasta Treatment	Raw	Boiled for 3 min	Boiled for 7 min
Hardness (N)			
Control	6.25±0.15 c, B	0.74±0.01 d, A	0.68±0.008 d, A
2.5% PSPP	4.26±0.11 b, C	0.71±0.01 c, B	0.63±0.01c, A
5.0% PSPP	3.52±0.09 a, C	0.71±0.007 c, B	0.61±0.01 c, A
7.5% PSPP	3.51±0.12 a, B	0.65±0.01 b, A	0.60±0.004 b, A
10% PSPP	3.44±0.05 a, C	0.62±0.01 a, B	0.58±0.01 a, A
Cohesiveness (-)			
Control	0.53±0.03 c, A	0.67±0.007 b, B	0.72±0.01 b, C
2.5% PSPP	0.44±0.04 b, A	0.67±0.01 b, B	0.71±0.01 b, C
5.0% PSPP	0.44±0.009 b, A	0.67±0.008 b, B	0.72±0.007 b, C
7.5% PSPP	0.41±0.005 ab, A	0.66±0.01 ab, B	0.70±0.01 ab, C
10% PSPP	0.39±0.008 a, A	0.65±0.01 a, B	0.69±0.02 a, C
Elasticity (-)			
Control	0.58±0.007 a, A	0.96±0.003 a, B	1.00±0.004 a, C
2.5% PSPP	0.68±0.008 b, A	0.95±0.006 a, B	0.99±0.005 a, C
5.0% PSPP	0.77±0.006 c, A	0.97±0.005 a, B	1.00±0.03 a, C
7.5% PSPP	0.76±0.03 c, A	0.96±0.03 a, B	1.02±0.03 a, C
10% PSPP	0.77±0.007 c, A	0.97±0.02 a, B	1.00±0.01 a, C
Gumminess (N)			
Control	3.30±0.11 d, B	0.50±0.01d, A	0.49±0.006 d, A
2.5% PSPP	1.85±0.17 c, B	0.47±0.005 c, A	0.45±0.02 c, A
5.0% PSPP	1.54±0.02 b, C	0.47±0.009 c, B	0.44±0.01 c, A
7.5% PSPP	1.43±0.06 ab, B	0.43±0.008 b, A	0.42±0.008 b, A
10% PSPP	1.36±0.04 a, B	0.40±0.02 a, A	0.40±0.01 a, A
Chewiness (-)			
Control	1.92±0.07 c, B	0.48±0.01 d, A	0.49±0.005 d, A
2.5% PSPP	1.26±0.11 b, B	0.45±0.006 c, A	0.44±0.01 c, A
5.0% PSPP	1.19±0.02 b, C	0.450.007 c, B	0.44±0.004 c, A
7.5% PSPP	1.09±0.03 a, B	0.41±0.009b, A	0.42±0.006 b, A
10% PSPP	1.04±0.03 a, B	0.39±0.01 a, A	0.40±0.008 a, A
Thickness (mm)			
Control	1.10±0.02 a, A	1.32±0.009 a, B	1.42±0.01 a, C
2.5% PSPP	1.12±0.009 ab, A	1.39±0.004 b, B	1.46±0.008 b, C
5.0% PSPP	1.13±0.09 b, A	1.39±0.02 b, B	1.47±0.01 b, C
7.5% PSPP	1.19±0.008 c, A	1.43±0.01 c, B	1.49±0.006 c, C
10% PSPP	1.19±0.007 c, A	1.45±0.009 c, B	1.53±0.007 d, C

1)Each value is the mean ± SD. The values followed by different small and capital letters within column and row, respectively, are significantly different ($p<0.05$).

Abbreviations: PSPP, purple sweet potato powder

4.3.3 Rupture properties of fresh pasta

Table 4.2 shows that the rupture force (RF) and rupture energy (RE) of all

PSPP-supplemented raw and boiled fresh pasta were significantly lower than the control (p<0.05). On the other hand, the rupture deformation (RD) of raw fresh pasta supplemented with 10% PSPP was significantly higher than the control and raw fresh pasta supplemented with 2.5% PSPP (p<0.05). Similarly, the RD of all PSPP-supplemented boiled fresh pastas were significantly higher than the control (p<0.05).

For the effect of boiling on rupture properties, results showed that the RF of boiled fresh pastas were significantly lower than the raw fresh pastas (p<0.05). The RE of boiled fresh pastas were significantly lower than the raw fresh pasta (p<0.05). Furthermore, the RE of fresh pastas boiled for 7 min were also significantly lower than fresh pastas boiled for 3 min in all treatments (p<0.05). On the other hand, the RD of boiled fresh pastas was significantly higher than the raw fresh pasta (p<0.05),while the RD of fresh pasta boiled for 7 minutes was significantly higher than the fresh pasta boiled for 3 min in all treatments (p<0.05).

