



รายงานวิจัยฉบับสมบูรณ์

โครงการ การพัฒนาผลิตภัณฑ์ข้าวเสริมถั่วที่มีไกลซีมิกต่ำโดย
ใช้เทคโนโลยีเอนกัษทุรชัณ

โดย ดร. พรพืมล มะยะเจียว

มิถุนายน 2558

สัญญาเลขที่ TRG5680036

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ผู้วิจัย ดร. พรพิมล มะยะเจียว สังกัด มหาวิทยาลัยทักษิณ

สนับสนุนโดยสำนักงานกองทุนสนับสนุนการวิจัยและมหาวิทยาลัยทักษิณ (ต้นสังกัด)

(ความเห็นในรายงานนี้เป็นของผู้วิจัย สกว.ไม่จำเป็นต้องเห็นด้วยเสมอไป)

กิตติกรรมประกาศ

ผู้วิจัยขอขอบคุณสำนักงานกองทุนสนับสนุนการวิจัย (สกว.) และมหาวิทยาลัยทักษิณ ที่ให้การสนับสนุนเงินทุนการวิจัยประเภททุนส่งเสริมนักวิจัยรุ่นใหม่ตลอดโครงการวิจัย ขอขอบพระคุณ ศาสตราจารย์ ดร. สักกมน เทพหัตดิน ณ อยุธยา ที่ให้คำปรึกษาในการทำวิจัยและเป็นกำลังใจในการทำงานวิจัยมาโดยตลอด ขอขอบพระคุณ คุณจุฬาลักษณ์ จารุณูช ในการให้คำปรึกษาการใช้งานเครื่อง เอ็กซ์ทราเตอร์ และสุดท้ายนี้ ขอขอบคุณมหาวิทยาลัยทักษิณที่สนับสนุนสถานที่และอุปกรณ์เครื่องมือในการวิจัย

ดร. พรพิมล มะยะเนียว

มหาวิทยาลัยทักษิณ

2559

Abstract

Project Code : TRG5680036

Project Title : Development of Low-Glycemic Index Rice Products with Fortification of Legumes using Extrusion Technology

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Legumes contain protein, micronutrients and bioactive compounds, which provide various health benefits. In this study, soybean or mung bean was mixed in rice flour to produce by extrusion instant functional legume-rice porridge powder. The effects of the type and percentage (10, 20 or 30% w/w) of legumes on the expansion ratio of the extrudates were first evaluated. Amino acid composition, color as well as selected physicochemical (bulk density, water absorption index and water solubility index), thermal (onset temperature, peak temperature and transition enthalpy) and pasting (peak viscosity, trough viscosity and final viscosity) properties of the powder were determined. The crystalline structure and formation of amylose-lipid complexes as well as the total phenolics content (TPC), antioxidant activity of the powder and average glycemic index were also measured. Soybean-blended porridge powder exhibited higher TPC, DPPH radical scavenging capacity, ferric reducing antioxidant power (FRAP), amino acid and fat contents than the mung bean-blended porridge powder. Incorporating either legume affected the product properties by decreasing the lightness and bulk density, while increasing the greenness and yellowness as well as the peak temperature and transition enthalpy. Expansion capacity of the extrudates increased with percentage of mung bean in the mixture but decreased as the percentage of soybean increased. Amylose-lipid complexes formation was confirmed by X-ray diffraction analysis results. Addition of soybean or mung bean resulted in significant pasting property changes of the porridge powder. In addition, soybean-blended porridge exhibited lower glycemic index. A study on the addition of the colored rice which contains many phytochemicals to produce legume-rice porridges should be done in the future to further validate the production of healthy rice porridges.

Keywords : Antioxidant activity; Legumes; Phenolics; Rice porridge; Starch-lipid complexes

บทคัดย่อ

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ชื่อโครงการ : การพัฒนาผลิตภัณฑ์ข้าวเสริมถั่วที่มีไกลซีมิกต่ำโดยใช้เทคโนโลยีเอ็กซ์ทรูชัน

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ถั่วอุดมไปด้วยโปรตีน สารอาหารและสารออกฤทธิ์ทางชีวภาพ ซึ่งมีประโยชน์ต่อร่างกาย ในงานวิจัยนี้ ถั่วเหลืองและถั่วเขียวถูกนำมาผสมกับแป้งข้าวเจ้าเพื่อผลิตอาหารเพื่อสุขภาพ คือโจ๊กข้าวผสมถั่วทั้งสำเร็จรูป โดยใช้เทคโนโลยีเอ็กซ์ทรูชัน งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของชนิด (และร้อยละของถั่ว (10, 20 or 30% w/w) ที่มีต่อคุณภาพของผลิตภัณฑ์โจ๊กข้าวเสริมถั่วที่มีไกลซีมิกต่ำโดยใช้เทคโนโลยีเอ็กซ์ทรูชัน วิธีการทดลอง คือทำการผลิตผลิตภัณฑ์โจ๊กข้าวเสริมถั่วที่มีการผสมชนิดและร้อยละของถั่วแตกต่างกันโดยใช้เครื่องเอ็กซ์ทรูชัน จากนั้นทำการวิเคราะห์คุณภาพผลิตภัณฑ์โจ๊กข้าวเสริมถั่ว ได้แก่ คุณลักษณะด้านสี สมบัติทางเคมีกายภาพ เช่น ความหนาแน่นรวม (Bulk density) ดัชนีการดูดซับน้ำ (Water absorption index) และดัชนีการละลายน้ำ (Water solubility index) สมบัติทางความร้อน (Thermal property) โครงสร้างผลึก การเกิดสารเชิงซ้อนอะมิโลส-ไขมัน (amylose-lipid complexes) ปริมาณฟีนอลิกทั้งหมด (Total phenolic content) กิจกรรมการต้านอนุมูลอิสระ (Antioxidant activity) และดัชนีไกลซีมิก ผลการศึกษาพบว่าผลิตภัณฑ์โจ๊กข้าวเสริมถั่วเหลืองมีปริมาณฟีนอลิกทั้งหมด กิจกรรมการต้านอนุมูลอิสระ (DPPH radical scavenging capacity และ ferric reducing antioxidant power) ปริมาณกรดอะมิโน และปริมาณไขมัน สูงกว่าผลิตภัณฑ์โจ๊กข้าวเสริมถั่วเขียว การเสริมถั่วในผลิตภัณฑ์โจ๊กข้าวเสริมถั่วทั้ง 2 ชนิด มีผลต่อคุณลักษณะของผลิตภัณฑ์ โดยส่งผลให้ค่าความสว่าง (L) และความหนาแน่นรวมลดลง ในขณะที่ค่าความเป็นสีเขียว (a) ค่าความเป็นสีเหลือง (b) รวมทั้งสมบัติทางความร้อน ได้แก่ ค่า T_p (Peak temperature) และ ΔH (Transition enthalpy) เพิ่มขึ้น เมื่อพิจารณาผลของร้อยละถั่วพบว่าอัตราการขยายตัวของผลิตภัณฑ์เอ็กซ์ทรูเดต (extrudates) มีแนวโน้มเพิ่มขึ้นเมื่อร้อยละของถั่วเขียวเพิ่มขึ้น ในขณะที่อัตราการขยายตัวของผลิตภัณฑ์ลดลงเมื่อร้อยละของถั่วเหลืองเพิ่มขึ้น ผลของ X-ray diffraction analysis แสดงถึงการเกิดสารเชิงซ้อนอะมิโลส-ไขมันของผลิตภัณฑ์โจ๊กข้าวผสมถั่ว การผสมถั่วเหลืองหรือถั่วเขียวส่งผลให้สมบัติการเกิดเพสของผลิตภัณฑ์โจ๊กเปลี่ยนแปลงไป นอกจากนี้ผลิตภัณฑ์โจ๊กข้าวที่มีการเสริมถั่วเหลืองมีค่าไกลซีมิกต่ำ แนวทางการศึกษาต่อไปควรศึกษาการเติมข้าวพันธุ์มีสีซึ่งอุดมไปด้วยสารพฤกษเคมีในการผลิตผลิตภัณฑ์โจ๊กข้าวผสมถั่วเพื่อผลิตผลิตภัณฑ์โจ๊กข้าวเพื่อสุขภาพ

คำหลัก : กิจกรรมการต้านอนุมูลอิสระ; ถั่ว; ฟีนอลิก; โจ๊กข้าว; สารเชิงซ้อนอะมิโลส-ไขมัน

Chapter 1

Introduction

Rice (*Oryza sativa* L.) is one of the most important gluten-free cereal crops and a staple food of over half of the world's population. Nowadays, a number of rice-based products exist in the market, with instant rice porridge, which is a value-added product of broken rice, being one of the most popular. However, instant rice porridge is normally classified as a starchy food with low protein content and limited functional ingredients. Development of a healthy instant rice porridge is therefore a good way to meet the current market demand. This can be done through a careful selection and addition of ingredients to the porridge (Abete and others 2008; King and others 2008).

Blending legumes, which are an excellent source of protein, dietary fiber, micronutrients and bioactive compounds, with rice may be an alternative to develop healthy porridge for patients suffering celiac disease. Legumes can indeed help supply important essential amino acids, including lysine, which is limited in rice. Among possible choices of legumes, soybean (*Glycine max* L. Merrill) and mung bean (*Vigna radiata* L.) are of interest as they contain high contents of protein, vitamins, minerals and lipids as well as phenolic compounds (Devi and others 2009). In particular, soybean contains many health-promoting bioactive compounds, especially isoflavones (β -glucosides, malonyl- β -glucosides, acetyl- β -glucosides and aglycones), which possess antioxidant activity as well as α -glucosidase inhibitory activity, which has proved effective in the treatment of type 2 diabetes mellitus (Niamnuy and others 2011). Soybean also contains saponins, which are an excellent nutraceuticals.

Extrusion is a versatile and robust technology that can be used to produce instant porridge. Blending starchy food with beans and subjected the mixture to heat during extrusion can nevertheless lead to changes in the properties of an extruded product. Anton and others (2009), for example, blended navy and red bean flours at 15, 30 and 45% with corn starch and reported that the increasing level of bean flours resulted in a significant decrease in the expansion and crispness of the extruded product. On the other hand, the breaking strength

increased at the higher levels of bean flour substitution. Pastor-Cavada and others (2011), who blended wild legumes (*Lathyrus*) with whole corn and brown rice, showed that the addition of legumes led to a decrease in the expansion index and an increase in the density and solubility of both rice- and corn-based extrudates. da Silva and others (2014) blended carioca bean (*Phaseolus vulgaris* L.) with corn flour and reported that increasing the level of bean flour increased the density of the extrudates. However, the increased bean flour content resulted in a decrease in the sectional and volumetric expansion index of the extrudates.

Formation of starch-lipid complexes can also occur during heating of flour or starch containing lipids, leading to changes in the crystalline structure and hence physical and physicochemical as well as glycemic characteristics of a product (Marti and others 2010). Starch-lipid complexes formation has indeed proven to reduce the glycemic index (GI) of flour- or starch-based products (Srikaeo and Sopade 2010). Such complexes can alter the starch molecular structure, resulting in retarded hydrolysis by digestive enzymes. Many studies have demonstrated that starch-lipid complexes can form during extrusion of flour with nuts and legumes. De Pilli and others (2008), for example, reported the formation of starch-lipid complexes when extruding a mixture of wheat flour and almond, especially at lower levels of feed moisture content. The presence of starch-lipid complexes in the extrudates was confirmed by differential scanning calorimetry with an endothermic peak at 100-110 °C. The formation of starch-lipid complexes led to a decrease in the expansion index and deformability and to an increase in the breaking strength of the extrudates. De Pilli and others (2011) later studied the formation of starch-lipid complexes in a model food (rice starch added with oleic acid) and in a real food (rice starch added with pistachio nut flour) during extrusion. It was found that the formation of starch-lipid complexes in rice starch added with pistachio nut was strongly dependent on the feed water content, which affected starch gelatinization. The hardest texture of the extrudates was observed under the processing conditions that favored maximal formation of starch-lipid complexes.

So far limited information is available on the effects of the type and content of legumes that may be incorporated with rice to prepare an instant functional rice porridge. The aim of this

study was therefore to evaluate the effect of adding soybean or mung bean on the production and quality parameters of high-antioxidant instant rice porridges via the process of extrusion. The effects of the type (soybean or mung bean) and percentage of legumes (10, 20 or 30%) on the expansion ratio of the extrudates were determined. Color as well as selected physicochemical, namely, bulk density, water absorption index (WAI) and water solubility index (WSI); thermal, namely, onset temperature (T_o), peak temperature (T_p) and transition enthalpy (ΔH); and pasting, namely, peak viscosity, trough viscosity and final viscosity, properties of the porridges were then investigated. Crystalline structure, as assessed by the X-ray diffraction (XRD) analysis, amylose-lipid complexes formation as well as the total phenolics content (TPC), antioxidant activity and average glycemic index of the porridges were also measured.

Chapter 2

Methodology

2.1 Extrusion experiments

Extrusion was carried out using a co-rotating twin-screw extruder (Hermann Berstorff Laboratory, ZE25×33D, Hannover, Germany) with the length/diameter ratio of 870:25. The extruder was equipped with a volumetric twin-screw feeder (K-Tron soder AG 5702, type 20, Niederlenz, Switzerland), which could maintain the solid feed rate at 22-23.6 kg/h.

Rice and legume flour were mixed well and fed to the extruder. The moisture content of the blend was adjusted using a water pump to 14% (w.b.); the solid feed and water input were individually controlled. The barrel temperature profile was as follows: 35 °C (section 1), 45 °C (section 2), 55 °C (section 3), 125 °C (section 4), 140 °C (section 5), 150 °C (section 6), 135 °C (section 7) and 120 °C (at the die plate). The die was a thick plate with a 3.5-mm diameter circular hole. During an extrusion experiment, the barrel temperature, die pressure, solid feed rate and screw speed were recorded by a data-acquisition system.

After extrusion extrudates were dried at 80 °C for 10 min in a convection oven, then cooled to room temperature and packed in polyethylene bags. To prepare an instant porridge, an extrudate was ground using the comminutor and passed through a 2-mm sieve. Dried instant legume-rice porridge powder was packed in aluminum-foil laminated polyethylene bags until further analysis.

2.2 Experimental design

The effects of the two legumes (soybean and mung bean) and fractional mass of legumes (10, 20 and 30% w/w) on the color as well as selected physicochemical, thermal and pasting properties as well as the X-ray diffraction (XRD) pattern, total phenolics content and antioxidant capacity of the instant legume-rice porridge powder were investigated. Experiments were designed using the completely randomized design (CRD). The sample codes for the independent variables are listed in Table 1.

2.3 Determination of expansion ratio of extrudates

The expansion ratio (ER) of an extrudate, which indicates the radial expansion of a sample during extrusion, was calculated as the diameter of the extrudate divided by the diameter of the die orifice (3.5 mm) (Sharif and others 2014). The diameters of 5 samples from each treatment were measured using a Vernier caliper (Mitutoyo, 530, Kanagawa, Japan) with an accuracy 0.05 mm. The average diameter was used for the ER calculation.

