

## Comparative study of physicochemical, nutritional and functional properties of whole and defatted legume flours

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### Abstract

The physicochemical, functional and nutritional properties of whole and defatted legume flours in five types of legumes [kidney bean (*Phaseolus vulgaris*), mung bean (*Vigna radiata*), pigeon pea (*Cajanus cajan*), soybean and black soybean (*Glycine max*)] were determined. Ash, protein and carbohydrate contents in defatted legume flours were higher than in whole legume flours. Bulk density (BD), water adsorption index (WAI) and water solubility index (WSI) of whole and defatted legume flours ranged from 0.43 g/mL - 0.92 g/mL, 2.04 g/g - 5.01 g/g and 20.67 g/100 g - 46.93 g/100 g, respectively. The water and oil absorption capacity of defatted black soybean flour and defatted soybean flour had improved ( $p < 0.05$ ) after the oil extraction process. Defatted legume flours exhibited higher emulsifying activity (EA) compared to whole legume flours ( $p < 0.05$ ), but lower emulsifying stability (ES) which ranged from 88.90% - 94.92% and 94.32% - 99.08%, respectively. Flour concentrations at 5 g/100 mL showed the highest foaming capacity (FC), with reduced foaming stability (FS) across time. Pearson correlation coefficient revealed a protein had significant relationship between physicochemical and functional properties of whole and defatted legume flours. The Pearson correlation coefficient revealed that protein positively correlated with most physicochemical and functional properties of whole and defatted legume flours, while carbohydrate only had a strong positive correlation with BD and WAI.

## 1. Introduction

Legumes are dicotyledonous seed plants that belong to the *Leguminosae* family. Interest in their utilization as food has grown tremendously due to consumers changing perception of animal-based products and veganism. An increase in food consumption due to the rise in world population has urged for optimum utilization of food crops too. The versatility of legumes has provided an alternative source for new food product development (Tiwari *et al.*, 2011). The ability of legume crops to fix the atmospheric nitrogen of soil had enhanced the productivity of the cropping system by increasing crop yield. They are also recognized as an environmentally sustainable crop due to their low

consumption of fertilizer, pesticide and irrigation (Reddy *et al.*, 2013).

Protein contents in legumes (17 g/100 g to 40 g/100 g) are comparable with animal protein, and they are 2- 3 times higher than cereal grains (3 g/100 g to 7 g/100 g). The amino acids profile provides essential nutrient compositions even though most legumes lack sulphur-containing amino acids. They also provide complex carbohydrates, dietary fibre, vitamins and minerals (Tharanathan and Mahadevamma, 2003). Many studies reported that legume enrichment in foods improves overall nutritional food quality (Anton *et al.*, 2009; Bouasla *et al.*, 2017) and the presence of polyphenols in

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legumes also act as antioxidants (Boateng *et al.*, 2008). However, legumes do contain anti-nutritional properties such as lectins, protease inhibitors and non-antnutritional compounds, angiotensin I-converting enzyme (ACE) inhibitors. They can be easily eliminated during processing, as legumes are not eaten as raw.

Legumes play important role in regulating blood sugar and lipid level in diabetic patients and healthy people due to their very low glycemic index (Rizkalla *et al.*, 2002). They also stimulate greater weight loss and regulate body weight by improving satiety. Incorporation of legumes into food products such as snack bars (Ramírez-Jiménez *et al.*, 2018), low-fat mayonnaise (Nikzade *et al.*, 2012), patty (Summo *et al.*, 2016), pasta (Bouasla *et al.*, 2017) and others (Jiménez-Martínez *et al.*, 2003; Turfani *et al.*, 2017) have also been studied. Supplementation of legumes in fermented beverages and yoghurt-like products has shown great lactic acid bacteria viability with a promising source of prebiotics (Zare *et al.*, 2011; Wang *et al.*, 2018). These studies demonstrated the versatility of legumes in various types of food production and provide foods with a better nutritional profile in the market.

The development of legume-based products will require knowledge of the chemical composition, and physicochemical and functional properties of legumes. These factors will influence the food system during processing, storage, cooking and consumption (Kaur and Singh, 2006). The profile of a legume-based food system is directly affected by water absorption, binding, swelling, viscosity, dispersibility and hydration properties (McWatters, 1983). The functional properties of legumes are also crucial for food texture and organoleptic characteristics. Thus, it is important to study its functional and physicochemical properties to efficiently utilize legumes in food products that are accepted by consumers.

This work studied the physicochemical, functional and nutritional properties of whole and defatted legumes which can provide insight into their use as an ingredient for food product development. It is also crucial to observe the changes in the legume flour properties after the defatting process by solvent extraction. The relationship between legume flours properties (functional and physicochemical) and nutritional values were also investigated by using the Pearson correlation coefficient.