4.3.4 Color properties of fresh pastas

Table 4.3 shows the color properties of raw and boiled fresh pastas. Results showed that the L* value of raw and boiled fresh pastas were significantly different from each other and decrease with the higher concentration of PSPP (p<0.05). For the effect of boiling on the color of pasta, results showed that the L* value of all boiled fresh pasta and those supplemented with PSPP were significantly higher than the raw fresh pasta (p<0.05). Moreover, the L*value of fresh pasta boiled for 7 min were significantly higher than the fresh pasta boiled for 3 min in all treatments (p<0.05).

Table 4.2. Rupture properties of PSPP-supplemented fresh pastas [1)]

Pasta Treatment	Raw	Boiled for 3 min	Boiled for 7 min
RF (N)			
Control	15.76±0.13 c, B	2.42±0.02 d, A	2.40±0.03 c, A
2.5% PSPP	13.44±0.18 b, C	2.32±0.04 c, B	2.14±0.06 b, A
5.0% PSPP	13.31±0.05 b, C	2.20±0.07 b, B	2.06±0.05 a, A
7.5% PSPP	13.01±0.02 a, C	2.19±0.04 b, B	2.05±0.06 a, A
10% PSPP	12.90±0.14 a, B	2.11±0.02 a, A	2.03±0.03 a, A
RE (J)			
Control	$2.25x10^{-3}$±$4.1x10^{-5}$ d, C	$1.11x10^{-3}$±$1.37x10^{-5}$ b, B	$1.03x10^{-3}$±$6.13x10^{-6}$ d, A
2.5% PSPP	$3.61x10^{-3}$±$4.53x10^{-5}$ c, C	$1.04x10^{-3}$±$3.08x10^{-5}$ a, B	$9.81x10^{-4}$±$1.43x10^{-5}$ c, A
5.0% PSPP	$3.56x10^{-3}$±$4.92x10^{-5}$ bc, C	$1.04x10^{-3}$±$5.05x10^{-6}$ a, B	$9.46x10^{-4}$±$3.60x10^{-6}$ b, A
7.5% PSPP	$3.51x10^{-3}$±$1.91x10^{-5}$ ab, C	$1.04x10^{-3}$±$7.69x10^{-6}$ a, B	$9.38x10^{-4}$±$1.28x10^{-5}$ ab, A
10% PSPP	$3.50x10^{-3}$±$3.77x10^{-5}$ a, C	$1.03x10^{-3}$±$2.22x10^{-5}$ a, B	$9.20x10^{-4}$±$1.84x10^{-5}$ a, A
RD (mm)			
Control	1.00±0.01 a, A	1.13±0.00 a, B	1.26±0.01 a, C
2.5% PSPP	1.00±0.00 a, A	1.21±0.02 b, B	1.29±0.00 b, C
5.0% PSPP	1.02±0.02 ab, A	1.23±0.00 c, B	1.29±0.02 b, C
7.5% PSPP	1.02±0.02 ab, A	1.23±0.01 c, B	1.29±0.02 b, C
10% PSPP	1.02±0.00 b, A	1.23±0.01 c, B	1.30±0.02 b, C

1)Each value is the mean ± SD. The values followed by different small and capital letters within column and row, respectively, are significantly different ($p<0.05$).

Abbreviations: PSPP, purple sweet potato powder; RF, rupture force; RE. rupture energy; RD, rupture deformation

In terms of a* value, **Table 4.3** shows that the control was the lowest among all treatments ($p<0.05$). The a* value of raw fresh pastas increase with the increase in amount of supplemented PSPP and were significantly different with each other except for 7.5 and 10% PSPP ($p<0.05$). Similarly, the a* value of fresh pastas boiled for 3 and 7 min were significantly different from each other, and increase with the increase in concentration of PSPP supplemented ($p<0.05$). For the effect of boiling, results showed that the a* value of the control, 2.5 and 5.0% PSPP fresh pasta boiled for 3 min were significantly lower than the raw fresh pasta ($p<0.05$). While the a* value of 10% PSPP boiled for 3 min was significantly higher than the raw fresh pasta. Moreover, the a* value of all PSPP-supplemented fresh pasta boiled for 7 min were significantly lower than the pasta boiled for 3 min.

Table 4.3. Color properties of fresh pastas supplemented with PSPP [1)]