2.4 Determination of amino acid composition of porridge powder

Amino acid composition of the legume-rice porridge powder was determined by the method of Hagen and others (1989). A sample (40 mg) was hydrolyzed with 15 mL of 6 N HCl. The solution was incubated in an oven at 110 °C for 24 h. One µL of the solution was then injected into an HPLC column (EZ:faast 4u AAA-MS 250×2.0 mm, Phenomenex, Torrance, CA). The flow rate of the mobile phase (10 mM ammonium formate) was set at 0.25 mL/min. The column temperature was controlled at 35 °C. Amino acid composition was analyzed using a liquid chromatograph/mass selective detector (LC/MSD) (Agilent, G1956B, Santa Clara, CA).

2.5 Determination of color of porridge powder

Color of a porridge sample was determined using a colorimeter (HunterLab, Miniscan XE plus, Reston, VA). Three Hunter parameters, namely, L (lightness), a (redness and greenness) and b (yellowness and blueness), were measured. The total color difference (ΔE) of each sample as compared to the color of the control (R100) was also calculated using Eq. (1):

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (1)$$

where L , a and b are the color values of a legume-rice porridge sample, while L_0 , a_0 and b_0 are the color values of the control sample.

2.6 Determination of physicochemical properties of porridge powder

2.6.1 Bulk density

A porridge sample was poured into a 100-mL measuring cylinder. The cylinder was gently tapped on a flat surface until a constant volume was obtained. The bulk density was calculated as the mass of the sample (g) divided by its volume (mL) (Nyombaire and others 2011).

2.6.2 Water absorption index and water solubility index

Water absorption index (WAI) and water solubility index (WSI) of the product were determined by the method of Nyombaire and others (2011). A sample (20 g) was suspended in 20 mL of distilled water for 30 min at room temperature; this was followed by centrifugation at $1000\times g$ for 15 min. The supernatant was decanted. WAI was calculated as an increase in the mass of the sediment (gel) formed after decanting the supernatant as follows:

$$\text{WAI (\%)} = \frac{\text{Mass of wet sediment (g)}}{\text{Mass of dried sediment (g)}} \times 100 \quad (2)$$

For the determination of WSI, the supernatant from the WAI determination was decanted in a pre-weighed evaporation dish and dried to a constant mass at 130°C . WSI was calculated using the following equation:

$$\text{WSI (\%)} = \frac{\text{Mass of dried supernatant (g)}}{\text{Mass of dry sample (g)}} \times 100 \quad (3)$$

where the mass of the dry sample means the dry mass of the 20-g sample.

2.7 Determination of total phenolics content and antioxidant activity of porridge powder

2.7.1 Sample preparation

A porridge sample (1 g) was extracted with 10 mL of methanol solution (80% v/v) at room temperature for 2 h. The mixture was filtered through Whatman no. 1 filter paper and transferred into a sample vial for further analysis (Wang and Ryu 2013).

2.7.2 Total phenolics content

The total phenolics content (TPC) of a sample extract was determined according to the Folin-Ciocalteu colorimetric method of Singleton and Rossi (1965) with some modification. An aliquot of the extract (200 μ L) was mixed with 1 mL of freshly diluted (10-fold) Folin-Ciocalteu reagent and incubated for 5 min. 1.5 mL of sodium carbonate solution (60 g/L) was then added to the mixture; this was followed by incubation at room temperature for 90 min. The absorbance of the solution was measured at 750 nm using a UV-vis spectrophotometer (Shimadzu, UV-1700, Kyoto, Japan). A standard curve was prepared using gallic acid as a standard ($R^2 > 0.99$). TPC of the extract is expressed in terms of mg gallic acid equivalent (GAE) per g dry sample (mg GAE/ g dry sample).

2.7.3 DPPH radical-scavenging activity

DPPH radical scavenging activity of a sample extract was determined according to the method of Brand-Williams and others (1995) with some modification. An aliquot of 1 mL of the sample extract was mixed with 2 mL of 0.5 mM DPPH $\cdot$ (in methanol) and incubated for 30 min in dark at room temperature. The absorbance was then measured at 517 nm using the UV-vis spectrophotometer. A standard curve was prepared using Trolox as a standard ($R^2 > 0.99$). The DPPH radical scavenging activity of the sample is expressed in terms of μ mol Trolox equivalent (TE) per g dry sample (μ mol Trolox/g dry sample).

2.7.4 Ferric reducing antioxidant power

Ferric reducing antioxidant power (FRAP) of a sample extract was measured according to the method of Benzie and Strain (1996) with some modification. 1.5 mL of FRAP reagent (mixture of 10 mM TPTZ solution in 40 mM HCl, 20 mM FeCl $_3$ ·6H $_2$ O and 300 mM acetate buffer (pH 3.6) at a ratio of 1:1:10 (v/v/v)) was mixed with 50 μ L of the extract and incubated in a water bath at 37 °C for 30 min. The absorbance of the ferrous tripyridyltriazine complex (colored product) was then measured at 593 nm using the UV-vis spectrophotometer. FRAP is expressed as mmol FeSO $_4$ /g dry sample.

2.8 Determination of fat content/complexing index of porridge powder

2.8.1 Fat content

The fat content of a sample was determined according to the AACC method (2003). Fat was extracted by diethyl ether in a Soxhlet system (Gerhardt, EV6All/16, Königswinter, Germany).

2.8.2 Complexing index

The complexing index (CI) can be used to indicate the degree of starch-lipid complexes formation, which is related to the formation of starch-iodine complex (De Pilli and others 2011). CI was determined using the method described by De Pilli and others (2008). The iodine solution used for the analysis was first prepared by dissolving 2 g of potassium iodide and 1.3 g of I_2 in 50 mL of distilled water and allowing the contents to dissolve overnight. Then, the final volume was made to 100 mL using distilled water. A porridge sample (5 g) was mixed with 25 mL of distilled water in a test tube for 2 min and centrifuged for 15 min at 3000 rpm. The supernatant (500 μ L) and distilled water (15 mL) was added to the iodine solution (2 mL) and turned over several times. The absorbance was then measured at 690 nm via the UV-vis spectrophotometer. CI was calculated using the following equation:

$$CI (\%) = \frac{ab_c - ab_s}{ab_c} \times 100 \quad (4)$$

where ab_c is the absorbance of the control sample and ab_s is the absorbance of the porridge sample. Rice flour-based porridge (R100) was used as the control sample.

2.9 Determination of XRD pattern of porridge powder

The crystalline structure and starch-lipid complexes formation of rice flour-based and legume-rice porridges were assessed via an X-ray diffractometer (X'Pert MPD, Philips, Almelo, The Netherlands) with Cu K α radiation at a wavelength of 0.154 nm and a scanning rate of 0.92° 2 θ /min at 40 kV and 40 mA. The relative intensity of the diffraction peaks was recorded in the scattering range (2 θ) of 10-30°. The A type X-ray diffraction pattern was evaluated.

2.10 Determination of thermal property of porridge powder

The chemical and structural changes, including starch gelatinization and starch-lipids complexes formation, of a porridge sample were determined via a differential scanning calorimeter (Perkin Elmer, DSC7, Cambridge, UK). A sample (3.0 mg) was weighed into an aluminum pan; distilled water was added using a microsyringe to reach a water-to-dry solid sample ratio of 2.5:1 (w/w). The sample was equilibrated for 5 h and then heated from 30 °C to 120 °C at a heating rate of 7 °C/min to determine the onset temperature (T_o), peak temperature (T_p) and transition enthalpy (ΔH), which are the indicators of starch-lipid complexes melting and starch gelatinization.

2.11 Determination of pasting property of porridge powder

The pasting property of rice flour and porridge powder was determined by a Rapid Visco Analyzer (Perten Instruments, RVA 4500, Hägersten, Sweden) at 8% (w/w) sample suspension. A sample was first held at 50 °C for 1 min, heated to 95 °C at 6 °C/min and then held at 95 °C for 5 min, cooled to 50 °C at 6 °C/min and held for 2 min to determine the RVA profile. The peak viscosity, trough viscosity and final viscosity were recorded in centipoise (cP).

2.12 Glycemic index

There were 2 steps to determine glycemic index.

Step 1: *In vitro* starch digestion

Starch digestion in the rice porridge samples was determined using a rapid *in vitro* digestibility assay based on glucometry (Srikaeo and Sopade, 2010). About 0.5 g of ground sample was treated with artificial saliva containing Porcine α -amylase before pepsin (pH 2.0) will be added and incubated at 37 °C for 30 min in a reciprocating water bath (85 rpm). The digesta was neutralized with NaOH before adjusting the pH to 6 (sodium acetate buffer) prior to the addition pancreatin and amyloglucosidase. The mixture was incubated for 4 hr, during which the glucose concentration in the digesta was measured with a glucometer at

specific periods (0, 10, 20, 30, 45, 60, 90, 120, 150, 180, 210 and 240 min). Digested starch per 100 g dry starch (DS) was calculated as Eq. (5):

$$DS = \frac{0.9 \times G_G \times V}{W \times S [100 - M]} \quad (5)$$

where G_G = glucometer reading (mM/l), V = volume of digesta (ml), W = weight of sample (g),

S = starch content of sample (g/100 g sample), M = moisture content of a sample (g/100 g sample) and 0.9 = stoichiometric constant for starch from glucose contents.

Step 2: Modelling starch digestogram

A modified first-order kinetic model, Eq. (6), was used to describe the starch digestograms:

$$D_t = D_0 + D_{\infty-0} (1 - \exp[-Kt]) \quad (6)$$

where D_t (g/100 g dry starch) is the digested starch at time t , D_0 is the digested starch at time $t = 0$, D_{∞} is the digestion at infinite time and K is the rate constant (min^{-1}).

In order to calculate the glycemic index of the samples, the areas under the digestograms (AUC_{exp}) were computed with Eq. (7), which was the integral form of Eq. (5):

$$\text{AUC}_{\text{exp}} = \left[D_{\infty} t + \frac{D_{\infty-0}}{K} \exp(-Kt) \right]_{t_1}^{t_2} \quad (7)$$

The hydrolysis index (HI) of each sample will be calculated by dividing the area under its digestogram by the area under the digestogram of a fresh white bread (≈ 6000 min g/100 g dry starch). The single-point measurements of starch digestion at 90 min in samples and fresh white bread as a reference can also be used to calculate GI (H_{90}). Hence, using the parameters of the modified first-order kinetic model (Eq. 6) for both the samples and fresh white bread, GI of the samples was also calculated, and the average GI for each sample was defined as below (Eq. 8):

$$GI = \frac{(39.21 + 0.803H_{90}) + (40.03 + 0.558HI)}{2} \quad (8)$$

2.13 Statistical analysis

All the experimental data are presented as mean values with standard deviations. Differences between the mean values were established using Duncan's new multiple range tests; the values were considered at a confidence level of 95%. All statistical analyses were performed using SPSS software (version 13, SPSS Inc., Chicago, IL). All experiments were performed in duplicate unless specified otherwise.

Chapter 3

Results



Fig. 1 Photographs of legume-rice extrudates

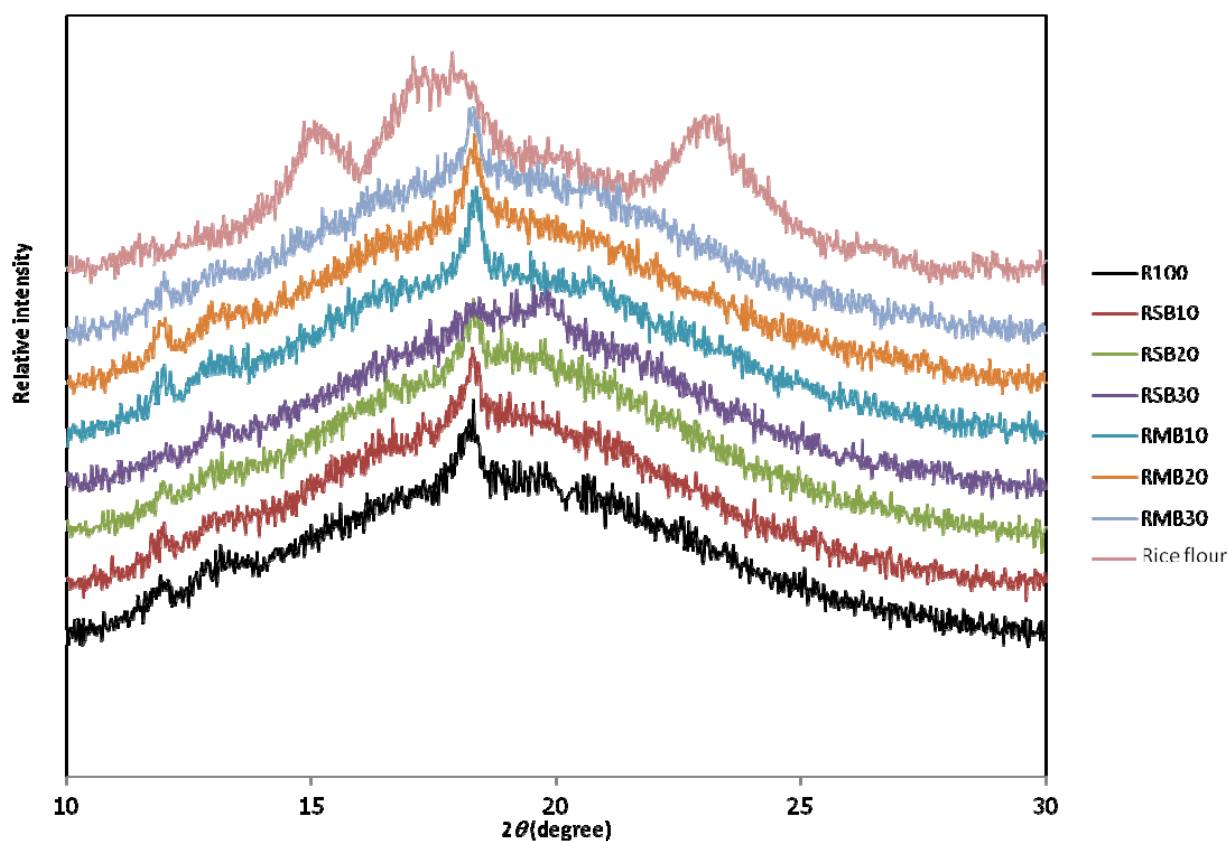


Fig. 2 The A type X-ray diffraction patterns of legume-rice porridges. R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean

Table 1 Completely randomized design-based codes of legume-rice mixtures

Sample code	Type and percentage (w/w) of ingredients
R100 (control)	100% Broken rice
RSB 10	90% Broken rice + 10% soybean
RSB 20	80% Broken rice + 20% soybean
RSB 30	70% Broken rice + 30% soybean
RMB 10	90% Broken rice + 10% mung bean
RMB 20	80% Broken rice + 20% mung bean
RMB 30	70% Broken rice + 30% mung bean

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean

Table 2 Expansion ratios of legume-rice extrudates

Sample code	Expansion ratio
R100	3.63±0.12 ^c
RSB 10	3.57±0.06 ^c
RSB 20	3.30±0.02 ^d
RSB 30	2.44±0.03 ^e
RMB 10	3.59±0.08 ^c
RMB 20	3.78±0.04 ^b
RMB 30	4.27±0.09 ^a

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p<0.05$)

Table 3 Amino acid compositions of legume-rice porridge powder

Amino acid	Amino acid content (g/100 g)		
	R100	RSB 30	RMB 30
Essential amino acid			
Histidine	0.15	0.78	0.45
Isoleucine	0.30	1.34	0.50
Leucine	0.63	2.12	0.96
Lysine	0.70	2.61	1.43
Methionine	0.52	0.56	0.35
Phenylalanine	0.37	1.23	0.77
Threonine	0.26	1.08	0.33
Valine	0.43	1.52	0.59
Tryptophan	0.00	0.13	0.00
Non-essential amino acid			
Alanine	0.34	1.39	0.39
Arginine	1.08	1.91	1.78
Aspartic acid	0.73	2.38	0.77
Cystine	0.00	0.32	0.00
Glutamic acid	1.19	3.22	1.03
Glycine	0.29	1.35	0.38
Proline	0.44	2.22	0.70
Serine	0.28	1.28	0.35
Tyrosine	0.34	0.89	0.43

R100: 100% broken rice; RSB 30: 70% broken rice+30% soybean; RMB 30: 70% broken rice+30% mung bean

Table 4 Color characteristics of legume-rice porridge powder

Sample code	Color parameter			
	<i>L</i>	<i>a</i>	<i>b</i>	ΔE
R100	81.09±0.35 ^e	-2.43±0.01 ^a	10.56±0.62 ^f	-
RSB 10	77.87±0.28 ^e	-2.48±0.11 ^a	18.67±0.18 ^e	8.72±0.19 ^e
RSB 20	77.70±0.37 ^d	-2.29±0.01 ^a	22.22±0.71 ^c	12.14±0.36 ^c
RSB 30	76.25±0.37 ^c	-2.08±0.11 ^a	25.68±0.44 ^a	15.88±0.31 ^a
RMB 10	78.40±0.22 ^d	-2.31±0.02 ^a	19.79±0.43 ^d	9.61±0.22 ^d
RMB 20	77.36±0.22 ^b	-1.78±0.07 ^a	22.45±0.47 ^c	12.47±0.25 ^c
RMB 30	75.27±0.21 ^a	-1.28±0.07 ^a	23.79±0.65 ^b	14.50±0.31 ^b

L (lightness); *a* (redness and greenness); *b* (yellowness and blueness); total color difference (ΔE).