## 2. Materials and methods

### 2.1 Materials

A total of five legume seeds namely, kidney bean (*Phaseolus vulgaris*), mung bean (*Vigna radiata*), pigeon pea (*Cajanus cajan*), soybean and black soybean

(*Glycine max*) were purchased from a local supermarket in Serdang, Selangor, Malaysia. Legumes seeds were washed thoroughly and air-dried at 40°C overnight. Dried legume seeds were stored at 4°C until processed.

### 2.2 Whole and defatted legume flour preparation

Whole legume flours were prepared by finely grinding the seeds in Waring blender (Waring, New Hartford, USA) to pass through a 0.21 mm sieve. The seeds were ground into course size prior to defatting, extraction was carried out for 1 hr under constant magnetic stirring (seed/n-hexane ratio: 1:3) (Ugwuona and Suwaba, 2013). The solvent was discarded from seeds by filtration, and extraction was repeated twice. Defatted seeds were dried in a fume hood overnight to remove the remaining hexane in the samples. Defatted course seeds were further processed into defatted legume flours by the same method mentioned above. Flours were packed in a zip lock polyethylene bag and stored at 4°C until used.

### 2.3 Proximate composition

The moisture, ash, fat, protein and fibre contents of legume flours were estimated according to the AOAC method (2005). Available carbohydrate was calculated by difference.

### 2.4 Physicochemical properties

#### 2.4.1 Bulk density

Bulk density was determined by the method by Du *et al.* (2014). Legume flours were gently transferred into a 10 mL graduated measuring cylinder. The bottom of the cylinder was gently tapped several times on the laboratory bench until there was no further diminution and the sample level was observed after it was filled up to the 10 mL mark. The results were expressed in g/mL.

#### 2.4.2 Water absorption index and water solubility index

The water absorption index (WAI) and water solubility index (WSI) of the legume flours were carried out following the method from Du *et al.* (2014). The legume flour sample (2.5 g) was dispersed in 30 mL distilled water and cooked at 90°C for 15 mins in a water bath (Memmert, Schwabach, Germany). The cooked paste was cooled to room temperature (23°C), transferred to pre-weighed centrifuge tubes, and then centrifuged at 3000×g for 10 mins (5810R, Eppendorf, Hamburg, Germany). The supernatant was decanted into a tared evaporating dish for determination of its solid content, while the sediment was weighed. The weight of dry solids was obtained by evaporating the supernatant at 105°C overnight (FD 115, Binder, Tuttlingen, Germany).

WAI and WSI were calculated based on the equations below:

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Weight of flour sample}}$$

$$\text{WSI (g/100 g)} = \frac{\text{Weight of dissolved solids in supernatant} \times 100}{\text{Weight of flour sample}}$$

## 2.5 Functional properties

### 2.5.1 Water and oil absorption capacities

Water and oil absorption of legume flours were determined as described by Kaur and Singh (2005). Results were expressed as g of water or oil bound per gram of the sample on a dry basis.

### 2.5.2 Emulsion activity and stability

The method described by Kaur and Singh (2005) was used to determine the emulsion properties of legume flours. Emulsion activity and emulsion stability were expressed as per cent of emulsified layer by legume flour and the per cent of emulsifying activity remained after heated, respectively.

### 2.5.3 Least gelation properties

A method from Kaushal *et al.* (2012) was used to determine the least gelation concentration (LGC) of legume flours. For each type of legumes flours, test tubes containing suspensions of 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 g/100 mL in 5 mL distilled water were heated in boiling water for 1 hr (Memmert, Schwabach, Germany). The suspensions were immediately cooled down by running tap water and further cooled at 4°C for another 2 hrs. LGC was identified based on the concentrations above which the samples did not fall down or slip when the tubes were inverted.

## 2.5.4 Foaming capacity and foaming stability

The foaming properties of legume flours were determined following methods described by Du *et al.* (2014). For foaming capacity, 50 mL of a 3 g/100 mL mixture of legume flours and distilled water were homogenized at 10,000 rpm for 3 mins. A graduated cylinder was used to promptly transfer the mixture and the homogenizer cup was rinsed with 10 mL of distilled water. The volume of the mixture was recorded before and after homogenization and expressed as the % of volume increased due to whipping. Foaming stability was observed based on the foam volume changes at intervals of 20, 40, 60 and 120 mins of storage. The effect of legume flours concentration on foaming was studied by homogenized 2, 5, 7 and 10 g/100 mL of samples as previously described, and expressed as per cent volume increases after whipping.

