

## Some physicochemical and functional properties of pea, chickpea and lentil whole flours

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### Abstract

The objective of this study was to evaluate the Physicochemical and functional properties of whole flour legumes. Phenolic content, flavonoid content and antioxidant activity of pea, chickpea and lentil flours were evaluated. The physicochemical and functional properties of their whole flours were determined. Lentil had the highest phenolic content and the highest antioxidant activity, followed by pea and chickpea. The proximate composition of the three legumes was comparable. The three flours had good functional properties. Thus, the study indicated that pea, chickpea and lentil whole flours would have great potential in various food applications.

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### Keywords

Whole legume flours

Polyphenols

Antioxidant

Functional properties

Potential

### Introduction

Legumes are produced and consumed widely throughout the world (Tharanathan and Mahadevamma, 2003). They are vital food resources which contribute to the nutritional wellbeing of diverse human diets (Uebersax and Occen, 2003). Dry Legumes or pulses are the edible seeds of plants in the legume family and include dry bean, pea, lentil and chickpea. The term pulses excludes grain legumes used for oil extraction (soybean, peanut) and those harvested green (green pea, green bean) (McCrory *et al.*, 2010). Legumes are recognized for their superior nutritional profile as they are low in fat, high in protein, high in dietary fiber and a source of micronutrients and phytochemicals. Their nutritional characteristics have been associated with a reduction in the incidence of various cancers, LDL cholesterol, type-2 diabetes and heart disease (Bassett *et al.*, 2010; Roy *et al.*, 2010; Cryne *et al.*, 2012). Although, total human food consumption of legumes globally has risen over the last four decades, this has been driven primarily by population growth. Unfortunately, Global average per capita consumption of legumes is on the decline (Watts, 2011). Finding new uses and creating new demand is critical to the success of the legume industry. New demand will come mainly from a sea-change of focus from marketing legumes as commodities to highlighting and promoting their use as higher value food ingredients. As consumers

have become increasingly discriminating and health conscious, they are demanding tasty and convenient food products that provide additional nutritional and health benefits (Bassett *et al.*, 2010). The food processing industry is increasingly interested in the potential to incorporate novel ingredients, such as legumes, into food products for nutritional purposes, including their high protein and fiber content, gluten-free status, low glycemic index, antioxidant levels, as well as functional properties like water binding and fat absorption. Health and nutrition present an enormous opportunity for the legume sector in coming years (Watts, 2011). A need exists for up-to-date information on novel and emerging technologies for the processing of whole legumes, techniques for fractionating legumes into ingredients, and the functional and nutritional properties of legumes and legume fractions, as well as novel and potential applications (Bassett *et al.*, 2010).

Several studies on legumes have been conducted (Khattab *et al.*, 2009; Sreerama *et al.*, 2012a; Sreerama *et al.*, 2012b; Wani *et al.*, 2013). While few works on local legumes (Algeria) have been reported, Such as composition (Amir *et al.*, 2007) and therapeutic effects (Boudjou *et al.*, 2013). There is, however, no information on the physicochemical and functional properties of Algerian legume flours. On the other hand, many studies have been conducted on functional properties of whole legume

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flours (Chau and Cheung, 1998; Ma *et al.*, 2011; Du *et al.*, 2014), however, a survey of the literature has shown that there is a dearth of information on the relationship between physicochemical characteristics of whole legume flours and their functional properties for predicting and optimizing food applications. Therefore, the present study is aimed to investigate and compare the physicochemical and functional properties of whole flours derived from three different legumes (pea, chickpea and lentil) among the most cultivated and consumed in Algeria and for which limited biochemical and functional characteristics are available. The lower cost of these legumes and their widespread availability, may, however, justify the choice of these samples. Studying such local legumes may provide useful information to consumers and also incentive to food manufacturers to promote the consumption and production of value-added foods for improving human health.

## Material and Method

### Seed material

Dry seeds of pea (*Pisum sativum*), chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*), commonly cultivated in Algeria, were harvested from the region of Ain Defla, Algeria, during July – August 2012. Samples were cleaned to remove foreign materials and damaged seeds, and divided into two sets. The first set constitutes intact seeds, and the second set was initially crushed in a traditional stone mill followed by an analytic mill (IKA A11 basic, Germany) then sieved (Tap sieve shaker AS 200 Retsch, Germany) to pass a 500  $\mu\text{m}$  screen, and kept in dark airtight glass containers at room temperature until further analysis. All determinations were run, at least, in triplicates. All other materials and chemicals used were purchased from regular suppliers and were of analytical grade.