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 5 WAI and WSI of legume-rice porridge powder

Sample code	Bulk density (g/mL)	WAI	WSI
R100	0.70±0.02 ^a	3.10±0.09 ^{ab}	30.44±1.39 ^{cd}
RSB 10	0.59±0.01 ^d	3.15±0.19 ^{ab}	25.64±3.86 ^d
RSB 20	0.56±0.01 ^e	2.92±0.11 ^{bc}	30.00±2.09 ^c
RSB 30	0.62±0.02 ^c	3.10±0.15 ^{ab}	27.40±2.63 ^{cd}
RMB 10	0.67±0.01 ^b	3.21±0.08 ^a	31.18±3.25 ^{bc}
RMB 20	0.62±0.01 ^c	3.10±0.08 ^{ab}	33.44±0.56 ^b
RMB 30	0.57±0.01 ^{de}	2.77±0.08 ^c	39.42±0.50 ^a

WAI: Water absorption index; WSI: water solubility index.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p<0.05$)

Table 6 TPC and antioxidant activity of legume-rice porridge powder

Sample code	TPC (mg GAE/ g sample)	DPPH (μ mol Trolox/ g dry sample)	FRAP (μ mol FeSO ₄ / g dry sample)
R100	1.09 $\pm$ 0.08 ^g	0.21 $\pm$ 0.01 ^g	2.76 $\pm$ 0.04 ^g
RSB 10	2.91 $\pm$ 0.15 ^c	0.88 $\pm$ 0.04 ^e	13.8 $\pm$ 0.06 ^c
RSB 20	3.52 $\pm$ 0.26 ^b	2.41 $\pm$ 0.18 ^c	14.7 $\pm$ 0.13 ^b
RSB 30	4.37 $\pm$ 0.28 ^a	3.07 $\pm$ 0.23 ^a	15.6 $\pm$ 0.17 ^a
RMB 10	1.82 $\pm$ 0.12 ^f	0.41 $\pm$ 0.02 ^f	4.54 $\pm$ 0.12 ^f
RMB 20	2.16 $\pm$ 0.13 ^e	1.47 $\pm$ 0.09 ^d	7.69 $\pm$ 0.23 ^e
RMB 30	2.69 $\pm$ 0.17 ^d	2.55 $\pm$ 0.15 ^b	9.53 $\pm$ 0.17 ^d

TPC: Total phenolics content; DPPH: DPPH radical scavenging activity; FRAP: Ferric reducing antioxidant power.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 7 Fat contents and complexing indices of legume-rice porridge powder

Sample code	Fat content (% wt)	Complexing index (%)
R100	0.57±0.03 ^g	-
RSB 10	1.43±0.08 ^c	75.10±0.13 ^c
RSB 20	2.74±0.17 ^b	75.45±0.18 ^b
RSB 30	4.95±0.16 ^a	76.70±0.24 ^a
RMB 10	0.84±0.03 ^f	54.84±0.12 ^d
RMB 20	1.03±0.06 ^e	29.04±0.11 ^e
RMB 30	1.25±0.12 ^{cd}	15.42±0.14 ^f

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 8 Thermal property values of legume-rice porridge powder

Sample code	T_o (°C)	T_p (°C)	ΔH (J/g)
R100	95.61±0.41 ^f	99.50±0.38 ^e	2.99±0.08 ^g
RSB 10	98.68±0.65 ^d	101.17±0.52 ^d	10.78±0.12 ^c
RSB 20	101.30±0.52 ^b	105.50±0.45 ^b	16.16±0.15 ^b
RSB 30	108.47±0.46 ^a	113.83±0.69 ^a	21.68±0.24 ^a
RMB 10	99.81±0.37 ^c	102.67±0.43 ^c	9.97±0.07 ^d
RMB 20	97.08±0.58 ^e	101.58±0.32 ^d	7.17±0.08 ^e
RMB 30	96.15±0.40 ^{ef}	101.25±0.38 ^d	3.14±0.05 ^f

T_o : onset temperature; T_p : peak temperature; ΔH : transition enthalpy.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Table 9 Pasting property of rice flour and legume-rice porridge powder

Sample code	Peak viscosity (cP)	Trough viscosity (cP)	Final viscosity (cP)
R100	134	43	64
RSB 10	85	36	55
RSB 20	73	35	52
RSB 30	47	33	49
RMB 10	128	42	60
RMB 20	115	40	56
RMB 30	109	37	53
Rice flour	1339	1248	2336

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean

Table 10 Glycemic index of rice flour and legume-rice porridge powder

Sample code	Average glycemic index
R100	81.46±1.13 ^a
RSB 10	75.15±1.40 ^c
RSB 20	71.27±0.81 ^d
RSB 30	65.74±1.25 ^e
RMB 10	76.95±1.04 ^c
RMB 20	77.31±1.73 ^{bc}
RMB 30	78.47±0.95 ^b

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean

Different superscripts in the same column mean that the values are significantly different ($p < 0.05$)

Chapter 4

Discussions and conclusion

The chemical compositions of the raw materials were first evaluated. Protein, fat and carbohydrate contents of the rice were approximately 6.04, 0.57 and 81.51%, respectively. Protein, fat and carbohydrate contents of the dehulled soybean seeds were approximately 37.28, 15.52 and 34.20%, respectively. Finally, the protein, fat and carbohydrate contents of the dehulled mung bean seeds were approximately 24.36, 1.43 and 60.93%, respectively. Soybean contained the highest protein and fat contents. On the other hand, soybean contained the lowest carbohydrate content. Mung bean possessed lower protein and fat contents than soybean by about 35 and 95%, respectively.

4.1 Expansion ratio of extrudates

The expansion ratios of legume-rice extrudates are listed in Table 2. Expansion capacity of the extrudates increased as the percentage of mung bean addition increased but decreased as the percentage of soybean addition increased. This may be because soybean contains smaller amount of starch compared with rice and mung bean. In addition, soybean protein could have induced starch-protein interactions, which limited the expansion of soybean-rice extrudates; the protein inhibited the formation of a continuous matrix, which contributed to the expansion (Allen and others 2007). In addition, starch-protein interactions might also inhibit the release of water vapor, thus limiting the expansion of the extrudates. On the other hand, addition of mung bean increased the expansion of the extrudates because mung bean flour contains a higher level of amylose (Sandhu and Lim, 2008); the higher content of amylose might help increase the formation of a continuous expandable matrix (Moraru and Kokini 2003).

4.2 Amino acid composition of porridge powder

Amino acid compositions of different porridge samples are listed in Table 3. When compared to the rice porridge (R100), incorporation of soybean (RSM 30) increased the amounts of all essential amino acids except for methionine; noted that soybean contains only a

small amount of methionine (Kim and others 2015). Lysine is the most dominant essential amino acid in the soybean-rice porridge sample because soybean is generally rich in lysine. Incorporation of soybean also increased the contents of non-essential amino acids, especially glutamic acid, aspartic acid and proline. Since rice contains limited amounts of amino acids, incorporation of soybean is an effective means to achieve a sufficient intake of amino acids when consuming this rice-based product.

In the case of the mung bean-rice porridge (RMB 30), addition of mung bean also increased the amounts of essential amino acids but to a lesser extent when compared with the addition of soybean. Threonine content slightly increased in the mung bean-rice porridge when compared with that in the rice porridge. Lack of tryptophan was noted in both rice and mung bean-rice porridge samples. Arginine, which is a non-essential amino acid, increased most significantly upon the addition of mung bean.

4.3 Color of porridge powder

The color values of porridge powder are presented in Table 4. The lightness (*L* value) of the rice porridge (R100) was 81.09, while the lightness of porridge powder made of rice mixed with soybean and mung bean varied between 76.25-77.87 and 75.27-78.40, respectively. Adding both legumes significantly affected the lightness of the samples ($p < 0.05$); the lightness decreased upon addition of both legumes. The *a* value and *b* value of different porridge powder varied between -2.48 and -1.28 and 10.56 to 25.68, indicating that the porridge powder exhibited light yellow color. As the percentage of either legume in the porridge powder increased, the *a* value and *b* value of the samples increased. Color variation among the porridge powder was attributed to the color of soybean and mung bean. Although it was also possible that reducing sugars present in both legumes could promote Maillard browning reaction during the extrusion process, which might in turn contribute to additional color changes of the porridge powder, it is noted that soybean and mung bean consist of only small amounts of reducing sugars. Mung bean contains 7.22 % total sugar and 0.05% glucose (Naivikul and D'Appolonia 1978).

The color changes of the rice porridge powder when blended with legumes were determined by the total color difference (ΔE); R100 was used as the control sample. As the percentage of either legume increased, ΔE of the porridge powder became larger.

4.4 Physicochemical properties of porridge powder

Physicochemical properties can present a relationship between the quality and composition of the porridge powder. Bulk density is an indicator of the structural change of a material during the extrusion process. The bulk density of the porridge powder varied from 0.57 to 0.70 g/mL (Table 5); the highest bulk density was noted in the case of the control rice porridge. Both soybean and mung bean decreased the bulk density of the porridge powder. This is probably because both legumes affected the gelatinization of starch. As gelatinization increases, the volume of an extruded product increases, while the bulk density decreases (Hagenimana and others 2006).

WAI and WSI of the porridge powder are also listed in Table 4. WAI measures the volume occupied by a product after swelling in excess water; WAI thus indirectly indicates the integrity of starch in an aqueous dispersion (Ding and others 2005). The soybean-rice porridge powder had WAI in the range of 2.92-3.15, whereas the mung bean-rice porridge powder had WAI in the range of 2.77-3.21. These values are in the same range as WAI of regular extruded foods, which is 1-6, depending on the type of raw material and extrusion condition (Oikonomou and Krokida 2012). No differences in the WAI among the porridge powder were observed, except for the product with 30% mung bean, which possessed the lowest WAI. This is probably because of the more severe degradation of starch granules due to the high shear force during the extrusion, which resulted in a decreased capacity of water absorption (Hagenimana and others 2006); noted that this formula contained the highest starch content and hence the most obvious effect. WSI of RSB 20 was higher than those of RSB 10 and RSB 30. This is because RMB 30 contained the highest mung bean starch content as compared with RMB 20 and RMB 10. Oikonomou and Krokida (2012) indeed reported that WAI is related to the composition of raw material and formulation. Lower WAI indicates that the porridge powder requires longer heating in water to induce adequate swelling for consumption.

WSI is often used as an indicator of the degradation of molecular components (Ding and others 2005) and hence measures the degree of starch conversion during the extrusion process. WSI indeed represents the amount of soluble polysaccharides that have been released from the starch components after extrusion. WSI of the soybean-rice porridge powder varied between 25.64 and 30.00, whereas WSI of the mung bean-rice porridge powder varied between 31.18 and 39.42. These values are in the same range as that of extruded rice, which is 20-55, depending on the feed moisture content. The porridge powder that contained higher percentage of mung bean had the higher WSI. This is due to the more extensive disruption of starch granules of the mung bean-rice porridge powder, which made the granules more soluble to water; noted again that mung bean flour contains higher amylose content than rice flour (Sandhu and Lim 2008) and hence the observed results. WSI of soybean-rice porridge powder was, on the other hand, lower than that of mung bean-rice porridge powder.

4.5 TPC and antioxidant activity of porridge powder

TPC of porridge powder of different formula is listed in Table 6. TPC of different porridge powder showed wide variation, ranging from 1.09 (R100) to 4.37 (RSB 30) mg GAE/g of dry sample. There were significant differences in TPC between porridge powder prepared from the two beans. Higher TPC was noted for porridge powder with soybean addition; more than two-fold higher TPC was noted for soybean-added porridge powder (2.91 to 4.37 mg GAE/g of dry sample) compared with the mung-bean added powder (1.82 to 2.69 mg GAE/g of dry sample). The results are in agreement with the observation of Huang and others (2014) who reported that TPC of soybean was higher than mung bean by about 2 folds. Isoflavones most probably played an important role on this observation as they are the important phenolic compound in soybean (Balisteiro and others 2013). TPC of legume-rice porridge powder increased with an increase in the percentage of both beans, as expected.

Antioxidant activity of the porridge powder was evaluated using two different assays; the results of both evaluation assays are listed in Table 6. The DPPH radical scavenging capacity of the porridge powder ranged from 0.21 to 3.07 μ mol Trolox/g dry sample. Soybean addition led to a significantly higher DPPH scavenging capacity compared to the values belonging to the

control sample and even the samples fortified with mung bean. The DPPH radical scavenging values of 10, 20 and 30% soybean-fortified porridge powder were 3.2, 10.5 and 13.6 folds higher, respectively, as compared with that of the control rice porridge powder. The DPPH radical scavenging capacities of 10, 20 and 30% mung bean-fortified porridge powder were only 1.0, 6.0 and 11.1 folds higher, respectively, as compared with that of the control rice porridge powder. The results were similar to those of the FRAP assay. No correlation was found between the DPPH radical scavenging activity and the legume fortification level in the porridge powder. This may be because the legumes caused the differences in the structural features of many molecular components of the porridges, which could in turn affect the scavenging activity. The higher DPPH scavenging capacity and FRAP of the soybean-fortified porridge powder are most probably due to the higher content of phenolics such as isoflavones in soybean (Cho and others 2013).