## 2.6 Statistical analysis

The significant differences in the mean values ( $n = 3$ ) were analyzed by ANOVA followed by Tukey's HSD *posthoc* test ( $p < 0.05$ ) using Minitab 17 (Minitab Inc., State College, PA, USA). All data were presented as mean value  $\pm$  standard deviation. Pearson correlation coefficient was conducted to observe the relationship between legume flour properties and its nutritional values.

## 3. Results and discussion

### 3.1 Proximate analysis

The nutritional compositions of legume flours were presented in Table 1. The moisture, ash, protein, fat and carbohydrate contents ranged from 9.63% to 11.31%,

Table 1. Proximate compositions of whole and defatted legume flours

Legume Flour	Moisture (%)	Ash (%)	Protein (%) <sup>#</sup>	Fat (%)	Crude Fibre (%)	Carbohydrate (%)
WKB	10.82 $\pm$ 0.27 <sup>a</sup>	3.28 $\pm$ 0.05 <sup>c</sup>	17.11 $\pm$ 0.17 <sup>c</sup>	0.96 $\pm$ 0.21 <sup>c</sup>	2.18 $\pm$ 0.51 <sup>c</sup>	64.66 $\pm$ 0.60 <sup>a,b</sup>
WMB	9.63 $\pm$ 0.27 <sup>b</sup>	3.44 $\pm$ 0.20 <sup>c</sup>	23.33 $\pm$ 2.54 <sup>c,d</sup>	1.23 $\pm$ 0.22 <sup>f</sup>	2.45 $\pm$ 0.41 <sup>c</sup>	59.91 $\pm$ 2.56 <sup>b</sup>
WSB	11.17 $\pm$ 0.29 <sup>a</sup>	4.62 $\pm$ 0.05 <sup>c</sup>	30.51 $\pm$ 0.91 <sup>b</sup>	21.72 $\pm$ 0.28 <sup>a</sup>	3.59 $\pm$ 0.02 <sup>b,c</sup>	28.38 $\pm$ 1.23 <sup>d</sup>
WBS	11.31 $\pm$ 0.27 <sup>a</sup>	4.85 $\pm$ 0.04 <sup>c</sup>	40.72 $\pm$ 0.47 <sup>a</sup>	20.16 $\pm$ 0.21 <sup>b</sup>	3.26 $\pm$ 0.30 <sup>c,d</sup>	19.69 $\pm$ 1.04 <sup>e</sup>
WPP	10.82 $\pm$ 0.27 <sup>a</sup>	3.36 $\pm$ 0.10 <sup>c</sup>	17.10 $\pm$ 1.49 <sup>c</sup>	1.94 $\pm$ 0.01 <sup>c</sup>	0.80 $\pm$ 0.12 <sup>f</sup>	65.99 $\pm$ 1.41 <sup>a</sup>
DKB	8.91 $\pm$ 0.52 <sup>b,c</sup>	3.88 $\pm$ 0.19 <sup>d</sup>	17.69 $\pm$ 1.21 <sup>d,e</sup>	0.99 $\pm$ 0.05 <sup>f</sup>	2.58 $\pm$ 0.10 <sup>d,e</sup>	65.94 $\pm$ 1.12 <sup>a</sup>
DMB	8.38 $\pm$ 0.14 <sup>c</sup>	4.19 $\pm$ 0.17 <sup>d</sup>	23.82 $\pm$ 0.17 <sup>c</sup>	0.96 $\pm$ 0.19 <sup>f</sup>	3.18 $\pm$ 0.19 <sup>c,d</sup>	59.47 $\pm$ 0.12 <sup>b</sup>
DSB	8.23 $\pm$ 0.23 <sup>c</sup>	5.33 $\pm$ 0.01 <sup>b</sup>	40.21 $\pm$ 0.93 <sup>a</sup>	7.44 $\pm$ 0.55 <sup>c</sup>	4.04 $\pm$ 0.18 <sup>b</sup>	34.75 $\pm$ 1.31 <sup>c</sup>
DBS	7.17 $\pm$ 0.29 <sup>d</sup>	5.87 $\pm$ 0.04 <sup>a</sup>	45.43 $\pm$ 5.09 <sup>a</sup>	6.25 $\pm$ 0.19 <sup>d</sup>	4.99 $\pm$ 0.09 <sup>a</sup>	30.30 $\pm$ 5.29 <sup>c,d</sup>
DPP	8.31 $\pm$ 0.33 <sup>c</sup>	3.31 $\pm$ 0.01 <sup>c</sup>	19.35 $\pm$ 0.43 <sup>c,d,e</sup>	1.11 $\pm$ 0.04 <sup>f</sup>	1.22 $\pm$ 0.12 <sup>f</sup>	66.70 $\pm$ 0.54 <sup>a</sup>

<sup>#</sup>Total nitrogen  $\times$  6.25.