### Proximate composition

The contents of moisture, crude protein, total lipid and ash in the samples were determined by the standard methods of AOAC (1998). The carbohydrate content was determined as the weight difference using moisture, crude protein, crude lipid and ash content data.

### Extraction of phenolic compounds

Legume flours (1 g) were extracted with 40 ml methanol 80 (v/v), acidified by HCl (methanol/HCl, 99 ml/1 ml) at room temperature (25°C) by maceration for 24 h, then, by constant magnetic stirring for 2 h. The mixture was centrifuged (Bench-top, NÜVE, NF

200, Turkey) at 5000 rpm for 30 min. The supernatant was used for determination of total phenolic content.

### Total phenolic content (TPC)

The total phenolic content was determined according to the Folin Ciocalteu spectrophotometric method (Singleton *et al.* 1999) as explained by Sharma and Gujral (2010, 2011). The results were expressed as mg of gallic acid equivalents (mg GAE/g dry sample).

### Flavonoids content (FC)

The flavonoids content was determined according to Djeridane *et al.* (2006). Flavonoids content was expressed in mg quercetin equivalents (mg QE/g dry sample).

### Methanol crude extract

Legume flour samples (1 g) were extracted with 40 ml methanol 80 (v/v) at room temperature (25°C) by maceration for 24 h, then, by constant magnetic stirring for 2 h. The mixture was centrifuged (Bench-top, NÜVE, NF 200, Turkey) at 5000 rpm for 30 min. The supernatant was used to evaluate the antioxidant activities.

### Reducing power

Reducing power of extracts were determined by the method of Oyaizu (1986) as described by Sharma *et al.* (2012) and Sreerama *et al.* (2012a) with minor modification. The extract (0.5 ml) was mixed with 1.25 ml of phosphate buffer (0.2 M, pH 6.6) and 1.25 ml potassium ferricyanide (1%) was added followed by incubation at 50°C. Then, 1.25 ml of trichloroacetic acid solution (10%) was added to mixture. Then, 2.5 ml of the solution was mixed with 2.5 ml distilled water and 0.5 ml ferric chloride (0.1%). The absorbance of the mixture was measured at 700 nm. A standard curve was prepared using various concentrations of ascorbic acid and results were reported as ascorbic acid equivalents (mg AAE/g dry sample).

### Radical scavenging activity by DPPH method

The DPPH assay was carried out according to Abd El-Moneim *et al.* (2012) with minor modification. Briefly, 5 mg of DPPH in 100 ml methanol was prepared and 2.9 ml of this solution was added to 0.1 ml of extract. The mixture was shaken vigorously and allowed to stand at room temperature (25°C) for 30 min in the dark. The absorbance was measured at 515 nm. The antioxidant capacity was expressed as trolox equivalent antioxidant capacity (mg troloxEAC/g dry sample).

#### *Antioxidant activity by the ABTS assay*

The ABTS radical cation decolorization assay was performed by the method of Re *et al.* (1999) as reported by Sasipriya and Siddhuraju (2012), with slight modification. Briefly, ABTS radical cation (ABTS) was generated by adding 2.45 mM potassium persulfate to 7 mM ABTS and incubated in dark at room temperature for 12–16 h. This stock solution of ABTS was diluted with ethanol to give an absorbance of 0.70 ( $\pm$  0.02) at 734 nm, which act as a positive control. 0.1 ml of extract was mixed with 2.9 ml of diluted ABTS solution and incubated at 30°C for 30 min. The absorbance value was measured at 734 nm with UV–visible spectrophotometer (Shimadzu, mini-1240, China). The antioxidant capacity was expressed as trolox equivalents (mg troloxE/g on dry sample).

#### *Bulk density*

Flour bulk density was evaluated by measuring the weight of a known volume of sample. Samples were poured into a graduated cylinder, gently tapped ten times and the volume is noted. Results are expressed as g/ml (Mariotti *et al.*, 2006).

#### *Granulometry*

The size distribution of flour particles was determined by sieving according to the method of Melcion (2000).