Pasta Treatment	Raw	Boiled for 3 min	Boiled for 7 min
L* value			
Control	78.18±0.96 e, A	78.03±0.34 e, A	79.24±0.36 e, B
2.5% PSPP	56.25±0.41 d, A	60.25±0.49 d, B	63.94±0.59 d, C
5.0% PSPP	46.56±0.57 c, A	51.11±0.48 c, B	55.43±0.33 c, C
7.5% PSPP	41.32±0.50 b, A	45.53±0.74 b, B	49.79±0.70 b, C
10% PSPP	38.61±0.58 a, A	41.06±0.62 a, B	46.53±0.76 a, C
a* value			
Control	-2.30±0.22 a, B	-3.59±0.04 a, A	-3.61±0.03 a, A
2.5% PSPP	15.04±0.33 b, C	9.62±0.33 b, B	5.89±0.22 b, A
5.0% PSPP	19.48±0.60 c, C	16.36±0.18 c, B	11.10±0.33 c, A
7.5% PSPP	21.52±0.53 d, B	21.14±0.43 d, B	16.40±0.62 d, A
10% PSPP	21.77±0.36 d, B	22.37±0.59 e, C	18.08±0.45 e, A
b* value			
Control	22.41±0.89 e, C	13.77±0.23 e, B	11.75±0.27 e, A
2.5% PSPP	1.16±0.08 d, B	0.67±0.20 d, A	1.10±0.12 d, B
5.0% PSPP	-4.88±0.10 c, B	-5.36±0.12 c, A	-4.92±0.10 c, B
7.5% PSPP	-7.12±0.10 b, C	-8.69±0.16 b, A	-8.43±0.09 b, B
10% PSPP	-8.19±0.13 a, C	-10.71±0.09 a, A	-10.41±0.16 a, B

1)Each value is the mean ± SD. The values followed by different small and capital letters within column and row, respectively, are significantly different ($p<0.05$).

Abbreviations: PSPP, purple sweet potato powder; L* , degree of lightness or darkness; a*, degree of redness or greeness; b*, degree of yellowness or blueness

Furthermore, **Table 4.3** shows that the b* value of raw fresh pasta were significantly different from each other and decrease with the higher concentration of supplemented PSPP ($p<0.05$). Similar trend can be observed among fresh pasta treatment boiled for 3 and 7 min ($p<0.05$). For the effect of boiling, results showed that the b* value of all treatments boiled for 3 min were significantly lower than the raw fresh pastas ($p<0.05$). While the b* value of control fresh pasta boiled for 7 min was significantly lower than the control pasta boiled for 3 min ($p<0.05$). Moreover, the b*value of all fresh pasta supplemented with PSPP and boiled for 7 min were significantly higher than the fresh pasta boiled for 3 min ($p<0.05$).

Ultimately, the same color change can be observed in the photograph of raw and boiled fresh pasta. Wherein the increase in the concentration of PSPP resulted in darker and purpler fresh pasta as shown in **Fig. 4.3**. In addition, a lighter color of fresh pasta can be observed after boiling for 3 and 7 min.

4.3.5 Sensory properties of boiled fresh pasta

Table 4.4 shows the quantitative descriptive evaluation of 3 min boiled fresh pasta in terms of purple color, sweet potato flavor, sweet potato taste, hardness, elasticity, cohesiveness and overall acceptability. Results showed that the purple color of boiled fresh pasta significantly increased with higher amount of PSPP (p<0.05). **Table 4.4** also shows that the 2.5 and 5.0% PSPP-supplemented fresh pastas were perceived to have significantly higher sweet potato aroma than the control but significantly lower than the 7.5 and 10% PSPP-supplemented fresh pasta (p<0.05). On the other hand, the sweet potato flavor of fresh pastas significantly increased with higher amount of PSPP (p<0.05). Hardness of all PSPP-supplemented fresh pasta were evaluated to be significantly softer than the control (p<0.05). Elasticity and cohesiveness of all fresh pasta treatments were not significantly different from each other (p<0.05). Furthermore, **Table 4.4** shows that the overall acceptability of 2.5 and 5.0% PSPP-supplemented fresh pasta were significantly different from each other and both significantly less acceptable than the control and 10% PSPP-supplemented fresh pasta (p<0.05). Ultimately, 7.5% PSPP was found to have the highest overall acceptability among the fresh pasta treatments (p<0.05).