Values are presented as mean $\pm$ SD of triplicate analyses. Values with different superscript within the same column are significantly different ( $P < 0.05$ ) by Tukey's Test. WKB: whole kidney bean, WMB: whole mung bean, WSB: whole soybean, WBS: whole black soybean, WPP: whole pigeon pea, DKB: defatted kidney bean, DMB: defatted mung bean, DSB: defatted soybean, DBS: defatted black soybean, DPP: defatted pigeon pea

3.28% to 4.85%, 17.11% to 40.72%, 1.23% to 21.72%, 0.80% to 3.59%, and 19.69% to 65.99%, respectively for whole legume flours. The values obtained were compared with other studies with slight variations (Siddiqi *et al.*, 2010; Kaushal *et al.*, 2012; Du *et al.*, 2014). The moisture, ash, protein, fat and carbohydrate contents of defatted legume flours were between 7.17% to 8.91%, 3.31% to 5.33%, 17.69% to 45.43%, 0.96% to 7.44%, 1.22% to 4.99%, and 30.30% to 66.70%, respectively. Defatted legume flours contained lower moisture content than whole legume flours due to the overnight drying process after oil extraction from the seed. Maintaining moisture at a lower level ( $\leq 12\%$ ) is crucial to avoid microbial growth and helps prolong flour's shelf life. Fat content in all legume flours had reduced significantly ( $p < 0.05$ ) after solvent extraction, except for defatted mung bean (DMB) flour. Fat removal in the flours can prolong its storage stability, as the high content of fat in whole flours (soybean and black soybean) are prone to hydrolytic and oxidative rancidity. The reduction of moisture and fat contents in defatted legume flours has allowed the relation proportion of other nutritional compositions to be increased, resulting in a more concentrated amount of minerals, protein, fibre and carbohydrates. Variation in nutritional properties among the types of legume flours is largely attributed to genetics, varieties, and growth environment (Kaur and Singh, 2007).

### 3.2 Physicochemical properties

Bulk density values of whole legume flours and defatted legume flours varied from 0.43 g/mL to 0.83 g/mL and 0.59 g/mL to 0.92 g/mL, respectively (Table 2). Significant increment in bulk density ( $p < 0.05$ ) of all legume flours after defatting observed this sequence:

DSB (defatted soybean) < DBS (defatted black soybean) < DPP (defatted pigeon pea) < DKB (defatted kidney bean) < DMB. Adebowale *et al.* (2005) reported an increase in bulk density values upon defatting flours from six *Mucuna* species. Du *et al.* (2014) reported that the bulk density of 10 types of the whole legume flours ranged from 0.543 g/mL to 0.816 g/mL, which was comparable with the results obtained in this study. Denser legume flours were observed prior to defatting resulting in increased bulk density values. The high bulk density of flours especially in DMB flour is favourable as a good thickener agent (Adebowale *et al.*, 2005).

The water absorption index (WAI) measures the volume of starch after swelling in excess water, maintaining the integrity of starch in aqueous dispersion (Qi *et al.*, 2019). Meanwhile, the water solubility index (WSI) is related to the presence of soluble molecules. WAI and WSI are important due to their hydrophilic/hydrophobic nature for dough-type food formulation and beverage applications (Kadan *et al.*, 2003). WAI and WSI ranged from 2.04 g/g to 5.01 g/g and 20.80 g/100 g to 46.80 g/100 g for the whole legume flours, and from 2.42 g/g to 4.68 g/g, and 16.13 g/100 g to 46.93 g/100 g for defatted legume flours, respectively (Table 2). High WAI values in WKB (whole kidney bean), WMB (whole mung bean), WPP (whole pigeon pea), DKB, DMB and DPP flours are reflected by high carbohydrate content in the flours. The WAI of legume flours were higher than the rice flour (2.433 g/g), and comparable with taro and pigeon pea flour, 4.286 g/g and 6.013 g/g respectively (Kaushal *et al.*, 2012).