#### *pH and titrable acidity (TA)*

The pH value was measured from an aliquot of 10 g of flour blended with 100 ml distilled water (AOAC, 1998). For the determination of titrable acidity, this suspension was titrated against 0.1M NaOH to a final pH value of 8.5 (Katina *et al.*, 2007). Total titrable acidity (TTA) was expressed as the amount of NaOH used (mM) for 100 g dry flour.

#### *Water and oil holding capacity (WHC and OHC)*

One gram of each flour sample was weighed into a preweighed centrifuge tube and 10 ml of distilled water were added. Samples were vortexed for one minute and allowed to stand for 30 min at desired temperature (25°C, 50°C and 75°C) before being centrifuged at 4000 rpm for 25 min. Excess water was decanted by inverting the tubes over absorbent paper and samples were allowed to drain for 10 min. For oil absorption, 10 ml refined corn oil were used. The weights of water and bound oil samples were determined by difference (Elkhalifa and Bernhardt, 2010).

#### *Protein solubility*

Protein solubility was determined at various pH values ranging from 1 to 10 according to Chau and Cheung (1998) method, with slight modification. In summary, 500 mg of flour sample was dispersed in 20 ml of distilled water and the pH was adjusted to the desired level using 1N HCl or 1N NaOH. The dispersions were continuously stirred for 45 min at room temperature (25°C) and centrifuged at 4000 rpm for 30 min. The amount of protein in the supernatant was determined by the method of Bradford (1976). Protein solubility was expressed as BSA equivalents (mg BSAE/g dry sample).

#### *Gelling properties*

The least gelling concentration of flours concentrates was determined according to the method described by Boye *et al.* (2010a) and Ma *et al.* (2011). The least gelling concentration (LGC) was estimated as the critical concentration below which no self-supporting gel was formed.

#### *Foaming Properties*

Two grams of the flour dispersed in 50 ml distilled water was blended for 3 min using an Ultra-Turrax mixer (IKA T18 basic) at 7000 rpm and poured into a graduated cylinder Sodini *et al.* (2006). The volumes were recorded before and after whipping and the percentage volume increase was calculated:

$$\text{Volume increase (\%)} = \frac{V_2 - V_1}{V_1} \times 100$$

Where  $V_1$  = initial volume of solution;  $V_2$  = volume of solution after whipping. Foam stability was determined as the volume of foam that remained after 1 h at room temperature (25°C) and expressed as the percentage of initial foam volume Seena and Sridhar (2005).

#### *Emulsifying properties*

The emulsion stability index (ESI) and emulsifying activity index (EAI) were determined by the turbidimetric method of Pearce and Kinsella (1978) as described by L'hocine *et al.* (2006).

#### *Statistical analysis*

All determinations were made in the triplicate and the values were averaged and reported along with the standard deviation. Statistical analysis was carried out using a one way analysis of variance (ANOVA) and the significant difference between the samples was determined using LSD test at  $p < 0.05$ .

## Result end Discussion

### Proximate composition

Proximate composition of the studied seeds is shown in Table 1. All the parameters showed significant difference ( $p < 0.05$ ) between samples. Moisture contents ranged between 7.68 and 8.41%. This low moisture content may be due to climatic conditions and to post-harvest storage. Ash contents ranged between 2.45 and 3.24 g/100g dry basis. Chickpea had the highest crude fat content of (5.57 g/100g dry basis) followed by pea (1.83 g/100g dry basis) and lentil (1.25 g/100g dry basis). Lentil had the highest crude protein content (26.34 g/100g d.b.) followed by chickpea (24.41 g/100g d.b.) and pea (22.25 g/100g d.b.). Pea had highest carbohydrate content of (72% d.b.), followed by lentil (69% d.b.) and chickpea (67% d.b.). In general, our results are comparable to those reported in the literature (Amir *et al.*, 2007; Khattab *et al.*, 2009; Boye *et al.*, 2010a).