4.6 Fat content and complexing index of porridge powder

The fat contents of different porridge powder are listed in Table 7. Mung bean-fortified porridge powder had significantly lower fat contents than the soybean-fortified porridge powder because mung bean exhibits lower fat content (Zhang and others 2013). As expected, the fat content of the porridge powder increased with an increase in the percentage of the legumes.

CI, which indicates the level of starch-lipid complexes and is related to the formation of starch-iodine complex (De Pilli and others 2011), of the porridge powder is also listed in Table 7. CI of soybean-fortified porridge powder was in the range of 75.10-76.70%, while that of mung bean-fortified porridge powder was in the range of 15.42-54.84%. CI increased with an increase in the percentage of soybean but decreased with the more extensive addition of mung bean. This is probably because complexes formation is less likely to occur at low concentration of fatty acids (Tang and Copeland 2006) due to the higher ratio of amylose content (about $31.6 \pm 0.7\%$) to lipid content of mung bean (Sandhu and Lim 2008). Many factors affect the formation of starch-lipid complexes such as the types of starch and lipids as well as the ratio of starch to lipids. In addition, some lipids tend to self-associate instead of forming starch-lipid

complexes (Tang and Copeland 2006), leading to the lower CI of mung bean-fortified porridge powder.

Complexes formation of starch (amylose) with lipids, which leads to a higher CI value, modifies the starch properties, leading to slower starch hydrolysis and reduced solubility in water (Tang and Copeland 2006). Amylose-lipid complexes have indeed been regarded as resistant starch and exhibit health benefits in terms of postprandial glycemic and insulinemic responses control (Hasjim and others 2013).

4.7 XRD patterns of porridge powder

XRD analysis was performed to indicate starch (amylose)-lipid complexes formation. The XRD patterns of rice flour and different porridge powder samples are presented in Fig. 2. Rice flour exhibited an A-type XRD pattern with the diffraction peaks at 15° , a doublet at 17° and 18° , and 23° (2θ), which represents the general characteristics of cereals such as rice, waxy maize and wheat (Wei and others 2011; Zhu and others 2011; Yang and others 2013). However, extrusion altered the structure of rice starch (from crystalline into amorphous structure) (Wei and others 2011). For the rice porridge (R100), diffraction peaks at 15° , a doublet at 17° and 18° , and 23° (2θ) disappeared; only one narrow peak at around 18.4° (2θ) was observed. This indicated the changes in the crystalline structure of rice flour due to the extrusion, which contributed to the expansion of the extrudates and the porridge properties such as WAI and WSI. Soybean-fortified porridge powder exhibited different XRD patterns compared with rice porridge powder. When increasing the percentage of soybean, the peak intensity at around 18.4° (2θ) decreased, indicating the loss of A-type crystallinity pattern of starch granules, which may be due to the formation of complexes between starch and lipids. Additionally, the peaks shifted to around 20° (2θ), which is a typical amylose-lipid complexes diffraction peak (Zhu and others 2011; Huang and others 2015).

The increase in CI of soybean-fortified porridge powder could also be used to support the presence of the amylose-lipid complexes, which was evidenced from the XRD patterns. Mung bean-fortified porridge powder nevertheless exhibited similar XRD pattern to the rice porridge powder with the peaks at 18.4° (2θ). However, the formation of amylose-lipid

complexes of mung bean-fortified porridge powder was still noted, with a weak peak at around $12-13^{\circ}$ (2θ). The result is similar to that reported by Dercyke and others (2005).

4.8 Thermal property of porridge powder

Thermal property values of legume-rice porridge powder are presented in Table 8. The endothermic peak of the rice porridge powder (R100) was not observed at $60-80^{\circ}\text{C}$, indicating the complete gelatinization of the rice starch. On the other hand, the soybean-fortified porridge powder exhibited endothermic transition peak, while mung bean-fortified porridge powder exhibited exothermic peak. Derycke and others (2005) reported an existence of an endothermic peak as a result of the melting of amorphous amylose-lipid complexes; the existence of the endothermic peak thus helped confirm the formation of such complexes in soybean-fortified samples. For the mung bean-fortified porridge powder, the exothermic peaks were probably the result of crystallization of starch-lipid complexes (Biliaderis and others 1986). T_o (onset temperature), T_p (peak temperature) and ΔH (transition enthalpy) of the soybean-fortified porridge powder were in the ranges of $98.68-108.47^{\circ}\text{C}$, $101.17-113.83^{\circ}\text{C}$ and $10.78-21.68\text{ J/g}$, respectively. For the mung bean-fortified porridge powder, T_o , T_p and ΔH were in the ranges of $96.15-99.81^{\circ}\text{C}$, $101.25-102.67^{\circ}\text{C}$ and $3.14-9.97\text{ J/g}$, respectively. It is seen that the soybean-fortified porridge powder had higher values of T_p than the mung bean-fortified porridge powder. This is attributed to the higher degrees of gelatinization of the soybean-fortified samples. The higher degree of gelatinization resulted in more extensive disruption of the crystalline region of the starch granules (as shown in the XRD results) as well as in the lower peak viscosity. The formation of starch-lipid complexes affected T_p (De Pilli and other 2011). The peak temperature and transition enthalpy of all legume-fortified porridge powder were higher than those of the rice porridge powder. This is attributed to the formation of starch-lipid complexes due to the addition of legumes; the results corresponded to the CI results and XRD patterns. The transition enthalpy of the porridge powder increased with an increase in the percentage of soybean and mung bean. Bhatnagar and Hanna (1994) reported that the endothermic transitions between $107-112^{\circ}\text{C}$ may be attributed to the formation of complexes between amylose and lipids and related to the melting of amylose crystallites in the resistant starch (Adamu 2001).

4.9 Pasting property of porridge powder

Pasting property of the porridge powder is reported in Table 9. The peak, trough, final and setback viscosities of rice and legume-rice porridge powder were much lower than those of the rice flour. Gelatinization of rice starch in the porridges during extrusion resulted in the lower viscosities as compared with those of the rice flour (Jongsutjarittam and Charoenrein 2014). The addition of soybean decreased the peak viscosity of the soybean-rice porridge powder. This is attributed to the lower fraction of amylose and amylopectin (Sereewat and others 2015) upon incorporation of soybean. Soybean contains high protein and lipids, which might restrain the starch granules from hydration and swelling, resulting in the lower viscosity (Zhou and others 2007). Restricted swelling of starch granules subsequently decreased peak and final viscosities due to the formation of amylose-inclusion complexes (Putseys and other 2010). In the case of mung bean-rice porridge powder, the peak viscosity decreased when the mung bean content increased; this trend is in agreement with the results of Wu and others (2015).

The observed pasting property confirmed that the addition of soybean and mung bean caused the changes of the starch structure of the porridge powder.

4.10 Glycemic index of porridge powder

Average glycemic index of legume-rice porridge powder are presented in Table 10. The rice porridge powder (R100) exhibited the highest average glycemic index. Blending of soybean resulted in lower glycemic index. Instant rice porridges are normally classified as a high-glycemic index ($GI > 80$) food; this is because of the rice starch gelatinization, which occurs during processing, that enhances the starch digestibility (Srikaeo and Sopade, 2010). Exposure of starchy food and lipid-containing ingredients like soybean to heat during extrusion may lead to formation of amylose-lipid complexes, which change the glycemic characteristics of porridge.

Conclusion

Fortification of rice porridge with either soybean or mung bean at different percentages to produce instant functional legume-rice porridge powder was investigated. The lightness and bulk density of the porridge powder decreased with an increase in the percentage of both

legumes, while the greenness and yellowness of the legume-rice porridge powder increased. WAI of the legume-rice porridge powder was not significantly different from that of the rice porridge powder, except for the product with 30% mung bean, which possessed the lowest WAI. Addition of higher percentage of mung bean led to the porridge powder with higher WSI. WSI of the soybean-rice porridge powder was, on the other hand, lower than that of the mung bean-rice porridge powder. Soybean-blended porridge powder exhibited higher TPC, DPPH radical scavenging capacity, ferric reducing antioxidant power as well as amino acid and fat contents compared with the mung bean-blended porridge powder. An increase in the percentage of either legume led to an increase in the peak temperature and transition enthalpy. In both the cases of soybean and mung bean-blended porridge powder, amylose-lipid complexes formation was confirmed by the XRD patterns. CI increased with an increase in the percentage of soybean but decreased with the more extensive addition of mung bean. The addition of soybean and mung bean decreased the peak viscosity of the legume-rice porridge powder. In all cases, blending in 30% soybean resulted in the higher TPC, antioxidant activity, amino acid content, complexing index and level of amylose-lipid complexes formation. Addition of soybean resulted in a reduction in the glycemic index.

Chapter 5

References

- AACC. 2003. Approved Methods of the American Association of Cereal Chemists. 10th ed. American Association of Cereal Chemists. St. Paul, Minnesota.
- Abete I, Parra D, Martinez JA. 2008. Energy-restricted diets based on a distinct food selection affecting the glycemic index induce different weight loss and oxidative response. Clin Nutr 27:545-551.
- Adamu BOA. 2001. Resistant starch derived from extruded corn starch and guar gum as affected by acid and surfactants: Structural characterization. Starch-Stärke 53:582-591.
- Allen KE, Carpenter CE, Walsh MK. 2007. Influence of protein level and starch type on an extrusion-expanded whey product. Int J Food Sci Tech 42:953-960.
- Anton AA, Fulcher RG, Arntfield SD. 2009. Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: Effects of bean addition and extrusion cooking. Food Chem 113:989-996.
- Balisteiro DM, Rombaldi CV, Genovese MI. 2013. Protein, isoflavones, trypsin inhibitory and in vitro antioxidant capacities: Comparison among conventionally and organically grown soybeans. Food Res Int 51:8-14.
- Benzie IFF, Strain JJ. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. Anal Biochem 239:70-76.
- Bhatnagar S, Hanna MA. 1994. Amylose-lipid complex formation during single screw extrusion of various corn starches. Cereal Chem 71:582-587.
- Biliaderis CG, Page CM, Maurice TJ, Juliano BO. 1986. Thermal characterization of rice starches: A polymeric approach phase transitions of granular starch. J Agr Food Chem 34:6-14.
- Brand-Williams W, Cuvelier ME, Berset C. 1995. Use of a free radical method to evaluate antioxidant activity. LWT - Food Sci Technol 28:25-30.
- Cho KM, Ha TJ, Lee YB, Seo WD, Kim JY, Ryu HW, Jeong SH, Kang YM, Lee JH. 2013. Soluble phenolics and antioxidant properties of soybean (*Glycine max* L.) cultivars with varying seed coat colors. J Funct Foods 5:1065-1076.

- da Silva EMM, Ascheri JLR, de Carvalho CWP, Takeiti CY, Berrios JDJ. 2014. Physical characteristics of extrudates from corn flour and dehulled carioca bean flour blend. *LWT - Food Sci Technol* 58:620-626.
- De Pilli T, Jouppila K, Ikonen J, Kansikas J, Derossi A, Severini C. 2008. Study on formation of starch-lipid complexes during extrusion-cooking of almond flour. *J Food Eng* 87:495-504.
- De Pilli T, Derossi A, Talja RA, Jouppila K, Severini C. 2011. Study of starch-lipid complexes in model system and real food produced using extrusion-cooking technology. *Innov Food Sci Emerg* 12:610-616.
- Derycke V, Vandeputte GE, Vermeylen R, De Man W, Goderis B, Koch MHJ, Delcour JA. 2005. Starch gelatinization and amylose-lipid interactions during rice parboiling investigated by temperature resolved wide angle X-ray scattering and differential scanning calorimetry. *J Cereal Sci* 42:334-343.
- Devi MKA, Gondi M, Sakthivelu G, Giridhar P, Rajasekaran T, Ravishankar GA. 2009. Functional attributes of soybean seeds and products, with reference to isoflavone content and antioxidant activity. *Food Chem* 114:771-776.
- Ding Q-B, Ainsworth P, Tucker G, Marson H. 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *J Food Eng* 66:283-289.
- Hagenimana A, Ding X, Fang T. 2006. Evaluation of rice flour modified by extrusion cooking. *J Cereal Sci* 43:38-46.
- Hasjim J, Ai Y, Jane J-I. 2013. Novel applications of amylose-lipid complex as resistant starch type 5. In: Shi Y-C, Maningat CC, Editors. *Resistant starch: sources, applications and health benefits*. Chichester, United Kingdom: John Wiley & Sons, Ltd. p 79-94.
- Huang X, Cai W, Xu B. 2014. Kinetic changes of nutrients and antioxidant capacities of germinated soybean (*Glycine max* L.) and mung bean (*Vigna radiata* L.) with germination time. *Food Chem* 143:268-276.
- Huang J, Shang Z, Man J, Liu Q, Zhu C, Wei C. 2015. Comparison of molecular structures and functional properties of high-amylose starches from rice transgenic line and commercial maize. *Food Hydrocolloids* 46:172-179.

- Jongsutjarittam O, Charoenrein S. 2014. The effect of moisture content on physicochemical properties of extruded waxy and non-waxy rice flour. *Carbohydr Polym* 114:133-140.
- Kim SH, Yu BR, Chung IM. 2015. Changes in the contents and profiles of selected phenolics, soyaapogenols, tocopherols, and amino acids during soybean-rice mixture cooking: Electric rice cooker vs electric pressure rice cooker. *Food Chem* 176:45-53.
- King RA, Noakes M, Bird AR, Morell MK, Topping DL. 2008. An extruded breakfast cereal made from a high amylose barley cultivar has a low glycemic index and lower plasma insulin response than one made from a standard barley. *J Cereal Sci* 48:526-530.
- Marti A, Seetharaman K, Pagani MA. 2010. Rice-based pasta: A comparison between conventional pasta-making and extrusion-cooking. *J Cereal Sci* 52:404-409.
- Moraru CI, Kokini JL. 2003. Nucleation and expansion during extrusion and microwave heating of cereal foods. *Compr Rev Food Sci F* 2:147-165.
- Naivikul O, D'Appolonia BL. 1978. Comparison of legumes and wheat flour carbohydrates. I. Sugar analysis. *Cereal Chem* 55:913-918.
- Niamnuy C, Nachaisin M, Laohavanich J, Devahastin S. 2011. Evaluation of bioactive compounds and bioactivities of soybean dried by different methods and conditions. *Food Chem* 129:899-906.
- Nyombaire G, Siddiq M, Dolan KD. 2011. Physico-chemical and sensory quality of extruded light red kidney bean (*Phaseolus vulgaris* L.) porridge. *LWT - Food Sci Technol* 44:1597-1602.
- Oikonomou NA, Krokida MK. 2012. Water absorption index and water solubility index prediction for extruded food products. *Inter J Food Prop* 15:157-168.
- Pastor-Cavada E, Drago SR, González RJ, Juan R, Pastor JE, Alaiz M, Vioque J, 2011. Effects of the addition of wild legumes (*Lathyrus annuus* and *Lathyrus clymenum*) on the physical and nutritional properties of extruded products based on whole corn and brown rice. *Food Chem* 128:961-967.
- Putseys JA, Lamberts L, Delcour JA. 2010. Amylose-inclusion complexes: Formation, identity and physico-chemical properties. *J Cereal Sci*. 51:238-247.