WSI in different chickpea cultivars has been reported with values ranging from 20.75 g/100 g to 22.89 g/100 g (Kaur and Singh, 2005), while Du *et al.* (2014) had

Table 2. Physicochemical and functional properties of whole and defatted legume flours

Legume Flour	Physicochemical properties			Functional properties			
	Bulk density (g/mL)	WAI (g/g)	WSI (g/100 g)	WAC (g/g)	OAC (g/g)	EA(%)	ES(%)
WKB	0.70±0.01 <sup>d</sup>	4.68±0.09 <sup>a,b</sup>	18.67±1.40 <sup>e,f</sup>	1.16±0.00 <sup>c</sup>	0.87±0.01 <sup>b,c,d</sup>	51.67±1.15 <sup>d,e</sup>	99.08±0.99 <sup>a</sup>
WMB	0.83±0.00 <sup>c</sup>	5.01±0.56 <sup>a</sup>	24.93±0.23 <sup>c</sup>	0.61±0.01 <sup>c</sup>	0.71±0.01 <sup>d</sup>	49.97±2.04 <sup>c</sup>	98.72±2.22 <sup>a,b</sup>
WSB	0.43±0.00 <sup>h</sup>	2.15±0.07 <sup>c</sup>	43.20±0.00 <sup>b</sup>	1.19±0.04 <sup>c</sup>	0.98±0.09 <sup>b</sup>	54.76±2.12 <sup>d</sup>	98.13±0.07 <sup>a,b,c</sup>
WBS	0.45±0.01 <sup>g</sup>	2.04±0.04 <sup>c</sup>	21.60±1.06 <sup>d</sup>	1.33±0.10 <sup>b</sup>	0.95±0.03 <sup>b,c</sup>	54.02±0.97 <sup>d,e</sup>	96.37±0.16 <sup>a,b,c</sup>
WPP	0.72±0.01 <sup>d</sup>	4.04±0.04 <sup>c</sup>	46.80±0.69 <sup>a</sup>	0.85±0.0 <sup>d</sup>	0.81±0.04 <sup>b,c,d</sup>	52.49±0.89 <sup>d,e</sup>	94.32±0.95 <sup>c,d,e</sup>
DKB	0.86±0.00 <sup>b</sup>	4.66±0.12 <sup>a,b</sup>	17.60±0.80 <sup>f</sup>	1.23±0.03 <sup>b,c</sup>	0.95±0.05 <sup>b,c</sup>	69.33±1.53 <sup>b</sup>	91.73±1.58 <sup>d,e,f</sup>
DMB	0.92±0.00 <sup>a</sup>	4.68±0.23 <sup>a,b</sup>	25.33±0.23 <sup>c</sup>	0.64±0.03 <sup>c</sup>	0.80±0.04 <sup>c,d</sup>	65.33±0.58 <sup>b,c</sup>	90.67±0.83 <sup>e,f</sup>
DSB	0.59±0.01 <sup>f</sup>	3.17±0.06 <sup>d</sup>	41.33±0.83 <sup>b</sup>	1.61±0.01 <sup>a</sup>	1.37±0.13 <sup>a</sup>	76.67±2.52 <sup>a</sup>	88.90±1.36 <sup>f</sup>
DBS	0.61±0.01 <sup>e</sup>	2.42±0.02 <sup>c</sup>	46.93±0.61 <sup>a</sup>	1.70±0.01 <sup>a</sup>	1.26±0.02 <sup>a</sup>	62.71±1.53 <sup>c</sup>	94.92±2.25 <sup>b,c,d</sup>
DPP	0.85±0.01 <sup>b</sup>	4.16±0.02 <sup>b,c</sup>	20.67±0.61 <sup>d,e</sup>	0.88±0.01 <sup>d</sup>	0.86±0.05 <sup>b,c,d</sup>	54.35±0.57 <sup>d,e</sup>	91.99±0.71 <sup>d,e,f</sup>

Values are presented as mean±SD of triplicate analyses. Values with different superscript within the same column are significantly different ( $P < 0.05$ ) by Tukey's Test. WKB: whole kidney bean, WMB: whole mung bean, WSB: whole soybean, WBS: whole black soybean, WPP: whole pigeon pea, DKB: defatted kidney bean, DMB: defatted mung bean, DSB: defatted soybean, DBS: defatted black soybean, DPP: defatted pigeon pea, WAI: Water absorption index, WSI: Water solubility index, WAC: Water absorption capacity, OAC: Oil absorption capacity, EA: Emulsion activity, ES: Emulsion stability.

varied WSI values (19.44 – 26.15 g/100 g) from different types of legume flours. These values reported by earlier studies were comparable with the data obtained, except for WSB (43.20 g/100 g), WPP (46.80 g/100 g), DSB (41.33 g/100 g) and DBS (46.93 g/100 g). DBS flour showed a significant increase ( $p < 0.05$ ) in WSI compared to whole black soybean (WBS) flour. Conversely, the defatted process had adversely affected the chemical composition in DPP with a drastic reduction of WSI ( $p < 0.05$ ). Normally, the solubility of molecules will be reduced by the rearrangement of less stable protein tertiary structure, and the formation of amylose-lipid and protein-starched complexes during the heating process (Nelles *et al.*, 2003; Herrero *et al.*, 2012). However, it is unclear how solvent extraction can affect molecules solubility, particularly in DPP, and further investigation is necessary.