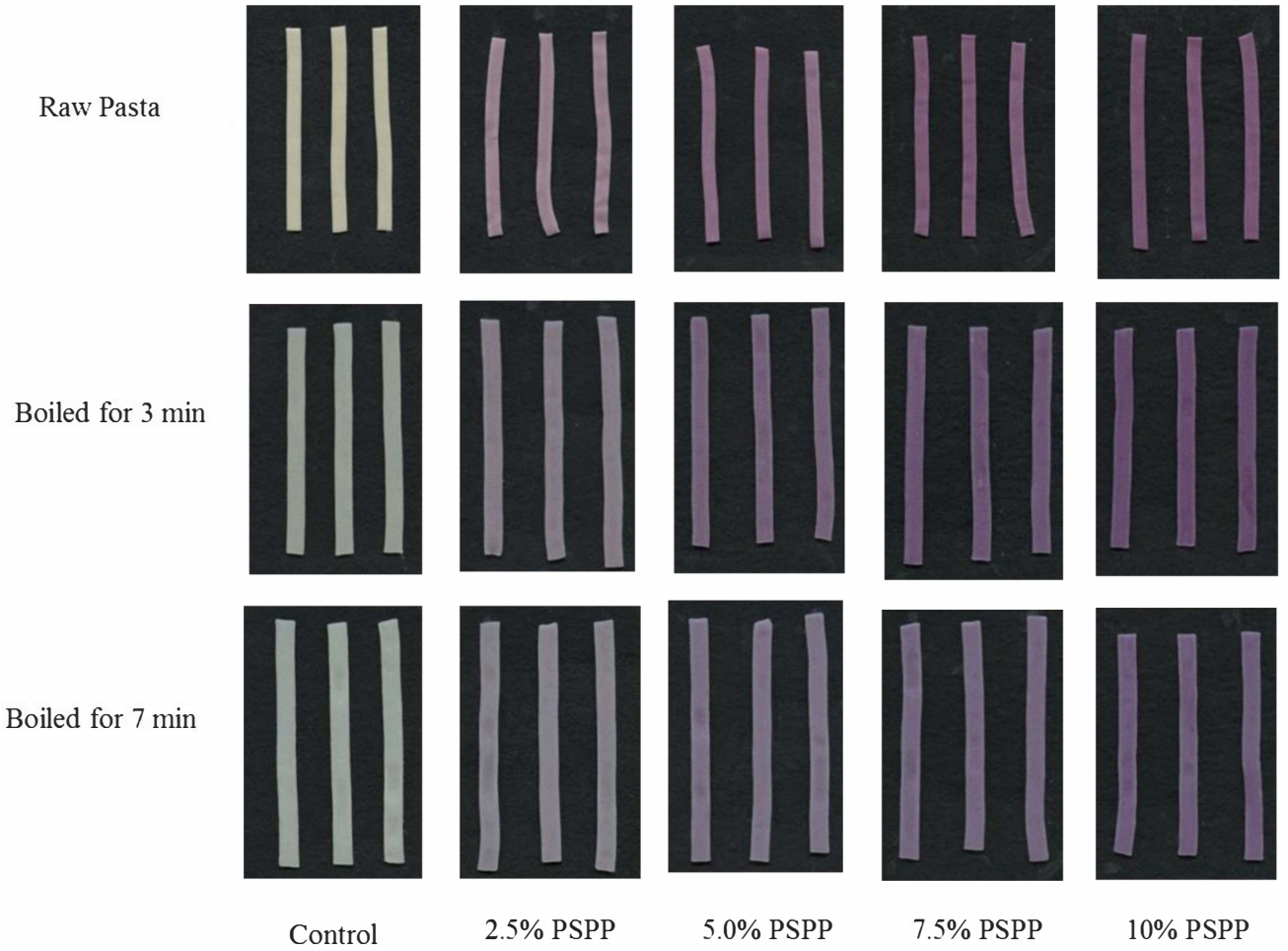

Fig. 4.3. Images of raw and boiled fresh pasta
Abbreviations: PSPP, purple sweet potato powder

Table 4.4. Sensory properties of boiled fresh pasta supplemented with PSPP[1)]

Pasta Treatments	Purple Color	Sweet Potato Aroma	Sweet Potato Flavor	Hardness	Elasticity	Cohesiveness	Overall acceptablity
Control	1.00±0.00 a	1.00±0.00 a	1.00±0.00 a	5.65±0.53 c	4.97±0.71 a	5.18±0.25 a	5.39±0.38 c
2.5% PSPP	2.93±0.50 b	2.27±0.56 b	2.28±0.49 b	4.07±0.40 b	4.86±0.39 a	5.17±0.40 a	4.22±0.35 a
5.0% PSPP	4.91±0.35 c	2.29±0.45 b	3.42±0.75 c	3.94±0.47 b	4.83±0.35 a	4.98±0.37 a	4.81±0.45 b
7.5% PSPP	7.67±0.44 d	3.42±0.72 c	3.89±0.46 d	3.69±0.39 b	4.92±0.59 a	5.11±0.65 a	6.00±0.45 d
10% PSPP	8.48±0.49 e	3.81±0.81 c	4.44±0.40 e	3.08±0.56 a	4.86±0.54 a	4.98±0.32 a	5.14±0.32 bc

[1)]Each value is the mean ± SD. The values followed by different letters within columns are significantly different ($p<0.05$).
Abbreviations: PSPP, purple sweet potato powder
Quantitative descriptive analysis scale: purple color, 1-no purple to 9-extremely purple; sweet potato aroma, 1-not perceivable to 9-extremely strong; sweet potato flavor, 1-not perceivable to 9-extremely strong; hardness, 1-extremely soft to 9-extremely hard; elasticity, 1-extremely low to 9-extremely high; cohesiveness, 1-extremely low to 9-extremely high; overall acceptability, 1-disliked extremely to 9-liked extremely

4.4 Discussion

4.4.1 Moisture content and cooking properties of fresh pasta

The higher moisture content of raw 5.0, 7.5 and 10% PSPP-supplemented fresh pasta as compared with the raw control can be attributed to the inherent sugar content and damaged starch content of PSPP which may have contributed to its higher water holding capacity (Park and Baik, 2002; Santiago *et al.* 2015b). Similarly, the significantly higher moisture content of all PSPP supplemented fresh pasta boiled for 3 min, and of 5.0, 7.5 and 10% PSPP supplemented fresh pastas boiled for 7 min than their corresponding boiled control fresh pasta can be attributed to the higher water absorbing capacity related with the inherent sugar content and damaged starch content of PSPP (Park and Baik, 2002).