Table 1. Proximate composition, phenolic compounds and antioxidant activity of investigated legumes

Component	Pea	Chickpea	Lentil
Moisture (% d.b.)	7.68±0.20 <sup>c</sup>	8.28±0.24 <sup>b</sup>	8.41±0.09 <sup>a</sup>
Ash (% d.b.)	3.24±0.00 <sup>a</sup>	2.45±0.27 <sup>c</sup>	2.63±0.15 <sup>b</sup>
Lipid (% d.b.)	1.83±0.11 <sup>b</sup>	5.57±0.66 <sup>a</sup>	1.25±0.12 <sup>c</sup>
Protein (% d.b.)	22.25±0.10 <sup>c</sup>	24.41±0.02 <sup>b</sup>	26.34±0.02 <sup>a</sup>
Carbohydrate* (% d.b.)	72.68	67.57	69.78
TPC (mg GAE/g)	2.364±0.02 <sup>b</sup>	1.502±0.05 <sup>c</sup>	6.217±0.18 <sup>a</sup>
FC (mg QE/g)	0.125±0.01 <sup>c</sup>	0.127±0.00 <sup>b</sup>	0.259±0.00 <sup>a</sup>
RP (mg AAE/g)	2.924±0.03 <sup>b</sup>	0.982±0.04 <sup>c</sup>	4.035±0.09 <sup>a</sup>
DPPH (mg troloxE/g)	2.551±0.06 <sup>b</sup>	0.561±0.04 <sup>c</sup>	4.913±0.03 <sup>a</sup>
ABTS (mg troloxE/g)	3.520±0.08 <sup>b</sup>	2.326±0.04 <sup>c</sup>	10.395±0.45 <sup>a</sup>

Values expressed are mean ± standard deviation. Means in the rows with different superscript are significantly different at  $p < 0.05$ . \*Carbohydrate was calculated by difference (= 100 - (ash + lipid + protein), including fiber). TPC: total phenolic content, FC: flavonoid content, RP: reducing power, DPPH: antioxidant activity by DPPH assay, ABTS: antioxidant activity by ABTS assay, mg GAE/g: mg gallic acid equivalents by g of dry flour, mg QE/g: mg quercetin equivalents by g of dry flour, mg AAE/g: mg ascorbic acid equivalents by g of dry flour, mg troloxE/g: mg trolox equivalents by g of dry flour

### Phenolic and flavonoid contents

Legume flour extracts differed significantly ( $p < 0.05$ ) in their total phenolic contents (TPC) (Table 1). Lentil extract showed the highest TPC of 6.21 mg GAE/g followed by pea (2.36 mg GAE/g) and chickpea (1.50 mg GAE/g). In general, the phenolic contents obtained in the present study were similar to those found in the literature (Xu and Chang, 2008), but lower than those noted in other legumes such as horse gram (14.31 mg GAE/g), cowpea (12.16 mg GAE/g) (Sreerama *et al.*, 2012a), faba bean (major and minor 30.93 mg GAE/g, 42.44 mg GAE/g respectively)

(Boudjou *et al.*, 2013). However, Marathe *et al.* (2011) reported TPC in the range of 0.46 – 1.36 mg GAE/g in different cultivars of chickpea and of 0.91 mg GAE/g in lentil and in the range of 0.93 – 1.04 mg GAE/g in pea.

The variation in phenolic content is known to be due to genetic factors, degree of maturity and environmental conditions. Secondly, extractability of phenolic compounds is governed by the type of solvent (polarity) used, degree of polymerization of phenolics, interaction of phenolics with other food constituents, as well as the extraction time and temperature (Marathe *et al.*, 2011; Oomah *et al.*, 2011).

Among phenolic compounds, flavonoids are the most important group of plant phenolics that have antioxidant potential (Kanatt *et al.*, 2011). These flavonoids are known to possess antioxidant, anticancer, anti-allergic, anti-inflammatory and gastroprotective properties (Sreerama *et al.*, 2012a). Total flavonoid content (TFC) of extracts is presented in table 1. Lentil extract (0.259 mg QE/g) had significantly ( $p < 0.05$ ) higher total flavonoid content as compared to chickpea (0.127 mg QE/g) and pea (0.125 mg QE/g) extracts. In general, the results of TFC of investigated legumes follow a similar trend to those reported for other leguminous seeds (Boudjou *et al.*, 2013). However, Nithiyantham *et al.* (2012) reported TFC of 10.65 mg rutin equivalents/g in acetone extract of raw chickpea and of 7.93 65 mg rutin equivalents/g in acetone extract of raw pea.