### 3.3 Functional properties

Water absorption capacity (WAC) of whole and defatted legume flours ranged from 0.61 g/g to 1.33 g/g and 0.64 g/g to 1.70 g/g, respectively (Table 2). Increased WAC has been observed in all defatted legume flours as compared with the whole legume flours, but the values were insignificant ( $p > 0.05$ ) in DKB, DMB and DPP flours. The water-binding sites on the side chain groups of protein units have been exposed during the defatting process, resulting in better WAC in defatted legume flours, with a similar observation reported by Adebawale *et al.* (2005). Variation in WAC between legume flours was due to the quantity of hydrophilic carbohydrates, presence of non-starch components (e.g. mucilage), as well as protein content and its structure (Kaur and Singh, 2007; Aboubakar *et al.*, 2008). WAC plays an important role in product characteristics, such as starch retrogradation, product moistness, sensory and staling. Syneresis or also known as wheying-off is a common defect that occurred during the storage of yoghurt, smoothies and desserts. Introducing food ingredients with high WAC is helpful for colloidal foods, which helps in reducing syneresis by providing enough water retention in the food system.

Oil absorption capacity (OAC) of whole and defatted legume flours ranged from 0.71 g/g to 0.98 g/g and 0.80 g/g to 1.37 g/g, respectively (Table 2). Removal of oil in legume flours significantly improved the OAC in DSB and DBB flours ( $p < 0.05$ ). An increase in protein and carbohydrate percentage in defatted legume flours suggested better OAC. Presence of non-polar side chains, which binds the hydrocarbon side chains of oil among the flours would explain differences in the oil binding capacity among the flours (Adebawale and Lawal, 2004). Several studies on legume flours have

shown an acceptable range of OAC with the data obtained (Kaur and Singh, 2005; Du *et al.*, 2014; Gupta *et al.*, 2018). Flours with high OAC help improve mouth feel, retain flavours in the food products and reduce fat losses of extended meat products (Wani *et al.*, 2013; Kaur *et al.*, 2015).

Emulsifying activity (EA) shows the capacity of proteins to aid the development of emulsion. Proteins act as emulsifiers by forming a film or skin around oil droplets dispersed in an aqueous medium, thereby, preventing structural changes such as coalescence, creaming, flocculation or sedimentation. Some types of polysaccharides too can assist in EA by increasing the viscosity of the system (Dickinson, 2009). EA for whole legume flours were less than 55%, and their activity increased significantly ( $p < 0.05$ ) after defatting for DBS, DMB, DKB and DSB with increments at 8%, 15%, 17% and 21%, respectively (Table 2). Legume flours in this study showed comparable EA to other bean flours (45.6% to 60.5%) as reported by Siddiq *et al.* (2010). In view of better EA performance in defatted legume flour than its respective whole legume flours, they can be used as ingredients in processed bakeries and meat products, and as a stabilizing agent in colloidal foods.

Emulsifying stability (ES) of whole legume flours was from 94% to 99%, however lower ES values were observed in defatted legume flours ranging from 88% to 94% with significant differences ( $p < 0.05$ ) in DKB, DMB and DSB (Table 2). ES measures the ability of the emulsion to resist stress and changes to its structure over a defined time period (Boye *et al.*, 2010). Although higher EA values were recorded on defatted legume flours than on whole legume flours, defatted legume flours failed to maintain the ES after being heated at 85° C for 15 mins. These findings are contradicted by some studies, showing better ES performance after flours were defatted (Jitngarmkusol *et al.*, 2008; Aloba *et al.*, 2009).

The least gelation concentration (LGC) measures the ability of flour to form a gel at the lowest concentration. LGC for various legume flours ranged from 8 g/100 mL to 18 g/100 mL for the whole legume flours, while for defatted legume flours, they ranged from 8 g/100 mL to 14 g/100 mL (Table 3). LGC of DSB and DBB flour had improved to 14 g/100 mL and 8 g/100 mL respectively, as responded to the rise of protein and carbohydrate contents which induced more intense intermolecular contacts from protein gelation and starch gelatinization (Zayas, 2012). Studies by Joshi *et al.* (2015) also show a decrease in LGC when seed flour with high-fat content is defatted. However, opposite results were obtained from DKB, DMB and DPP. The LGC of the flours had increased to 12, 10 and 14 (g/100 mL) for DKB, DMB

Table 3. Least gelation concentrations of whole and defatted legume flours.