On the other hand, the lower CWG of PSPP supplemented fresh pastas compared with the control and the decreasing trend of CWG with the increase in concentration of PSPP can be attributed with the loss of dry matter during cooking or boiling. This observation is supported by the high or significant inverse correlation of the CWG of PSPP-supplemented fresh pasta with their CDML with correlation coefficients of -0.667 and -0.985 ($p<0.01$) for fresh pasta boiled for 3 and 7 min, respectively ($p<0.01$). These observations indicate the solubility of the high sugar, damaged starch and anthocyanin content of PSPP-supplemented fresh pasta to water during boiling (Hatcher *et al.* 2002). The same decrease in CWG and increase in cooking weight loss was observed by Li *et al.* (2012) with higher amount of yam flour proportion added to salted noodles. Moreover, the increase in cooking weight loss or CDML relates to the decrease in gluten protein content as reported

by Hou *et al.* (2013).

4.4.2 Texture properties of fresh pasta

The significantly lower hardness, cohesiveness, gumminess and chewiness of raw PSPP-supplemented fresh pasta compared with the control may be attributed to the high gelatinized and damaged starch content of PSPP resulting in weaker starch-protein interaction (Oh *et al.* 1985). The softer texture of raw PSPP-supplemented fresh pasta can be also related with its higher moisture content as evidenced by the rather high inverse correlation of the hardness, cohesiveness, gumminess and chewiness of raw fresh pastas with their moisture content; the Pearson's correlation coefficient were -0.695, -0.624, -0.656 and -0.632, respectively. Correspondingly, the significantly higher MC of PSPP supplemented raw fresh pasta may have contributed to its softer texture (Kojima *et al.* 2004).

Similar high or significant inverse correlation of hardness, cohesiveness, gumminess and chewiness of fresh pasta boiled for 3 and 7 min with their moisture content was observed having correlation coefficient ranges of -0.807 to -0.589 and -0.924 (p<0.05) to -0.835, respectively. Ultimately, this softer texture can be related with the high water absorbing capacity of the supplemented PSPP resulting in higher moisture content. On the other hand, the significantly higher elasticity of raw PSPP-supplemented fresh pasta than the raw control can be attributed to the gelatinized starch of the supplemented PSPP which acts as binder between starch particles compensating the lack of gluten and reinforcing its elasticity (Wieser, 2007; Chillo *et al.* 2009). The significantly higher thickness of raw fresh pasta supplemented with more than 5.0% PSPP than the control can be related with the

high gelatinized starch content of PSPP. Moreover, the significantly higher thickness of boiled PSPP-supplemented fresh pastas indicates greater swelling and water absorption related to the high sugar and damage starch content of PSPP (Oh *et al.* 1983; Hatcher *et al.* 2002; Park and Baik, 2002). Boiling resulted in softer texture of fresh pasta which can be related to the absorption of water and gelatinization of starch (Ishida *et al.* 2003). Moreover, boiling resulted in significantly higher elasticity and cohesiveness attributed to the gelatinization of the starch component of the fresh pasta providing a sticky and paste-like structure. Eventually, boiling the fresh pasta for longer time of 7 min resulted in higher degree of gelatinization of starch which explains its significantly higher elasticity and cohesiveness than the fresh pasta boiled for 3 min.

4.4.3 Rupture properties of fresh pasta

The significantly lower RF and RE of all raw PSPP-supplemented fresh pasta and higher RD of 10% PSPP compared with the control indicates that PSPP-supplementation results in softer texture. This was evidenced by the high or significant correlation of the RF (r=0.983, $p<0.01$) and RE (r=0.985, $p<0.01$), and inverse correlation of the RD (r=-0.808) of raw fresh pasta with hardness of texture properties. Correspondingly, the significantly higher MC of PSPP supplemented raw fresh pasta may have contributed to its lower RF and RE and higher RD (**Fig. 4.1**). This is verified by the considerably high or significant inverse correlation of RF and RE, and direct correlation of RD with the MC of raw fresh pasta having correlation coefficients of -0.599, -0.589 and 0.941 ($p<0.05$), respectively.

Similarly, the significant lower RF and RE, and higher RD of all boiled

PSPP-supplemented fresh pasta confirm its softer texture than the control. This relates with the rather high or significant correlation of RF (r=0.876 (p<0.05) - 0.967 (p<0.01)) and RE (r=0.688 to 0.989 (p<0.01)) and inverse correlation of RD (r=-0.688 to -0.9525 (p<0.05)) with the hardness of boiled fresh pastas on texture properties. Moreover, the RF (r= -0.680 - -0.779) and RE (r= -0.500 - -0.777) showed the rather high inverse correlation, whereas RD (r=0.496-0.645) directly and considerably correlates with the MC of boiled fresh pasta. Hence, these show that the rupture properties of fresh pasta are influenced by their moisture content related with the high water absorbing capacity of PSPP (**Fig. 4.1**).