### Antioxidant activity

Natural antioxidants have demonstrated beneficial effects in maintenance of health, management of age related diseases, ameliorating the harmful effects of toxic agents both chemical and physical (Mishra *et al.*, 2012). Antioxidant activity determination is reaction mechanism dependent. The specificity and sensitivity of a single method does not lead to the complete examination of all phytochemicals in the extract. Therefore, a combination of several tests could provide a more reliable assessment of the antioxidant profiles of food legumes (Xu and Chang, 2012). In the present study, three chemical based antioxidant analyses (DPPH free radical scavenging (DPPH) assay, ABTS free radical scavenging (ABTS) assay, and Ferric Reducing Antioxidant Power (FRAP)) were conducted.

### Ferric Reducing Antioxidant Power (FRAP)

Antioxidant activity has been proposed to be related to reducing power. Therefore, the antioxidant potential of methanol extracts for legume samples

were estimated for their ability to reduce Fe (III) to Fe (II). The ferric reducing ability of the extracts revealed that all of them gave good FRAP activity (Table 1). It was expressed in mg ascorbic acid equivalents by g of flour dry basis (mg AAE/g). The highest activity was noted for lentil (4.03 mg AAE/g) followed by pea (2.92 mg AAE/g) and chickpea (0.98 mg AAE/g). Significant differences ( $p < 0.05$ ) were found between the three samples.

#### DPPH and ABTS

DPPH values (expressed in mg troloxE/g dry basis) of the investigated legumes are presented in Table 1. The DPPH values ranged from 0.56 mg troloxE/g in chickpea to 4.91 mg troloxE/g in lentil, whereas pea value was of 2.551 mg troloxE/g. Significant differences ( $p < 0.05$ ) were found between samples. ABTS values (expressed in mg troloxE/g dry basis) of legumes are presented in Table 1. The highest ABTS value was found in lentil (10.39 mg troloxE/g), followed by pea (3.52 mg troloxE/g), and chickpea (2.326 mg troloxE/g). Significant differences ( $p < 0.05$ ) were found between samples. Chickpea having light color seed coat (cream) exhibited low phenolic content and weak antioxidant activity, while lentil having dark color seed coat (green-brown) possessed high phenolic content and strong antioxidant activity. This result was also noted by Marathe *et al.* (2011) for various legumes. A strong positive correlation existed between total phenolic content and antioxidant activities (DPPH, ABTS and FRAP); this is in agreement with Marathe *et al.* (2011) and Oomah *et al.* (2011).

#### Bulk density, pH and acidity

Table 2 shows that chickpea flour is significantly ( $p < 0.05$ ) more dense (1.09 g/ml) than pea (0.99 g/ml) and lentil flours (0.93 g/ml). Basically, results obtained in present study were comparable to those reported by Benítez *et al.* (2013). However, they were higher than those reported by (Wani *et al.*, 2013) for bulk density of kidney beans flours. This property is important with regard to the packaging and depends on the structural characteristics of the product, the particle size and their distribution, and is related to other physicochemical properties (Berton *et al.*, 2002; Benítez *et al.*, 2013; Wani *et al.*, 2013). The pH values of legume flours were found to range from 6.38 to 6.52 (Table 2). These results of pH are in agreement with the pH values of many legume flours (Chau and Cheung, 1998). There is a poor negative correlation ( $R^2 = -0.49$ ;  $p < 0.01$ ) between pH and acidity, this might be due to the difference in the buffering capacity of legume flours.

Table 2. Physicochemical and functional properties of legume flours

Parameter	Pea	Chickpea	Lentil
Bulk density(g/ml)	0.99 ± 0.005 <sup>b</sup>	1.09 ± 0.005 <sup>a</sup>	0.93 ± 0.005 <sup>c</sup>
pH	6.38 ± 0.03 <sup>b</sup>	6.41 ± 0.01 <sup>b</sup>	6.52 ± 0.02 <sup>a</sup>
TTA (mMNaOH/100g)	7.22 ± 0.15 <sup>a</sup>	4.17 ± 0.31 <sup>c</sup>	4.90 ± 0.00 <sup>b</sup>
FC (%)	50.95 ± 1.86 <sup>a</sup>	32.42 ± 1.97 <sup>c</sup>	42.36 ± 10.14 <sup>b</sup>
FS (%)	41.31 ± 2.75 <sup>b</sup>	46.10 ± 5.52 <sup>b</sup>	71.36 ± 11.23 <sup>a</sup>
LGC (%)	12.00 ± 0.00	8.00 ± 0.00	12.00 ± 0.00
EAI (m <sup>2</sup> /g)	54.65 ± 0.59 <sup>a</sup>	47.38 ± 0.55 <sup>b</sup>	38.81 ± 4.03 <sup>c</sup>
ESI (min)	47.04 ± 3.23 <sup>a</sup>	32.73 ± 5.59 <sup>b</sup>	26.1 ± 4.13 <sup>b</sup>