- Sandhu KS, Lim S-T. 2008. Digestibility of legume starches as influenced by their physical and structural properties. *Carbohydr Polym* 71:245-252.
- Sereewat P, Suthipinittham C, Sumathaluk S, Puttanlek C, Uttapap D, Rungsardthong V. 2015. Cooking properties and sensory acceptability of spaghetti made from rice flour and defatted soy flour. *LWT - Food Sci Technol* 60:1061-1067.
- Sharif MK, Rizvi SSH, Paraman I. 2014. Characterization of supercritical fluid extrusion processed rice-soy crisps fortified with micronutrients and soy protein. *LWT - Food Sci Technol* 56:414-420.
- Singleton VL, Rossi JA. 1965. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *Am J Enol Viticult* 16:144-158.
- Srikaeo K, Sopade PA. 2010. Functional properties and starch digestibility of instant Jasmine rice porridges. *Carbohydr Polym* 82:952-957.
- Tang MC, Copeland L. 2007. Analysis of complexes between lipids and wheat starch. *Carbohydr Polym* 67:80-85.
- Wang YY, Ryu G-H. 2013. Physicochemical and antioxidant properties of extruded corn grits with corn fiber by CO₂ injection extrusion process. *J Cereal Sci* 58:110-116.
- Wei C, Qin F, Zhou W, Xu B, Chen C, Chen Y, Wang Y, Gu M, Liu Q. 2011. Comparison of the crystalline properties and structural changes of starches from high-amylose transgenic rice and its wild type during heating. *Food Chem* 128:645-652.
- Wu F, Meng Y, Yang N, Tao H, Xu X. 2015. Effects of mung bean starch on quality of rice noodles made by direct dry flour extrusion. *LWT - Food Sci Technol*, 63:1199-1205.
- Yang Z, Gu Q, Hemar Y. 2013. In situ study of maize starch gelatinization under ultra-high hydrostatic pressure using X-ray diffraction. *Carbohydr Polym* 97:235-238.
- Zhang X, Shang P, Qin F, Zhou Q, Gao B, Huang H, Yang H, Shi H, Yu L. 2013. Chemical composition and antioxidative and anti-inflammatory properties of ten commercial mung bean samples. *LWT - Food Sci Technol* 54:171-178.
- Zhou Z, Robards K, Helliwell S, Blanchard C. 2007. Effect of the addition of fatty acids on rice starch properties. *Food Res Int* 40:209-214.

Zhu L-J, Liu Q-Q, Wilson JD, Gu M-H, Shi Y-C. 2011. Digestibility and physicochemical properties of rice (*Oryza sativa* L.) flours and starches differing in amylose content. Carbohydr Polym 86:1751-1759.

Physicochemical and Thermal Properties of Extruded Instant Functional Rice Porridge Powder as Affected by the Addition of Soybean or Mung Bean

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Abstract: Legumes contain protein, micronutrients, and bioactive compounds, which provide various health benefits. In this study, soybean or mung bean was mixed in rice flour to produce by extrusion instant functional legume-rice porridge powder. The effects of the type and percentage (10%, 20%, or 30%, w/w) of legumes on the expansion ratio of the extrudates were first evaluated. Amino acid composition, color, and selected physicochemical (bulk density, water absorption index, and water solubility index), thermal (onset temperature, peak temperature, and transition enthalpy), and pasting (peak viscosity, trough viscosity, and final viscosity) properties of the powder were determined. The crystalline structure and formation of amylose-lipid complexes and the total phenolics content (TPC) and antioxidant activity of the powder were also measured. Soybean-blended porridge powder exhibited higher TPC, 2,2-diphenyl-1-picrylhydrazyl radical scavenging capacity, ferric reducing antioxidant power, amino acid, and fat contents than the mung bean-blended porridge powder. Incorporating either legume affected the product properties by decreasing the lightness and bulk density, while increasing the greenness and yellowness and the peak temperature and transition enthalpy. Expansion capacity of the extrudates increased with percentage of mung bean in the mixture but decreased as the percentage of soybean increased. Amylose-lipid complexes formation was confirmed by X-ray diffraction analysis results. Addition of soybean or mung bean resulted in significant pasting property changes of the porridge powder.

Keywords: antioxidant activity, DSC, legumes, phenolics, starch-lipid complexes, XRD

Practical Application: This work illustrates the feasibility of producing a starch-based functional food via appropriate addition of legumes and use of a simple extrusion process.

Introduction

Rice (*Oryza sativa* L.) is one of the most important gluten-free cereal crops and a staple food of over half of the world's population. Nowadays, a number of rice-based products exist in the market, with instant rice porridge, which is a value-added product of broken rice, being one of the most popular. However, instant rice porridge is normally classified as a starchy food with low protein content and limited functional ingredients. Development of a healthy instant rice porridge is therefore a good way to meet the current market demand. This can be done through a careful selection and addition of ingredients to the porridge (Abete and others 2008; King and others 2008).

Blending legumes, which are an excellent source of protein, dietary fiber, micronutrients, and bioactive compounds, with rice may be an alternative to develop healthy porridge for patients suffering celiac disease. Legumes can indeed help supply important essential amino acids, including lysine, which is limited in

rice. Among possible choices of legumes, soybean (*Glycine max* L. Merrill), and mung bean (*Vigna radiata* L.) are of interest as they contain high contents of protein, vitamins, minerals, and lipids as well as phenolic compounds (Devi and others 2009). In particular, soybean contains many health-promoting bioactive compounds, especially isoflavones (β -glucosides, malonyl- β -glucosides, acetyl- β -glucosides, and aglycones), which possess antioxidant activity as well as α -glucosidase inhibitory activity, which has proved effective in the treatment of type 2 diabetes mellitus (Niamnuy and others 2011). Soybean also contains saponins, which are an excellent nutraceuticals.

Extrusion is a versatile and robust technology that can be used to produce instant porridge. Blending starchy food with beans and subjected the mixture to heat during extrusion can nevertheless lead to changes in the properties of an extruded product. Anton and others 2009, for example, blended navy and red bean flours at 15%, 30%, and 45% with corn starch and reported that the increasing level of bean flours resulted in a significant decrease in the expansion and crispness of the extruded product. However, the breaking strength increased at the higher levels of bean flour substitution. Pastor-Cavada and others 2011, who blended wild legumes (*Lathyrus*) with whole corn and brown rice, showed that the addition of legumes led to a decrease in the expansion index and an increase in the density and solubility of both rice- and corn-based extrudates. da Silva and others 2014 blended carioca bean (*Phaseolus vulgaris* L.) with corn flour and reported that

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increasing the level of bean flour increased the density of the extrudates. However, the increased bean flour content resulted in a decrease in the sectional and volumetric expansion index of the extrudates.

Formation of starch–lipid complexes can also occur during heating of flour or starch containing lipids, leading to changes in the crystalline structure and hence physical and physicochemical as well as glycemic characteristics of a product (Marti and others 2010). Starch–lipid complexes formation has indeed proven to reduce the glycemic index (GI) of flour- or starch-based products (Srikaeo and Sopade 2010). Such complexes can alter the starch molecular structure, resulting in retarded hydrolysis by digestive enzymes. Many studies have demonstrated that starch–lipid complexes can form during extrusion of flour with nuts and legumes. De Pilli and others 2008, for example, reported the formation of starch–lipid complexes when extruding a mixture of wheat flour and almond, especially at lower levels of feed moisture content. The presence of starch–lipid complexes in the extrudates was confirmed by differential scanning calorimetry with an endothermic peak at 100 to 110 °C. The formation of starch–lipid complexes led to a decrease in the expansion index and deformability and to an increase in the breaking strength of the extrudates. De Pilli and others 2011 later studied the formation of starch–lipid complexes in a model food (rice starch added with oleic acid) and in a real food (rice starch added with pistachio nut flour) during extrusion. It was found that the formation of starch–lipid complexes in rice starch added with pistachio nut was strongly dependent on the feed water content, which affected starch gelatinization. The hardest texture of the extrudates was observed under the processing conditions that favored maximal formation of starch–lipid complexes.

So far, limited information is available on the effects of the type and content of legumes that may be incorporated with rice to prepare an instant functional rice porridge. The aim of this study was therefore to evaluate the effect of adding soybean or mung bean on the production and quality parameters of high-antioxidant instant rice porridges via the process of extrusion. The effects of the type (soybean or mung bean) and percentage of legumes (10%, 20%, or 30%) on the expansion ratio of the extrudates were determined. Color as well as selected physicochemical, namely, bulk density, water absorption index (WAI), and water solubility index (WSI); thermal, namely, onset temperature (T_o), peak temperature (T_p), and transition enthalpy (ΔH); and pasting, namely, peak viscosity, trough viscosity and final viscosity, properties of the porridges were then investigated. Crystalline structure, as assessed by the X-ray diffraction (XRD) analysis, amylose–lipid complexes formation as well as the total phenolics content (TPC) and antioxidant activity of the porridges were also measured.

Materials and Methods

Chemicals

Folin-Ciocalteu reagent, gallic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,4,6-tri(2-pyridinyl)-1,3,5-triazine (TPTZ), iron(III) chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), and iron(II) sulphate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) were obtained from Sigma-Aldrich (St. Louis, Mo., U.S.A.). Methanol was purchased from Fisher Scientific (Leicester, UK). Hydrochloric acid and sodium carbonate were purchased from RCI Labscan (Bangkok, Thailand).

Table 1—Completely randomized design-based codes of legume–rice mixtures.

Sample code	Type and percentage (w/w) of ingredients
R100 (control)	100% Broken rice
RSB 10	90% Broken rice + 10% soybean
RSB 20	80% Broken rice + 20% soybean
RSB 30	70% Broken rice + 30% soybean
RMB 10	90% Broken rice + 10% mung bean
RMB 20	80% Broken rice + 20% mung bean
RMB 30	70% Broken rice + 30% mung bean

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean

Materials

Thai jasmine rice (*Oryza sativa* L. cv. KDML105), dehulled soybean (yellow color with 15.5% fat, 65.5 g/1000 seeds) and dehulled mung bean (yellow color with 1.4% fat, 32.7 g/1000 seeds) were purchased from a supermarket in Phattalung province, Thailand. Rice kernels (broken white polished rice) and beans were ground using a comminutor (Fitzmill, M5; Elmhurst, Ill., U.S.A.) and sieved through a 250- μm sieve.

Extrusion experiments

Extrusion was carried out using a corotating twin-screw extruder (Hermann Berstorff Laboratory, ZE25 $\times$ 33D, Hannover, Germany) with the length/diameter ratio of 870:25. The extruder was equipped with a volumetric twin-screw feeder (K-Tron soder AG 5702, type 20; Niederlenz, Switzerland), which could maintain the solid feed rate at 22 to 23.6 kg/h.

Rice and legume flour were mixed well and fed to the extruder. The moisture content of the blend was adjusted using a water pump to 14% (w.b.); the solid feed and water input were individually controlled. The barrel temperature profile was as follows: 35 °C (section 1), 45 °C (section 2), 55 °C (section 3), 125 °C (section 4), 140 °C (section 5), 150 °C (section 6), 135 °C (section 7), and 120 °C (at the die plate). The die was a thick plate with a 3.5-mm-dia. circular hole. During an extrusion experiment, the barrel temperature, die pressure, solid feed rate, and screw speed were recorded by a data-acquisition system.

After extrusion extrudates were dried at 80 °C for 10 min in a convection oven, then cooled to room temperature and packed in polyethylene bags. To prepare an instant porridge, an extrudate was ground using the comminutor and passed through a 2-mm sieve. Dried instant legume–rice porridge powder was packed in aluminum-foil laminated polyethylene bags until further analysis.

Experimental design

The effects of the 2 legumes (soybean and mung bean) and fractional mass of legumes (10%, 20%, and 30%, w/w) on the color as well as selected physicochemical, thermal, and pasting properties as well as the XRD pattern, TPC, and antioxidant capacity of the instant legume–rice porridge powder were investigated. Experiments were designed using the completely randomized design (CRD). The sample codes for the independent variables are listed in Table 1.

Determination of expansion ratio of extrudates

The expansion ratio (ER) of an extrudate, which indicates the radial expansion of a sample during extrusion, was calculated as the diameter of the extrudate divided by the diameter of the die orifice

(3.5 mm; Sharif and others 2014). The diameters of 5 samples from each treatment were measured using a Vernier caliper (Mitutoyo, 530, Kanagawa, Japan) with an accuracy 0.05 mm. The average diameter was used for the ER calculation.

Determination of amino acid composition of porridge powder

Amino acid composition of the legume-rice porridge powder was determined by the method of Hagen and others (1989). A sample (40 mg) was hydrolyzed with 15 mL of 6 N HCl. The solution was incubated in an oven at 110 °C for 24 h. One microliter of the solution was then injected into an HPLC column (EZ:fast 4u AAA-MS 250×2.0 mm; Phenomenex, Torrance, Calif., U.S.A.). The flow rate of the mobile phase (10 mM ammonium formate) was set at 0.25 mL/min. The column temperature was controlled at 35 °C. Amino acid composition was analyzed using a liquid chromatograph/mass selective detector (LC/MSD) (Agilent, G1956B, Santa Clara, Calif., U.S.A.).

Determination of color of porridge powder

Color of a porridge sample was determined using a colorimeter (HunterLab, Miniscan XE plus, Reston, Va., U.S.A.). Three Hunter parameters, namely, L (lightness), a (redness and greenness), and b (yellowness and blueness) were measured. The total color difference (ΔE) of each sample as compared to the color of the control (R100) was also calculated using Eq. (1):

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (1)$$

where L , a , and b are the color values of a legume-rice porridge sample, whereas L_0 , a_0 , and b_0 are the color values of the control sample.

Determination of physicochemical properties of porridge powder

Bulk density. A porridge sample was poured into a 100-mL measuring cylinder. The cylinder was gently tapped on a flat surface until a constant volume was obtained. The bulk density was calculated as the mass of the sample (g) divided by its volume (mL) (Nyombaire and others 2011).

WAI and WSI. WAI and WSI of the product were determined by the method of Nyombaire and others 2011. A sample (20 g) was suspended in 20 mL of distilled water for 30 min at room temperature; this was followed by centrifugation at $1000 \times g$ for 15 min. The supernatant was decanted. WAI was calculated as an increase in the mass of the sediment (gel) formed after decanting the supernatant as follows:

$$\text{WAI (\%)} = \frac{\text{Mass of wet sediment (g)}}{\text{Mass of dried sediment (g)}} \times 100 \quad (2)$$

For the determination of WSI, the supernatant from the WAI determination was decanted in a preweighed evaporation dish and dried to a constant mass at 130 °C. WSI was calculated using the following equation:

$$\text{WSI (\%)} = \frac{\text{Mass of dried supernatant (g)}}{\text{Mass of dry sample (g)}} \times 100 \quad (3)$$

where the mass of the dry sample means the dry mass of the 20-g sample.

Determination of TPC and antioxidant activity of porridge powder

Sample preparation. A porridge sample (1 g) was extracted with 10 mL of methanol solution (80%, v/v) at room temperature for 2 h. The mixture was filtered through Whatman no. 1 filter paper and transferred into a sample vial for further analysis (Wang and Ryu 2013).