Legume Flour	Concentration (g/100 mL)									
	2	4	6	8	10	12	14	16	18	20
WKB	-	-	-	+	+	+	+	+	+	+
WMB	-	-	-	+	+	+	+	+	+	+
WSB	-	-	-	-	-	-	-	-	+	+
WBS	-	-	-	-	-	-	-	+	+	+
WPP	-	-	-	+	+	+	+	+	+	+
DKB	-	-	-	-	-	+	+	+	+	+
DMB	-	-	-	-	+	+	+	+	+	+
DSB	-	-	-	-	-	-	+	+	+	+
DBS	-	-	-	+	+	+	+	+	+	+
DPP	-	-	-	-	-	-	+	+	+	+

(-): no gelling, (+): complete gelling, WKB: whole kidney bean, WMB: whole mung bean, WSB: whole soybean, WBS: whole black soybean, WPP: whole pigeon pea, DKB: defatted kidney bean, DMB: defatted mung bean, DSB: defatted soybean, DBS: defatted black soybean, DPP: defatted pigeon pea

and DPP, respectively. It is important to note that, whenever heat was introduced in the methods (WSI, ES and LGC), it would negatively influence the functional and physicochemical properties of defatted legume flours. Further investigation of oil extraction and thermal processing of flour components' composition and characteristics is required for a better understanding of this behaviour in defatted legume flours. Knowledge of the LGC of flours plays an important role to determine the concentration of flours needed to form a stable gel for some food systems such as vegan yoghurt. It helps to control the viscosity, texture and firmness of gel based on desired quality. From this study, defatted legume flours have a narrow range of LGC, making it easier to standardize the flours concentration required for food formulation which gel formation plays a major role in its production.

Foaming capacity and stability depend on the formation of interfacial film by protein and they help in maintaining air bubbles in the suspension and decelerating the rate of coalescence (Du *et al.*, 2014). All

legume flours showed the highest values of FC at 5 g/100 mL concentration, ranging from 34% to 72% (Figure 1A). Defatted legume flours had improved FC values than whole legume flours. Studies by Adebawale *et al.* (2005) also showed significant differences in FC of full fat and defatted *Mucuna* flours. According to Adebawale and Lawal (2004), FC will reach its maximum value when protein content reaches a certain limit, which is in agreement with the results obtained. The FC of the legume flours reach max values when the concentration of flour was at 5 g/100 mL. However, the FC dropped when the concentrations ranged from 5 g/100 mL to 10 g/100 mL, which is consistent with results obtained by Du *et al.* (2014).

Defatted legume flours showed higher foam stability (FS) at the beginning of storage compared to their respective whole legume flours (Figure 1B). All the flours were not able to maintain foam stability across the time and showed drastic foam reduction at 40 mins. The ability of the legume flours to maintain the FS will require high surface activities of soluble proteins in the

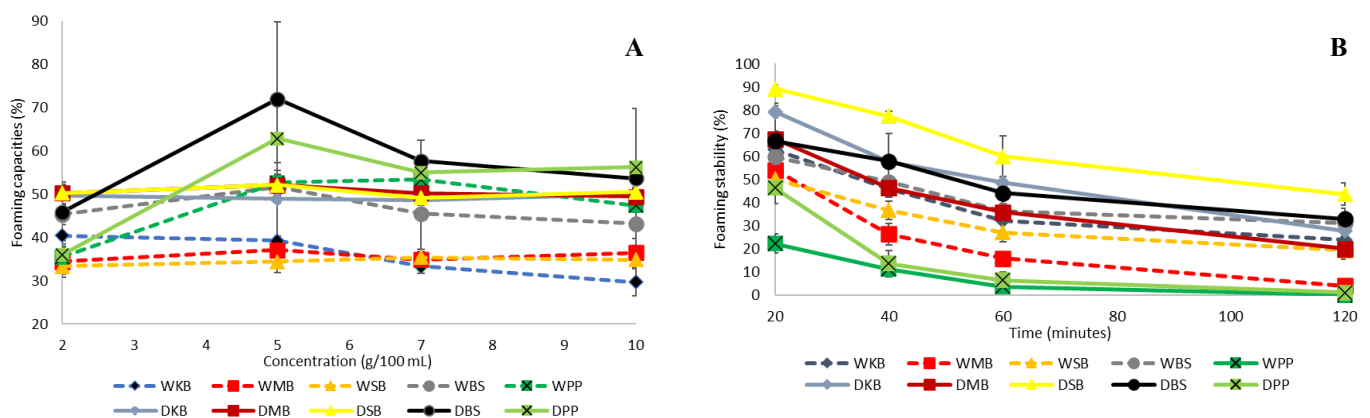


Figure 1. Effect of flour concentration on foaming ability of legume flours (A); foam stability of the legume flours at 3 g/100 mL flour concentration (B). Three replicates were taken for data analysis. WKB: whole kidney bean, WMB: whole mung bean, WSB: whole soybean, WBS: whole black soybean, WPP: whole pigeon pea, DKB: defatted kidney bean, DMB: defatted mung bean, DSB: defatted soybean, DBS: defatted black soybean, DPP: defatted pigeon pea.