The significantly lower RF and RE and higher RD of boiled fresh pasta indicates softer texture which can be attributed to the gelatinization of starch and absorption of water during boiling (Ishida *et al.* 2003). Furthermore, the significantly lower RE and higher RD of fresh pasta boiled for 7 min than the fresh pasta boiled for 3 min can be related with the higher degree of gelatinization and water absorption.

4.4.4 Color properties of fresh pastas

PSPP-supplementation resulted in darker, bluer and redder color of raw and boiled fresh pasta as indicated by the significant decrease in L* and b* value, and increase in a* value (**Table 4.3**), respectively. As also shown in **Fig. 4.3**, the darker, bluer and redder purple color of PSPP-supplemented fresh pastas can be attributed to the dark purple anthocyanin pigments of PSPP (Kano *et al*. 2005; Montilla *et al.* 2011).

On the other hand, boiling resulted in lighter color of fresh pasta as

indicated by the significantly higher L* value compared with the raw fresh pasta. Boiling of the control fresh pasta also resulted in greener color as indicated by their significantly lower a* value compared with the raw control fresh pasta. Boiling for 3 min significantly decreased the degree of redness of 2.5 and 5.0% PSPP fresh pasta as evidenced by their lower a* value than the raw pasta, while for 10% PSPP-supplemented fresh pasta, the degree of redness was intensified after boiling for 3 min. The significant decrease in b* value of the control and 2.5% PSPP boiled for 3 min means lower degree of yellowness than the raw fresh pasta. Conversely, the decrease in b* value of 5.0, 7.5 and 10% PSPP after boiling for 3 min indicates higher degree of blueness compared with the raw fresh pasta. Ultimately, the significantly higher L* and b* value, and lower a* value of all PSPP-supplemented fresh pasta boiled for 7 min than the pasta boiled for 3 min signify lower degree of darkness, blueness and redness, respectively. This lighter and less purple color of fresh pasta boiled for 7 min indicate leaching of water soluble anthocyanin due to longer boiling time.

4.4.5 Sensory properties of boiled fresh pasta

PSPP-supplementation significantly affect the perceived purple color of 3 min boiled fresh pastas. The fresh pastas were perceived to have no purple color for the control to extremely strong purple color for the 10% PSPP-supplemented fresh pasta. While the 2.5, 5.0 and 7.5% PSPP fresh pastas were evaluated to have slight, moderate and very strong purple color, respectively (**Table 4.4**).

The sweet potato flavor was not perceived in the control, whereas, it was barely perceivable in the 2.5 and 5.0% PSPP fresh pasta. Moreover, the 7.5 and

10% PSPP fresh pastas were evaluated to have slightly perceivable sweet potato flavor. On the other hand, the judges evaluated that the sweet potato taste of the fresh pastas ranged from not perceivable for the control to moderately perceivable for the 10% PSPP. The 2.5, 5.0 and 7.5 PSPP fresh pastas were rated to have barely, slightly and slight-moderately perceivable sweet potato taste, respectively (**Table 4.4**).

The hardness of the control fresh pasta was rated to be slightly hard, whereas, the 2.5, 5.0 and 7.5 % PSPP were evaluated as slightly soft. The 10% PSPP was judged as soft fresh pasta (**Table 4.4**). All fresh pastas were perceived to have moderate elasticity and cohesiveness (**Table 4.4**). The judge's perception of the hardness to show much difference among all samples considerably correlates with the hardness on texture properties measured using the creep meter, with correlation coefficients of 0.857.

The judges slightly disliked the 2.5% PSPP, whereas the control, 5.0%, and 10.0% PSPP were neither liked nor disliked. Ultimately, the 7.5% PSPP was liked slightly and perceived as the most acceptable among the all fresh pasta treatments (**Table 4.4**). These results generally agree with the not-significantly different overall acceptability of cooked salted noodles supplemented with purple yam flour with the control as reported by Li *et al.* (2012).

4.5 Conclusion

PSPP-supplementation improved the water holding and absorbing capacities of fresh pasta resulting in softer texture as evidenced by the inverse correlation of their moisture content with hardness, rupture force and rupture energy.

Moreover, PSPP provides higher amount of gelatinized starch resulting in softer and more elastic raw fresh pasta. Ultimately, PSPP provides dark purple color attributable to the intrinsic anthocyanin content.

On the other hand, sensory evaluation show that PSPP-supplementation results in fresh pasta with slight to extremely strong purple color, barely to slightly perceivable sweet potato flavor, barely to moderately perceivable sweet potato taste, slightly soft to soft firmness, and moderate elasticity and cohesiveness. Furthermore, the overall acceptability of the 5% and 10% PSPP were neither liked nor disliked along with the control, whereas the 7.5% PSPP has a slightly higher acceptability. These results indicate that PSPP-supplementation gives rise to acceptable fresh pasta that may potentially lead to the increased utilization of PSPP in noodle processing.