TPC. The TPC of a sample extract was determined according to the Folin-Ciocalteu colorimetric method of Singleton and Rossi 1965 with some modification. An aliquot of the extract (200 μ L) was mixed with 1 mL of freshly diluted (10-fold) Folin-Ciocalteu reagent and incubated for 5 min. 1.5 mL of sodium carbonate solution (60 g/L) was then added to the mixture; this was followed by incubation at room temperature for 90 min. The absorbance of the solution was measured at 750 nm using a UV-vis spectrophotometer (Shimadzu, UV-1700, Kyoto, Japan). A standard curve was prepared using gallic acid as a standard ($R^2 > 0.99$). TPC of the extract is expressed in terms of mg gallic acid equivalent (GAE) per g dry sample (mg GAE/g dry sample).

DPPH radical-scavenging activity. DPPH radical-scavenging activity of a sample extract was determined according to the method of Brand-Williams and others 1995 with some modification. An aliquot of 1 mL of the sample extract was mixed with 2 mL of 0.5 mM DPPH $^{\bullet}$ (in methanol) and incubated for 30 min in dark at room temperature. The absorbance was then measured at 517 nm using the UV-vis spectrophotometer. A standard curve was prepared using Trolox as a standard ($R^2 > 0.99$). The DPPH radical scavenging activity of the sample is expressed in terms of μ mol Trolox equivalent (TE) per g dry sample (μ mol Trolox/g dry sample).

Ferric reducing antioxidant power. Ferric reducing antioxidant power (FRAP) of a sample extract was measured according to the method of Benzie and Strain 1996 with some modification. 1.5 mL of FRAP reagent (mixture of 10 mM TPTZ solution in 40 mM HCl, 20 mM FeCl $_3$ ·6H $_2$ O and 300 mM acetate buffer (pH 3.6) at a ratio of 1:1:10 [v/v/v]) was mixed with 50 μ L of the extract and incubated in a water bath at 37 °C for 30 min. The absorbance of the ferrous tripyridyltriazine complex (colored product) was then measured at 593 nm using the UV-vis spectrophotometer. FRAP is expressed as mmol FeSO $_4$ /g dry sample.

Determination of fat content/complexing index of porridge powder

Fat content. The fat content of a sample was determined according to the AOAC method 2003. Fat was extracted by diethyl ether in a Soxhlet system (Gerhardt, EV6All/16, Königswinter, Germany).

Complexing index. The complexing index (CI) can be used to indicate the degree of starch-lipid complexes formation, which is related to the formation of starch-iodine complex (De Pilli and others 2011). CI was determined using the method described by De Pilli and others 2008. The iodine solution used for the analysis was first prepared by dissolving 2 g of potassium iodide and 1.3 g of I $_2$ in 50 mL of distilled water and allowing the contents to dissolve overnight. Then, the final volume was made to 100 mL using distilled water. A porridge sample (5 g) was mixed with 25 mL of distilled water in a test tube for 2 min and centrifuged for 15 min at 3000 rpm. The supernatant (500 μ L) and distilled water (15 mL) was added to the iodine solution (2 mL) and turned over several times. The absorbance

was then measured at 690 nm via the UV-vis spectrophotometer. CI was calculated using the following equation:

$$CI(\%) = \frac{ab_c - ab_s}{ab_c} \times 100 \quad (4)$$

where ab_c is the absorbance of the control sample and ab_s is the absorbance of the porridge sample. Rice flour-based porridge (R100) was used as the control sample.

Determination of XRD pattern of porridge powder

The crystalline structure and starch-lipid complexes formation of rice flour-based and legume-rice porridges were assessed via an X-ray diffractometer (X'Pert MPD, Philips, Almelo, The Netherlands) with $\text{CuK}\alpha$ radiation at a wavelength of 0.154 nm and a scanning rate of $0.92^\circ 2\theta/\text{min}$ at 40 kV and 40 mA. The relative intensity of the diffraction peaks was recorded in the scattering range (2θ) of 10° to 30° . The A type XRD pattern was evaluated.

Determination of thermal property of porridge powder

The chemical and structural changes, including starch gelatinization and starch-lipids complexes formation, of a porridge sample were determined via a differential scanning calorimeter (Perkin Elmer, DSC7, Cambridge, UK). A sample (3.0 mg) was weighed into an aluminum pan; distilled water was added using a microsyringe to reach a water-to-dry solid sample ratio of 2.5:1 (w/w). The sample was equilibrated for 5 h and then heated from 30 to 120 °C at a heating rate of 7 °C/min to determine the onset temperature (T_o), peak temperature (T_p), and transition enthalpy (ΔH), which are the indicators of starch-lipid complexes melting and starch gelatinization.

Determination of pasting property of porridge powder

The pasting property of rice flour and porridge powder was determined by a Rapid Visco Analyzer (Perten Instruments, RVA 4500, Hågersten, Sweden) at 8% (w/w) sample suspension. A sample was first held at 50 °C for 1 min, heated to 95 °C at 6 °C/min and then held at 95 °C for 5 min, cooled to 50 °C at 6 °C/min and held for 2 min to determine the RVA profile. The peak viscosity, trough viscosity and final viscosity were recorded in centipoise (cP).

Statistical analysis

All the experimental data are presented as mean values with standard deviations. Differences between the mean values were established using Duncan's new multiple range tests; the values were considered at a confidence level of 95%. All statistical analyses were performed using SPSS software (version 13, SPSS Inc., Chicago, Ill., U.S.A.). All experiments were performed in duplicate unless specified otherwise.

Results and Discussion

The chemical compositions of the raw materials were first evaluated. Protein, fat, and carbohydrate contents of the rice were approximately 6.04%, 0.57%, and 81.51%, respectively. Protein, fat, and carbohydrate contents of the dehulled soybean seeds were approximately 37.28%, 15.52%, and 34.20%, respectively. Finally, the protein, fat, and carbohydrate contents of the dehulled mung bean seeds were approximately 24.36%, 1.43%, and 60.93%, respectively. Soybean contained the highest protein and fat contents. However, soybean contained the lowest carbohydrate content. Mung bean possessed lower protein and fat contents than soybean by about 35% and 95%, respectively.

Table 2—Expansion ratios of legume-rice extrudates.

Sample code	Expansion ratio
R100	3.63 ± 0.12 ^c
RSB 10	3.57 ± 0.06 ^c
RSB 20	3.30 ± 0.02 ^d
RSB 30	2.44 ± 0.03 ^e
RMB 10	3.59 ± 0.08 ^c
RMB 20	3.78 ± 0.04 ^b
RMB 30	4.27 ± 0.09 ^a

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean. Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

Table 3—Amino acid compositions of legume-rice porridge powder.

Amino acid	Amino acid content (g/100 g)		
	R100	RSB 30	RMB 30
Essential amino acid			
Histidine	0.15	0.78	0.45
Isoleucine	0.30	1.34	0.50
Leucine	0.63	2.12	0.96
Lysine	0.70	2.61	1.43
Methionine	0.52	0.56	0.35
Phenylalanine	0.37	1.23	0.77
Threonine	0.26	1.08	0.33
Valine	0.43	1.52	0.59
Tryptophan	0.00	0.13	0.00
Non-essential amino acid			
Alanine	0.34	1.39	0.39
Arginine	1.08	1.91	1.78
Aspartic acid	0.73	2.38	0.77
Cystine	0.00	0.32	0.00
Glutamic acid	1.19	3.22	1.03
Glycine	0.29	1.35	0.38
Proline	0.44	2.22	0.70
Serine	0.28	1.28	0.35
Tyrosine	0.34	0.89	0.43

R100: 100% broken rice; RSB 30: 70% broken rice + 30% soybean; RMB 30: 70% broken rice + 30% mung bean.

Expansion ratio of extrudates

The expansion ratios of legume-rice extrudates are listed in Table 2. Expansion capacity of the extrudates increased as the percentage of mung bean addition increased but decreased as the percentage of soybean addition increased (Figure 1). This may be because soybean contains smaller amount of starch compared with rice and mung bean. In addition, soybean protein could have induced starch-protein interactions, which limited the expansion of soybean-rice extrudates; the protein inhibited the formation of a continuous matrix, which contributed to the expansion (Allen and others 2007). In addition, starch-protein interactions might also inhibit the release of water vapor, thus limiting the expansion of the extrudates. However, addition of mung bean increased the expansion of the extrudates because mung bean flour contains a higher level of amylose (Sandhu and Lim, 2008); the higher content of amylose might help increase the formation of a continuous expandable matrix (Moraru and Kokini 2003).

Amino acid composition of porridge powder

Amino acid compositions of different porridge samples are listed in Table 3. When compared to the rice porridge (R100), incorporation of soybean (RSM 30) increased the amounts of all essential amino acids except for methionine; noted that soybean contains

only a small amount of methionine (Kim and others 2015). Lysine is the most dominant essential amino acid in the soybean-rice porridge sample because soybean is generally rich in lysine. Incorporation of soybean also increased the contents of nonessential amino acids, especially glutamic acid, aspartic acid, and proline. Because rice contains limited amounts of amino acids, incorporation of soybean is an effective means to achieve a sufficient intake of amino acids when consuming this rice-based product.

In the case of the mung bean-rice porridge (RMB 30), addition of mung bean also increased the amounts of essential amino acids but to a lesser extent when compared with the addition of soybean. Threonine content slightly increased in the mung bean-rice porridge when compared with that in the rice porridge. Lack of tryptophan was noted in both rice and mung bean-rice porridge samples. Arginine, which is a nonessential amino acid, increased most significantly upon the addition of mung bean.

Color of porridge powder

The color values of porridge powder are presented in Table 4. The lightness (*L* value) of the rice porridge (R100) was 81.09, whereas the lightness of porridge powder made of rice mixed with soybean and mung bean varied between 76.25 to 77.87 and 75.27 to 78.40, respectively. Adding both legumes significantly affected the lightness of the samples ($P < 0.05$); the lightness decreased upon addition of both legumes. The *a* and *b* value of different porridge powder varied between -2.48 and -1.28 and 10.56 to 25.68 , indicating that the porridge powder exhibited light yellow color. As the percentage of either legume in the porridge powder increased, the *a* and *b* value of the samples increased. Color variation among the porridge powder was attributed to the color of soybean and mung bean. Although it was also possible that reducing sugars present in both legumes could promote Maillard browning reaction during the extrusion process, which might in turn contribute to additional color changes of the porridge powder, it is noted that soybean and mung bean consist of only small amounts of reducing sugars. Mung bean contains 7.22 % total sugar and 0.05% glucose (Naivikul and D'Appolonia 1978).

The color changes of the rice porridge powder when blended with legumes were determined by the total color difference (ΔE); R100 was used as the control sample. As the percentage of either legume increased, ΔE of the porridge powder became larger.

Physicochemical properties of porridge powder

Physicochemical properties can present a relationship between the quality and composition of the porridge powder. Bulk density is an indicator of the structural change of a material during the extrusion process. The bulk density of the porridge powder varied from 0.57 to 0.70 g/mL (Table 5); the highest bulk density was noted in the case of the control rice porridge. Both soybean and mung bean decreased the bulk density of the porridge powder. This is probably because both legumes affected the gelatinization of starch. As gelatinization increases, the volume of an extruded product increases, whereas the bulk density decreases (Hagenimana and others 2006).

WAI and WSI of the porridge powder are also listed in Table 4. WAI measures the volume occupied by a product after swelling in excess water; WAI thus indirectly indicates the integrity of starch in an aqueous dispersion (Ding and others 2005). The soybean-rice porridge powder had WAI in the range of 2.92 to 3.15, whereas the mung bean-rice porridge powder had WAI in the range of 2.77 to 3.21. These values are in the same range as WAI of regular extruded foods, which is 1 to 6, depending on the type of

raw material and extrusion condition (Oikonomou and Krokida 2012). No differences in the WAI among the porridge powder were observed, except for the product with 30% mung bean, which possessed the lowest WAI. This is probably because of the more severe degradation of starch granules due to the high shear force during the extrusion, which resulted in a decreased capacity of water absorption (Hagenimana and others 2006); noted that this formula contained the highest starch content and hence the most obvious effect. WSI of RSB 20 was higher than those of RSB 10 and RSB 30. This is because RMB 30 contained the highest mung bean starch content as compared with RMB 20 and RMB 10. Oikonomou and Krokida 2012 indeed reported that WAI is related to the composition of raw material and formulation. Lower WAI indicates that the porridge powder requires longer heating in water to induce adequate swelling for consumption.

WSI is often used as an indicator of the degradation of molecular components (Ding and others 2005) and hence measures the degree of starch conversion during the extrusion process. WSI indeed represents the amount of soluble polysaccharides that have been released from the starch components after extrusion. WSI of the soybean-rice porridge powder varied between 25.64 and 30.00, whereas WSI of the mung bean-rice porridge powder varied between 31.18 and 39.42. These values are in the same range as that of extruded rice, which is 20 to 55, depending on the feed moisture content. The porridge powder that contained higher percentage of mung bean had the higher WSI. This is due to the more extensive disruption of starch granules of the mung bean-rice porridge powder, which made the granules more soluble to water; noted again that mung bean flour contains higher amylose content than rice flour (Sandhu and Lim 2008) and hence the observed results. WSI of soybean-rice porridge powder was, however, lower than that of mung bean-rice porridge powder.

TPC and antioxidant activity of porridge powder

TPC of porridge powder of different formula is listed in Table 6. TPC of different porridge powder showed wide variation, ranging from 1.09 (R100) to 4.37 (RSB 30) mg GAE/g of dry sample. There were significant differences in TPC between porridge powder prepared from the 2 beans. Higher TPC was noted for porridge powder with soybean addition; more than 2-fold higher TPC was noted for soybean-added porridge powder (2.91 to 4.37 mg GAE/g of dry sample) compared with the mung-bean added powder (1.82 to 2.69 mg GAE/g of dry sample). The results are in agreement with the observation of Huang and others 2014 who reported that TPC of soybean was higher than mung bean by about 2 folds. Isoflavones most probably played an important role on this observation as they are the important phenolic compound in soybean (Balisteiro and others 2013). TPC of legume-rice porridge powder increased with an increase in the percentage of both beans, as expected.

Antioxidant activity of the porridge powder was evaluated using 2 different assays; the results of both evaluation assays are listed in Table 6. The DPPH radical scavenging capacity of the porridge powder ranged from 0.21 to 3.07 $\mu\text{mol Trolox/g}$ dry sample. Soybean addition led to a significantly higher DPPH scavenging capacity compared to the values belonging to the control sample and even the samples fortified with mung bean. The DPPH radical scavenging values of 10%, 20%, and 30% soybean-fortified porridge powder were 3.2-, 10.5-, and 13.6-fold higher, respectively, as compared with that of the control rice porridge powder. The DPPH radical scavenging capacities of 10%, 20%, and 30% mung bean-fortified porridge powder were only 1.0-, 6.0-, and

Table 4—Color characteristics of legume-rice porridge powder.