continuous water phase (Kaur and Singh, 2005). Results reported in this study demonstrated minimal capacity in FS, suggesting limited surface-active effects in its soluble protein. In addition, physical differences in main proteins among legume flours offer diversity in FS (Du et al., 2014). Flour with good foaming capability can be used as a whipping agent in whipped toppings, frozen desserts and sponge cakes. DSB can be utilized for these food products in view of their good foaming properties.

The interactions between nutritional, physicochemical and functional properties of legume flours were explored using Pearson Correlation (Table 4). The moisture contents of the legume flours were excluded from the correlation analysis as they were more important for storage purposes. The protein content of legume flours showed a positive correlation towards most of the functional and physicochemical properties, except for WAI and BD. It indicated that protein content plays an essential role in determining the functional and physicochemical properties of legume flour. Meanwhile, a medium to weak negative correlation was observed between carbohydrate content and functional properties of legume flours. While, WAI and BD of legume flours showed a strong positive correlation in carbohydrate content, indicating the importance of carbohydrates in these particular properties. Meanwhile, only 5% of FC was included in the correlation study as it showed the highest foaming capacity compared to other concentrations tested. FC was found to influence the FS of legume flours, where a strong positive correlation was observed.

#### 4. Conclusion

Variations in nutritional, physicochemical and functional properties of whole and defatted flours from 5 types of legumes were investigated. The oil extraction process had increased the ash, protein and carbohydrates content in defatted legume flours. Defatted legume flours produced from solvent extraction have exhibited high bulk density, WAC, OAC and EA, but lower ES compared to whole legume flours. The physicochemical and functional properties of legume flours were greatly influenced by the starch and protein contents. The properties of the type of legume flours differed based on the varieties. These properties help in better utilization of legume flours in the development and processing of food products, which show suitability in gluten-free products, and as stabilizing agents. The ability of legume flours to hold water retention and form a gel structure has demonstrated their potential as ingredients in colloidal food system formulation, especially in vegan yoghurt-like products.

#### Conflict of interest

The authors declare no conflict of interest.

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Table 4. Correlation coefficient of nutritional composition, physicochemical properties and functional properties of legume flours.

	Ash	Pro	Fat	Fiber	Carbohydrate	WHC	OHC	EA	ES	FC (5%)	FS (20 min)	FS (40 min)	FS (60 min)	FS (120 min)	WAI	WSI
Ash	1.00															
Protein	0.95	1.00														
Fat	0.52	0.60	1.00													
Fiber	0.92	0.85	0.44	1.00												
Carbohydrate	-0.85	-0.92	-0.86	-0.76	1.00											
WHC	0.79	0.73	0.42	0.68	-0.67	1.00										
OHC	0.85	0.76	0.29	0.73	-0.62	0.91	1.00									
EA	0.55	0.35	-0.11	0.52	-0.17	0.49	0.69	1.00								
ES	-0.24	-0.08	0.32	-0.08	-0.12	-0.14	-0.40	-0.81	1.00							
FC (5%)	0.42	0.38	-0.23	0.20	-0.10	0.37	0.43	0.32	-0.53	1.00						
FS (20 min)	0.52	0.41	-0.01	0.66	-0.26	0.52	0.59	0.79	-0.42	0.07	1.00					
FS (40min)	0.72	0.60	0.20	0.79	-0.49	0.72	0.75	0.79	-0.34	0.10	0.92	1.00				
FS (60 min)	0.70	0.57	0.19	0.78	-0.47	0.71	0.73	0.81	-0.38	0.10	0.93	0.99	1.00			
FS (120 min)	0.78	0.69	0.36	0.80	-0.62	0.82	0.80	0.70	-0.27	0.15	0.84	0.97	0.96	1.00		
WAI	-0.77	-0.81	-0.87	-0.59	0.93	-0.69	-0.60	-0.07	-0.11	-0.23	-0.04	-0.30	-0.28	-0.47	1.00	
WSI	0.53	0.46	0.27	0.34	-0.42	0.37	0.51	0.16	-0.06	0.23	-0.23	0.05	0.02	0.10	-0.52	1.00
Bulk density	-0.59	-0.67	-0.91	-0.47	0.87	-0.64	-0.50	0.08	-0.36	0.13	0.01	-0.28	-0.24	-0.45	0.90	-0.47

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