Chapter 5

Summary, Conclusion and Recommendations

In the past two decades the development of functional food became very popular. Today, the demand of consumers for food is not only on the basis of hunger satisfaction but also considers its functionality in preventing nutrition-related diseases, and improving human well-being. Colored non-cereal energy crops such as purple potato, yam and sweet potato are utilized for the production of functional food products due to their stable color and inherent high concentration of bioactive compounds like anthocyanin, carotenoids, phenolic acids and essential amino acids. As functional food, these non-cereal crops have given rise to the creation of specialty breads and pastries that has added nutrients, flavor and color, and colored-noodles that has added phytochemicals known for beneficial effects on human health.

This study utilized the purple sweet potato powder (PSPP) in the processing of bread and fresh pasta, and its effects on bread and noodle making qualities were determined.

This study showed that PSPP-substitution results in bread with darker crust and light purple crumb that were attributed to the reducing sugar and natural purple color of the anthocyanin pigments contributed by the PSPP. However, PSPP-substitution also resulted in low gas retention of dough (GRD) and specific loaf

volume (SLV) which is related to the lack of gluten protein as well as with the high damaged starch and fiber contents of PSPP. Moreover, PSPP supplementation produced bread with a higher firming rate caused by greater gelatinized starch-gluten interaction, as shown by the structure of dough, and attributed to the high damaged starch content of PSPP. Moisture loss and rupture force of PSPP bread were the same as the control, which can be related with the high water holding capacity of sugars in PSPP. In this regard, PSPP-substitution has been confirmed to affect the bread making quality and texture of bread by giving the crumb a slightly hard, and moderately elastic and cohesive characteristic. Nevertheless, PSPP was a good natural colorant as shown by the judges' perception of a moderate purple color that they liked.

On the other hand, the α-amylase (AM) and hemicellulase (HC) treatments on PSPP dough improved the GRD, GP and SLV of the resulting bread brought about by the degradation of damaged starch and hemicellulose into mono-, di- and oligo-saccharides, which do not interfere with the formation of the gluten network during bread dough development. The activities of AM and HC were evidenced by the increase in soluble sugar, reducing and total sugar content, and decrease in damaged starch, apparent amylose, neutral detergent fiber, acid detergent fiber and hemicellulose contents of the bread dough.

Treatment with AM and HC also resulted in bread with lower firming rate, enthalpy change for retrogradation of starch, amylose content, rupture force and energy, and moisture loss during storage. These improvements are related with the anti-staling properties and hydrolytic activities of AM and HC resulting in the

production of sugar and dextrin products that prevents moisture loss and starch retrogradation, and lower starch-gluten interaction, as shown by the dough and bread structures. The perceptions of a moderate purple color, and enhanced textural properties, enthalpy change for retrogradation of starch and structure, indicate a more acceptable bread, than can potentially lead to the increased utilization of purple sweet potato in the baking industry.

PSPP-substitution also imparted a slight to extremely strong purple color, barely to slightly perceivable sweet potato flavor, barely to moderately perceivable sweet potato taste, slightly soft to soft firmness, and moderate elasticity and cohesiveness to “extra strong flour” fresh pasta. The imparted color is attributable to the natural dark purple color of PSPP. On the other hand, the soft and moderately elastic and cohesive texture of the PSPP-supplemented fresh pasta can be related to its improved water holding and absorbing capacities as evidenced by the inverse correlation of their moisture content with hardness, rupture force and rupture energy. Moreover, PSPP provides higher amount of gelatinized starch resulting in a softer and more elastic raw fresh pasta. Ultimately, the overall acceptability of the 5% and 10% PSPP were neither liked nor disliked along with the control, whereas the 7.5% PSPP was slightly liked. These results indicate that PSPP-supplementation gives rise to acceptable fresh pasta that may potentially lead to the increased utilization of PSPP in noodle processing.

This study proved that purple sweet potato is a stable natural colorant that imparts acceptable color to bread and fresh pasta. Although it affects the bread making and noodle making properties, some processing techniques like enzyme

treatments can be done to maintain an acceptable quality. With regards to this, further utilization of purple sweet potato powder in other baked products like cake, confectioneries, steamed bread can be done. In addition, the determination of the effects of purple potato and purple yam substitution in baking and noodle processing should be explored and compared with purple sweet potato powder. Ultimately, the antioxidant and other functional property analysis of colored non-cereal energy crops-supplemented bread and noodle products should be done to establish the potential health benefits of the products to consumers.