Sample code	Color parameter			
	<i>L</i>	<i>a</i>	<i>b</i>	ΔE
R100	81.09 ± 0.35 ^c	−2.43 ± 0.01 ^a	10.56 ± 0.62 ^f	—
RSB 10	77.87 ± 0.28 ^c	−2.48 ± 0.11 ^a	18.67 ± 0.18 ^c	8.72 ± 0.19 ^c
RSB 20	77.70 ± 0.37 ^d	−2.29 ± 0.01 ^a	22.22 ± 0.71 ^c	12.14 ± 0.36 ^c
RSB 30	76.25 ± 0.37 ^c	−2.08 ± 0.11 ^a	25.68 ± 0.44 ^a	15.88 ± 0.31 ^a
RMB 10	78.40 ± 0.22 ^d	−2.31 ± 0.02 ^a	19.79 ± 0.43 ^d	9.61 ± 0.22 ^d
RMB 20	77.36 ± 0.22 ^b	−1.78 ± 0.07 ^a	22.45 ± 0.47 ^c	12.47 ± 0.25 ^c
RMB 30	75.27 ± 0.21 ^a	−1.28 ± 0.07 ^a	23.79 ± 0.65 ^b	14.50 ± 0.31 ^b

L (lightness); *a* (redness and greenness); *b* (yellowness and blueness); total color difference (ΔE).

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

Table 5—WAI and WSI of legume-rice porridge powder.

Sample code	Bulk density (g/mL)	WAI	WSI
R100	0.70 ± 0.02 ^a	3.10 ± 0.09 ^{ab}	30.44 ± 1.39 ^{cd}
RSB 10	0.59 ± 0.01 ^d	3.15 ± 0.19 ^{ab}	25.64 ± 3.86 ^d
RSB 20	0.56 ± 0.01 ^c	2.92 ± 0.11 ^{bc}	30.00 ± 2.09 ^c
RSB 30	0.62 ± 0.02 ^c	3.10 ± 0.15 ^{ab}	27.40 ± 2.63 ^{cd}
RMB 10	0.67 ± 0.01 ^b	3.21 ± 0.08 ^a	31.18 ± 3.25 ^{bc}
RMB 20	0.62 ± 0.01 ^c	3.10 ± 0.08 ^{ab}	33.44 ± 0.56 ^b
RMB 30	0.57 ± 0.01 ^{de}	2.77 ± 0.08 ^c	39.42 ± 0.50 ^a

WAI, water absorption index; WSI, water solubility index.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

Table 6—TPC and antioxidant activity of legume-rice porridge powder.

Sample code	TPC (mg GAE/g sample)	DPPH (μ mol Trolox/g dry sample)	FRAP (μ mol FeSO ₄ /g dry sample)
R100	1.09 ± 0.08 ^g	0.21 ± 0.01 ^g	2.76 ± 0.04 ^g
RSB 10	2.91 ± 0.15 ^c	0.88 ± 0.04 ^c	13.8 ± 0.06 ^c
RSB 20	3.52 ± 0.26 ^b	2.41 ± 0.18 ^c	14.7 ± 0.13 ^b
RSB 30	4.37 ± 0.28 ^a	3.07 ± 0.23 ^a	15.6 ± 0.17 ^a
RMB 10	1.82 ± 0.12 ^f	0.41 ± 0.02 ^f	4.54 ± 0.12 ^f
RMB 20	2.16 ± 0.13 ^c	1.47 ± 0.09 ^d	7.69 ± 0.23 ^c
RMB 30	2.69 ± 0.17 ^d	2.55 ± 0.15 ^b	9.53 ± 0.17 ^d

TPC, total phenolics content; DPPH: DPPH radical scavenging activity; FRAP: Ferric reducing antioxidant power.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

11.1-fold higher, respectively, as compared with that of the control rice porridge powder. The results were similar to those of the FRAP assay. No correlation was found between the DPPH radical scavenging activity and the legume fortification level in the porridge powder. This may be because the legumes caused the differences in the structural features of many molecular components of the porridges, which could in turn affect the scavenging activity. The higher DPPH scavenging capacity and FRAP of the soybean-fortified porridge powder are most probably due to the higher content of phenolics such as isoflavones in soybean (Cho and others 2013).

Fat content and complexing index of porridge powder

The fat contents of different porridge powder are listed in Table 7. Mung bean-fortified porridge powder had significantly lower fat contents than the soybean-fortified porridge powder because mung bean exhibits lower fat content (Zhang and others 2013). As expected, the fat content of the porridge powder increased with an increase in the percentage of the legumes.

Table 7—Fat contents and complexing indices of legume-rice porridge powder.

Sample code	Fat content (% wt)	Complexing index (%)
R100	0.57 ± 0.03 ^g	—
RSB 10	1.43 ± 0.08 ^c	75.10 ± 0.13 ^c
RSB 20	2.74 ± 0.17 ^b	75.45 ± 0.18 ^b
RSB 30	4.95 ± 0.16 ^a	76.70 ± 0.24 ^a
RMB 10	0.84 ± 0.03 ^f	54.84 ± 0.12 ^d
RMB 20	1.03 ± 0.06 ^c	29.04 ± 0.11 ^c
RMB 30	1.25 ± 0.12 ^{cd}	15.42 ± 0.14 ^f

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

CI, which indicates the level of starch–lipid complexes and is related to the formation of starch–iodine complex (De Pilli and others 2011), of the porridge powder is also listed in Table 7. CI

of soybean-fortified porridge powder was in the range of 75.10% to 76.70%, while that of mung bean-fortified porridge powder was in the range of 15.42% to 54.84%. CI increased with an increase in the percentage of soybean but decreased with the more extensive addition of mung bean. This is probably because complexes formation is less likely to occur at low concentration of

fatty acids (Tang and Copeland 2007) due to the higher ratio of amylose content (about $31.6 \pm 0.7\%$) to lipid content of mung bean (Sandhu and Lim 2008). Many factors affect the formation of starch-lipid complexes such as the types of starch and lipids as well as the ratio of starch to lipids. In addition, some lipids tend to self-associate instead of forming starch-lipid complexes (Tang and

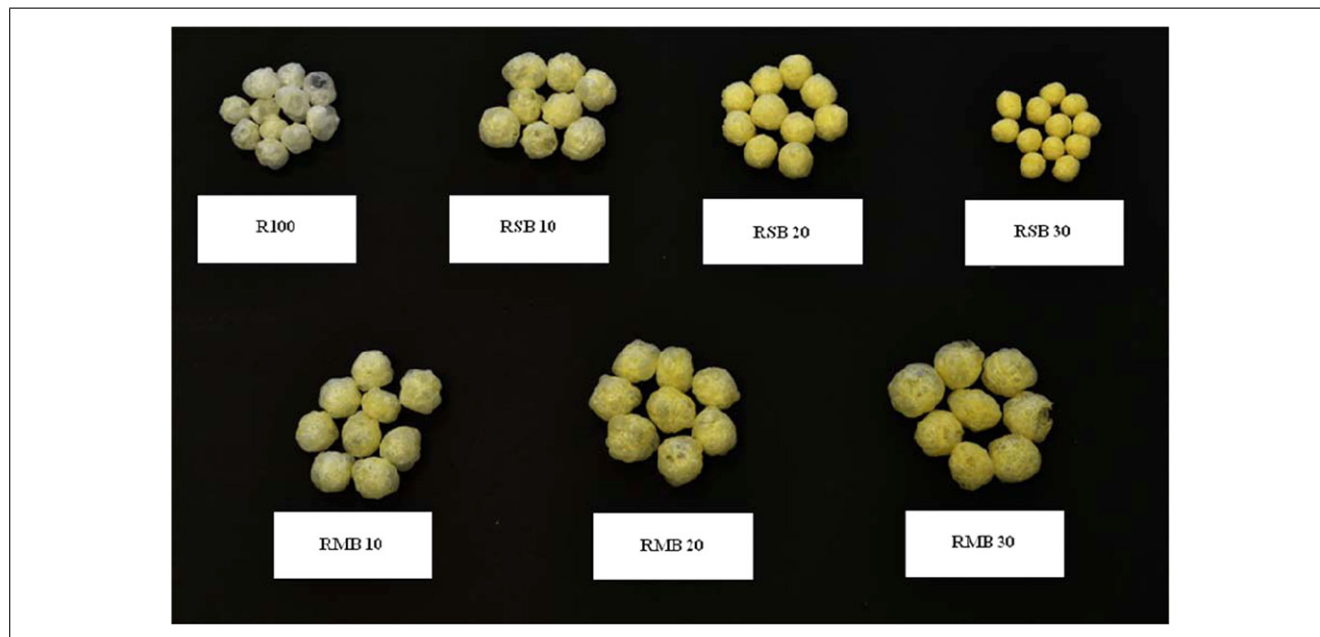


Figure 1—Photographs of legume-rice extrudates.

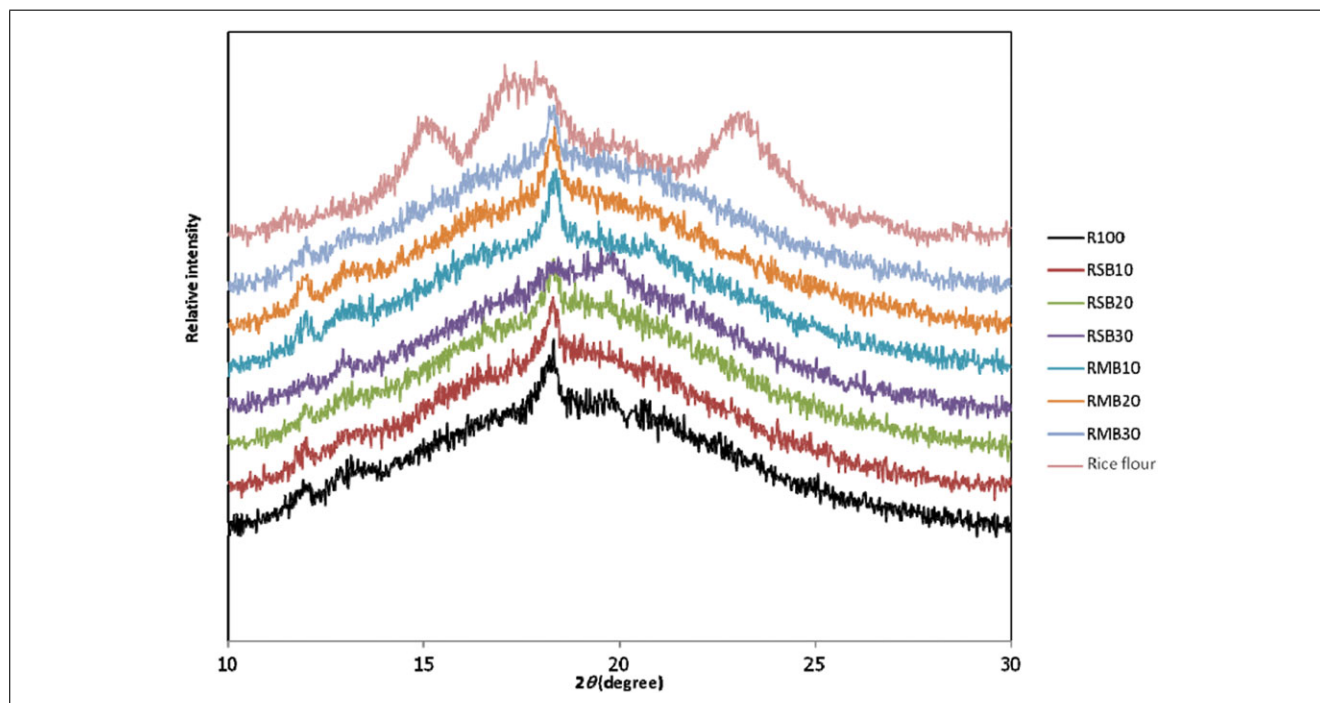


Figure 2—The A type X-ray diffraction patterns of legume-rice porridges. R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Copeland 2007), leading to the lower CI of mung bean-fortified porridge powder.

Complexes formation of starch (amylose) with lipids, which leads to a higher CI value, modifies the starch properties, leading to slower starch hydrolysis and reduced solubility in water (Tang and Copeland 2007). Amylose–lipid complexes have indeed been regarded as resistant starch and exhibit health benefits in terms of postprandial glycemic and insulinemic responses control (Hasjim and others 2013).

XRD patterns of porridge powder

XRD analysis was performed to indicate starch (amylose)–lipid complexes formation. The XRD patterns of rice flour and different porridge powder samples are presented in Fig. 2. Rice flour exhibited an A-type XRD pattern with the diffraction peaks at 15°, a doublet at 17° and 18°, and 23° (2 θ), which represents the general characteristics of cereals such as rice, waxy maize, and wheat (Wei and others 2011; Zhu and others 2011; Yang and others 2013). However, extrusion altered the structure of rice starch (from crystalline into amorphous structure; Wei and others 2011). For the rice porridge (R100), diffraction peaks at 15°, a doublet at 17° and 18°, and 23° (2 θ) disappeared; only one narrow peak at around 18.4° (2 θ) was observed. This indicated the changes in the crystalline structure of rice flour due to the extrusion, which contributed to the expansion of the extrudates and the porridge properties such as WAI and WSI. Soybean-fortified porridge powder exhibited different XRD patterns compared with rice porridge powder. When increasing the percentage of soybean, the peak intensity at around 18.4° (2 θ) decreased, indicating the loss of A-type crystallinity pattern of starch granules, which may be due to the formation of complexes between starch and lipids. In addition, the peaks shifted to around 20° (2 θ), which is a typical amylose–lipid complexes diffraction peak (Zhu and others 2011; Huang and others 2015).

The increase in CI of soybean-fortified porridge powder could also be used to support the presence of the amylose–lipid complexes, which was evidenced from the XRD patterns. Mung bean-fortified porridge powder nevertheless exhibited similar XRD pattern to the rice porridge powder with the peaks at 18.4° (2 θ). However, the formation of amylose–lipid complexes of mung bean-fortified porridge powder was still noted, with a weak peak at around 12° to 13° (2 θ). The result is similar to that reported by Derycke and others 2005.

Thermal property of porridge powder

Thermal property values of legume-rice porridge powder are presented in Table 8. The endothermic peak of the rice porridge powder (R100) was not observed at 60 to 80 °C, indicating the complete gelatinization of the rice starch. On the other hand, the soybean-fortified porridge powder exhibited endothermic transition peak, while mung bean-fortified porridge powder exhibited exothermic peak. Derycke and others 2005 reported an existence of an endothermic peak as a result of the melting of amorphous amylose–lipid complexes; the existence of the endothermic peak thus helped confirm the formation of such complexes in soybean-fortified samples. For the mung bean-fortified porridge powder, the exothermic peaks were probably the result of crystallization of starch–lipid complexes (Biliaderis and others 1986). T_o (onset temperature), T_p (peak temperature) and ΔH (transition enthalpy) of the soybean-fortified porridge powder were in the ranges of 98.68–108.47 °C, 101.17–113.83 °C and 10.78–21.68 J/g, respectively. For the mung bean-fortified porridge powder, T_o , T_p and

Table 8—Thermal property values of legume-rice porridge powder.

Sample code	T_o (°C)	T_p (°C)	ΔH (J/g)
R100	95.61 $\pm$ 0.41 ^f	99.50 $\pm$ 0.38 ^c	2.99 $\pm$ 0.08 ^g
RSB 10	98.68 $\pm$ 0.65 ^d	101.17 $\pm$ 0.52 ^d	10.78 $\pm$ 0.12 ^c
RSB 20	101.30 $\pm$ 0.52 ^b	105.50 $\pm$ 0.45 ^b	16.16 $\pm$ 0.15 ^b
RSB 30	108.47 $\pm$ 0.46 ^a	113.83 $\pm$ 0.69 ^a	21.68 $\pm$ 0.24 ^a
RMB 10	99.81 $\pm$ 0.37 ^c	102.67 $\pm$ 0.43 ^c	9.97 $\pm$ 0.07 ^d
RMB 20	97.08 $\pm$ 0.58 ^c	101.58 $\pm$ 0.32 ^d	7.17 $\pm$ 0.08 ^c
RMB 30	96.15 $\pm$ 0.40 ^{ef}	101.25 $\pm$ 0.38 ^d	3.14 $\pm$ 0.05 ^f

T_o , onset temperature; T_p , peak temperature; ΔH , transition enthalpy.

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

Different superscripts in the same column mean that the values are significantly different ($P < 0.05$).

Table 9—Pasting property of rice flour and legume-rice porridge powder.

Sample code	Peak viscosity (cP)	Trough viscosity (cP)	Final viscosity (cP)
R100	134	43	64
RSB 10	85	36	55
RSB 20	73	35	52
RSB 30	47	33	49
RMB 10	128	42	60
RMB 20	115	40	56
RMB 30	109	37	53
Rice flour	1339	1248	2336

R100: 100% broken rice; RSB 10: 90% broken rice + 10% soybean; RSB 20: 80% broken rice + 20% soybean; RSB 30: 70% broken rice + 30% soybean; RMB 10: 90% broken rice + 10% mung bean; RMB 20: 80% broken rice + 20% mung bean; RMB 30: 70% broken rice + 30% mung bean.

ΔH were in the ranges of 96.15–99.81 °C, 101.25–102.67 °C and 3.14–9.97 J/g, respectively. It is seen that the soybean-fortified porridge powder had higher values of T_p than the mung bean-fortified porridge powder. This is attributed to the higher degrees of gelatinization of the soybean-fortified samples. The higher degree of gelatinization resulted in more extensive disruption of the crystalline region of the starch granules (as shown in the XRD results) as well as in the lower peak viscosity. The formation of starch–lipid complexes affected T_p (De Pilli and other 2011). The peak temperature and transition enthalpy of all legume-fortified porridge powder were higher than those of the rice porridge powder. This is attributed to the formation of starch–lipid complexes due to the addition of legumes; the results corresponded to the CI results and XRD patterns. The transition enthalpy of the porridge powder increased with an increase in the percentage of soybean and mung bean. Bhatnagar and Hanna 1994 reported that the endothermic transitions between 107 and 112 °C may be attributed to the formation of complexes between amylose and lipids and related to the melting of amylose crystallites in the resistant starch (Adamu 2001).

Pasting property of porridge powder

Pasting property of the porridge powder is reported in Table 9. The peak, trough, final and setback viscosities of rice, and legume-rice porridge powder were much lower than those of the rice flour. Gelatinization of rice starch in the porridges during extrusion resulted in the lower viscosities as compared with those of the rice flour (Jongsutjarittam and Charoenrein 2014). The addition of soybean decreased the peak viscosity of the soybean-rice porridge powder. This is attributed to the lower fraction of amylose and

amylopectin (Sereewat and others 2015) upon incorporation of soybean. Soybean contains high protein and lipids, which might restrain the starch granules from hydration and swelling, resulting in the lower viscosity (Zhou and others 2007). Restricted swelling of starch granules subsequently decreased peak and final viscosities due to the formation of amylose-inclusion complexes (Putseys and other 2010). In the case of mung bean-rice porridge powder, the peak viscosity decreased when the mung bean content increased; this trend is in agreement with the results of Wu and others 2015. The observed pasting property confirmed that the addition of soybean and mung bean caused the changes of the starch structure of the porridge powder.

Conclusion

Fortification of rice porridge with either soybean or mung bean at different percentages to produce instant functional legume-rice porridge powder was investigated. The lightness and bulk density of the porridge powder decreased with an increase in the percentage of both legumes, while the greenness and yellowness of the legume-rice porridge powder increased. WAI of the legume-rice porridge powder was not significantly different from that of the rice porridge powder, except for the product with 30% mung bean, which possessed the lowest WAI. Addition of higher percentage of mung bean led to the porridge powder with higher WSI. WSI of the soybean-rice porridge powder was, on the other hand, lower than that of the mung bean-rice porridge powder. Soybean-blended porridge powder exhibited higher TPC, DPPH radical scavenging capacity, ferric reducing antioxidant power as well as amino acid and fat contents compared with the mung bean-blended porridge powder. An increase in the percentage of either legume led to an increase in the peak temperature and transition enthalpy. In both the cases of soybean and mung bean-blended porridge powder, amylose-lipid complexes formation was confirmed by the XRD patterns. CI increased with an increase in the percentage of soybean but decreased with the more extensive addition of mung bean. The addition of soybean and mung bean decreased the peak viscosity of the legume-rice porridge powder. In all cases, blending in 30% soybean resulted in the higher TPC, antioxidant activity, amino acid content, complexing index and level of amylose-lipid complexes formation. A study on the glycemic index of the legume-rice porridges should be done in the future to further validate the production of healthy rice porridges.

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References

- AACC. 2003. Approved methods of the American Association of Cereal Chemists. 10th ed. St. Paul, Minnesota: American Association of Cereal Chemists.
- Abete I, Parra D, Martinez JA. 2008. Energy-restricted diets based on a distinct food selection affecting the glycemic index induce different weight loss and oxidative response. *Clin Nutr* 27:545–551.
- Adamu BOA. 2001. Resistant starch derived from extruded corn starch and guar gum as affected by acid and surfactants: Structural characterization. *Starch-Stärke* 53:582–591.
- Allen KE, Carpenter CE, Walsh MK. 2007. Influence of protein level and starch type on an extrusion-expanded whey product. *Int J Food Sci Tech* 42:953–960.
- Anton AA, Fulcher RG, Arntfield SD. 2009. Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: effects of bean addition and extrusion cooking. *Food Chem* 113:989–996.
- Balistero DM, Rombaldi CV, Genovese MI. 2013. Protein, isoflavones, trypsin inhibitory and in vitro antioxidant capacities: comparison among conventionally and organically grown soybeans. *Food Res Int* 51:8–14.
- Benzie IFF, Strain JJ. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. *Anal Biochem* 239:70–76.
- Bhatnagar S, Hanna MA. 1994. Amylose-lipid complex formation during single screw extrusion of various corn starches. *Cereal Chem* 71:582–587.
- Biliaderis CG, Page CM, Maurice TJ, Juliano BO. 1986. Thermal characterization of rice starches: a polymeric approach phase transitions of granular starch. *J Agric Food Chem* 34:6–14.
- Brand-Williams W, Cuvelier ME, Berset C. 1995. Use of a free radical method to evaluate antioxidant activity. *LWT-Food Sci Technol* 28:25–30.
- Cho KM, Ha TJ, Lee YB, Seo WD, Kim JY, Ryu HW, Jeong SH, Kang YM, Lee JH. 2013. Soluble phenolics and antioxidant properties of soybean (*Glycine max* L.) cultivars with varying seed coat colors. *J Funct Foods* 5:1065–1076.
- da Silva EMM, Ascheri JLR, de Carvalho CWP, Takeiti CY, Berrios JDJ. 2014. Physical characteristics of extrudates from corn flour and dehulled carioca bean flour blend. *LWT-Food Sci Technol* 58:620–626.
- De Pilli T, Jouppila K, Ikonen J, Kansikas J, Derossi A, Severini C. 2008. Study on formation of starch-lipid complexes during extrusion-cooking of almond flour. *J Food Eng* 87:495–504.
- De Pilli T, Derossi A, Talja RA, Jouppila K, Severini C. 2011. Study of starch-lipid complexes in model system and real food produced using extrusion-cooking technology. *Innov Food Sci Emerg* 12:610–616.
- Derycke V, Vandeputte GE, Vermeylen R, De Man W, Goderis B, Koch MHJ, Delcour JA. 2005. Starch gelatinization and amylose-lipid interactions during rice parboiling investigated by temperature resolved wide angle X-ray scattering and differential scanning calorimetry. *J Cereal Sci* 42:334–343.
- Devi MKA, Gondi M, Sakthivelu G, Giridhar P, Rajasekaran T, Ravishankar GA. 2009. Functional attributes of soybean seeds and products, with reference to isoflavone content and antioxidant activity. *Food Chem* 114:771–776.
- Ding Q-B, Ainsworth P, Tucker G, Marson H. 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *J Food Eng* 66:283–289.
- Hagen SR, Frost B, Augustin J. 1989. Precolumn phenylisothiocyanate derivatization and liquid-chromatography of amino-acids in food. *J Assoc Off Anal Chem* 72:912–916.
- Hagenimana A, Ding X, Fang T. 2006. Evaluation of rice flour modified by extrusion cooking. *J Cereal Sci* 43:38–46.
- Hasjim J, Ai Y, Jane J-L. 2013. Novel applications of amylose-lipid complex as resistant starch type 5. In: Shi Y-C, Maningat CC, editors. *Resistant starch: sources, applications and health benefits*. Chichester, United Kingdom: John Wiley & Sons, Ltd. p 79–94.
- Huang X, Cai W, Xu B. 2014. Kinetic changes of nutrients and antioxidant capacities of germinated soybean (*Glycine max* L.) and mung bean (*Vigna radiata* L.) with germination time. *Food Chem* 143:268–276.
- Huang J, Shang Z, Man J, Liu Q, Zhu C, Wei C. 2015. Comparison of molecular structures and functional properties of high-amylose starches from rice transgenic line and commercial maize. *Food Hydrocolloids* 46:172–179.
- Jongsutjarittam O, Charoenrein S. 2014. The effect of moisture content on physicochemical properties of extruded waxy and non-waxy rice flour. *Carbohydr Polym* 114:133–140.
- Kim SH, Yu BR, Chung IM. 2015. Changes in the contents and profiles of selected phenolics, soyasapogenols, tocopherols, and amino acids during soybean-rice mixture cooking: electric rice cooker vs electric pressure rice cooker. *Food Chem* 176:45–53.
- King RA, Noakes M, Bird AR, Morell MK, Topping DL. 2008. An extruded breakfast cereal made from a high amylose barley cultivar has a low glycemic index and lower plasma insulin response than one made from a standard barley. *J Cereal Sci* 48:526–530.
- Marti A, Seetharaman K, Pagani MA. 2010. Rice-based pasta: A comparison between conventional pasta-making and extrusion-cooking. *J Cereal Sci* 52:404–409.
- Moraru CI, Kokini JL. 2003. Nucleation and expansion during extrusion and microwave heating of cereal foods. *Compr Rev Food Sci F* 2:147–165.
- Naivikul O, D'Appolonia BL. 1978. Comparison of legumes and wheat flour carbohydrates. I. Sugar analysis. *Cereal Chem* 55:913–918.
- Niamnuy C, Nachaisin M, Laohavanich J, Devahastin S. 2011. Evaluation of bioactive compounds and bioactivities of soybean dried by different methods and conditions. *Food Chem* 129:899–906.
- Nyombaire G, Siddiq M, Dolan KD. 2011. Physico-chemical and sensory quality of extruded light red kidney bean (*Phaseolus vulgaris* L.) porridge. *LWT-Food Sci Technol* 44:1597–1602.
- Oikonomou NA, Krokida MK. 2012. Water absorption index and water solubility index prediction for extruded food products. *Inter J Food Prop* 15:157–168.
- Pastor-Cavada E, Drago SR, González RJ, Juan R, Pastor JE, Alai M, Vioque J. 2011. Effects of the addition of wild legumes (*Lathyrus annuus* and *Lathyrus clymenum*) on the physical and nutritional properties of extruded products based on whole corn and brown rice. *Food Chem* 128:961–967.
- Putseys JA, Lamberts L, Delcour JA. 2010. Amylose-inclusion complexes: Formation, identity and physico-chemical properties. *J Cereal Sci* 51:238–247.
- Sandhu KS, Lim S-T. 2008. Digestibility of legume starches as influenced by their physical and structural properties. *Carbohydr Polym* 71:245–252.
- Sereewat P, Suthipinittham C, Sumathaluk S, Puttanlek C, Uttapap D, Rungsardthong V. 2015. Cooking properties and sensory acceptability of spaghetti made from rice flour and defatted soy flour. *LWT-Food Sci Technol* 60:1061–1067.
- Sharif MK, Rizvi SSH, Paraman I. 2014. Characterization of supercritical fluid extrusion processed rice-soy crisps fortified with micronutrients and soy protein. *LWT-Food Sci Technol* 56:414–420.
- Singleton VL, Rossi JA. 1965. Colorimetry of total phenolics with phosphomolybdic phosphotungstic acid reagents. *Am J Enol Viticult* 16:144–158.
- Srikao K, Sopade PA. 2010. Functional properties and starch digestibility of instant Jasmine rice porridges. *Carbohydr Polym* 82:952–957.
- Tang MC, Copeland L. 2007. Analysis of complexes between lipids and wheat starch. *Carbohydr Polym* 67:80–85.
- Wang YY, Ryu G-H. 2013. Physicochemical and antioxidant properties of extruded corn grits with corn fiber by CO₂ injection extrusion process. *J Cereal Sci* 58:110–116.
- Wei C, Qin F, Zhou W, Xu B, Chen C, Chen Y, Wang Y, Gu M, Liu Q. 2011. Comparison of the crystalline properties and structural changes of starches from high-amylose transgenic rice and its wild type during heating. *Food Chem* 128:645–652.
- Wu F, Meng Y, Yang N, Tao H, Xu X. 2015. Effects of mung bean starch on quality of rice noodles made by direct dry flour extrusion. *LWT-Food Sci Technol* 63:1199–1205.

- Yang Z, Gu Q, Hemar Y. 2013. In situ study of maize starch gelatinization under ultra-high hydrostatic pressure using X-ray diffraction. *Carbohydr Polym* 97:235–238.
- Zhang X, Shang P, Qin F, Zhou Q, Gao B, Huang H, Yang H, Shi H, Yu L. 2013. Chemical composition and antioxidative and anti-inflammatory properties of ten commercial mung bean samples. *LWT-Food Sci Technol* 54:171–178.
- Zhou Z, Robards K, Helliwell S, Blanchard C. 2007. Effect of the addition of fatty acids on rice starch properties. *Food Res Int* 40:209–214.
- Zhu L-J, Liu Q-Q, Wilson JD, Gu M-H, Shi Y-C. 2011. Digestibility and physicochemical properties of rice (*Oryza sativa* L.) flours and starches differing in amylose content. *Carbohydr Polym* 86:1751–1759.
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Output จากโครงการวิจัยที่ได้รับทุนจากสกว.

1. ผลงานตีพิมพ์ในวารสารวิชาการนานาชาติ

Mayachiew, P., Charunuch, C. and Devahastin, S. 2015. Physicochemical and Thermal Properties of Extruded Instant Functional Rice Porridge Powder as Affected by the Addition of Soybean or Mung Bean. Journal of Food Science. Vol. 80, Nr. 12, E2782-E2791.

2. การนำผลงานวิจัยไปใช้ประโยชน์

- เชิงพาณิชย์ -
- เชิงนโยบาย -
- เชิงสาธารณะ -
- เชิงวิชาการ: สร้างนักวิจัยใหม่ 1 คน

3. อื่นๆ -