JAPANESE SUMMARY

日本語要約

過去２０年において、機能性食品の開発は、非常に一般的になった。今日、食品に対する消費者の要求は、空腹を満たすだけでなく、栄養に関する病気、人々の幸福度の改善も包含している。紫ポテト、ヤム、スイートポテトのような非穀物性カラフル作物が機能性食品の生産のために利用されており、それは、それらが化学的に安定な色とアントシアニン、カロチノイド類、フェノール酸、必須アミノ酸類のような固有の生理活性物質を包含しているからである。機能性食品として、これらの非穀物性作物は、栄養素類、風味、色が付与された特殊パンやペーストリー、人々の健康に関して効果が明らかになっているファイトケミカル類が付与されたカラフル麺の開発を可能にする。

本研究では、パンと生パスタの加工に紫スイートポテト粉末（ＰＳＰＰ）を利用し、その製パン、製麺性に対する効果が評価された。

これらの研究から、ＰＳＰＰの添加よって暗色のクラストと明るい紫色のクラムを持ったパンが得られることが判った。そして、それは、ＰＳＰＰ中に含まれる還元糖、アントシアニン色素の紫色に関係していた。しかしながら、ＰＳＰＰの添加は、低い生地のガス保持性（ＧＲＤ）とパンの比容積（ＳＬＶ）をもたらし、それは、ＰＳＰＰ中の高い損傷デンプン量と繊維含量に伴うグルテンタンパク含量の低下に関係していた。さらに、ＰＳＰＰ添加によって速い硬化（老化）を示すパンが製造され、それは、ＰＳＰＰ中の高濃度の損傷デンプン含量に伴う強固な糊化デンプンとグルテンタンパク質の相互作用によって引き起こされる。ＰＳＰＰ添加パンの水分ロスと破断力は対照のパンと同様であり、それは、ＰＳＰＰ中の糖類の高い水分保持性に関係していた。これらのことから、ＰＳＰＰ添加は、製パン性、やや硬いパンのテクスチャー、中程度の弾性や凝集性に影響することが明らかになった。それでも、ＰＳＰＰは人々が好む適当な紫色であると評価されていることから良好な天然色素である。

一方、ＰＳＰＰ添加生地をα－アミラーゼ（ＡＭ）やヘミセルラーゼ（ＨＣ）で処理することによって、ＧＲＤ、生地ガス発生量（ＧＰ）、ＳＬＶが改善され、それは、パン生地中の損傷デンプンやヘミセルロースが、パン生地の形成時のグルテンネットワーク形成を阻害しない単糖、二糖、オリゴ糖に分解された結果であった。 ＡＭとＨＣの作用によって、生地中の可溶性糖、還元糖、全糖が増加し、損傷デンプン、アミロース含量、中性溶媒繊維、酸性溶媒繊維、ヘミセルロース含量が低下することが明らかになった。

また、ＡＭとＨＣの処理によって、パン保存中の低い老化速度、デンプンの老化エンタルピー変化、アミロース含量、破断力、破断エネルギー、水分ロスを示すパンが得られた。これらの改善は、ＡＭとＨＣによる抗老化特性と加水分解特性に関係しており、それは、水分損失とデンプン老化を抑制するＡＭとＨＣの作用で生産される糖とデキストリン等の生産物が関係していると考えられる。ＰＳＰＰ添加酵素処理パンにおける良好な紫色の色相、硬い食品テクスチャー特性、老化特性、パン構造の結果は、製パン工業における紫スイートポテトの効果的な利用拡大を推進することを可能にする良好なパン品質に向上させた。

ＰＳＰＰ添加生パスタは、超強力小麦粉の生パスタに対して、わずかから非常に強

い紫色、極わずかからわずかなスイートポテトフレーバー、わずかに柔らかいから柔らかい食品テクスチャー、中程度の弾性と凝集性を示した 。この色相は、ＰＳＰＰの暗い紫色に関係しており、一方、ＰＳＰＰ添加生パスタの柔らかで中程度の弾性と凝集性、改善された水保持性、吸水性に関係していると考えられ、このことは、生パスタの水分含量と硬さ、破断力、破断エネルギーとの間に逆相関の関係があることから裏付けられる。さらに、ＰＳＰＰは、よりソフトで弾力的な生の生パスタ特性に関係する高濃度の糊化デンプンを包含している。最終的に、総合的な５%、１０%ＰＳＰＰ添加生パスタの品質の許容性は、対照と比べ同程度であり、７．５%ＰＳＰＰ添加生パスタのそれは、対照よりやや良好であった。これらの結果から、ＰＳＰＰ添加は、製麺プロセスにおいて、ＰＳＰＰの効果的利用拡大の推進を可能にする良好な生パスタ品質にそれを向上させた。

これらの研究から、紫スイートポテトは、パンや生パスタに適当な色を付与する天然の化学的に安定的な色素素材であることが明らかになった。 ＰＳＰＰの添加は、製パン性や製麺特性に影響するけれども、酵素処理のようないくつかの加工技術によって、適当な品質を維持することが可能である。この点おいて、ケーキ、菓子類、蒸しパンのような他の焼成食品における更なる紫スイートポテトの利用が可能になるであろう。さらに、焼成や麺食品における紫ポテトや紫ヤム添加に関する評価が研究され、紫スイートポテトの評価と比較されるべきである。最終的に、カラフル非穀物性作物添加のパンや麺製品の抗酸化性とその他の機能性について、消費者へのこれらの製品の健康に関する有用性が確立されるべきである。

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