Values expressed are mean ± standard deviation. Means in the rows with different superscript are significantly different at  $p < 0.05$ . TTA: total titrable acidity, FC: foaming capacity, FS: foaming stability, LGC: least gelation capacity, EAI: emulsifying activity index, ESI: emulsifying stability index

#### Granulometry

Particle size distributions of flours were measured by sieving. The results obtained are represented in figure 1, results showed a strong similarity of particle size distribution between pea and lentil, chickpea flour granulometry differed significantly to the other flours. The fraction of < 160 µm is the most important, since it equal to 70% for chickpea, 54.5% for pea and 53.19 % for lentil. The other fractions are comparable each other. Flour granulometry is an important parameter, as it affects the behavior of the food during processing. Since, it affects density, hydration properties (Berton *et al.*, 2002).

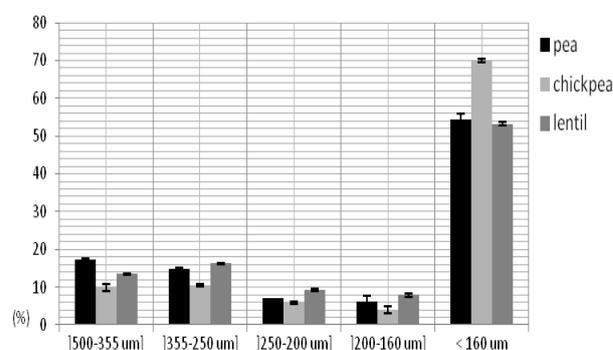


Figure 1. Particle size distribution

#### Protein Solubility

To provide useful information towards effective utilization of dry legumes in various food applications, the protein solubility of the flours was investigated at pH ranging from 1 to 10 (Figure 2). The solubility profiles for flours were very similar and it was found to be pH-dependent. The protein solubility of flours was the minimum at pH 3.0 to 5.0 (ranging from 7.51 mg BSAE/g to 18.45 mg BSAE/g), and increased gradually below pH 3.0 and above pH 5.0 to reach maximum at high alkaline pH values ( $\approx$ pH 8) and at low acidic pH values ( $\approx$ pH 2). This might represent

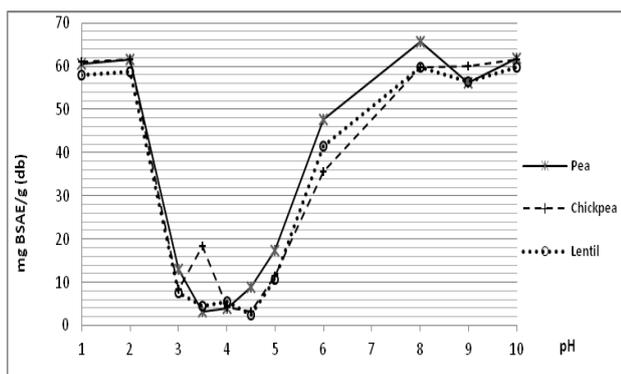


Figure 2. Protein solubility of investigated legume whole flours

the isoelectric point region (pH 3.5–4.5) at which protein–protein interactions disfavor solubility when compared to the other pH levels studied. In general, at higher pH values, the increased net negative charge on the protein dissociates the protein aggregates, and the solubility might increase, whilst at lower pH values, the increased net positive charge contributes to the solubility (Yin *et al.*, 2011). Basically, the nitrogen solubility patterns against pH of all three flours were similar to each other and in agreement with those of other seed flours reported in the literature (Chau and Cheung, 1998; Boye *et al.*, 2010a; Sreerama *et al.*, 2012b; Sridaran *et al.*, 2012; Wani *et al.*, 2013). For food applications, protein solubility is an important parameter that influences the extent of utilization in different food matrices (Sreerama *et al.*, 2012b). Furthermore, it is probably the most critical parameter, because it affects other properties, such as emulsification ability, foaming and gelling properties (Sreerama *et al.*, 2012b). The high solubility at acidic pH could make it a very promising candidate for use in acidic beverages (Boye *et al.*, 2010a). On the other hand, the nitrogen solubility profiles against pH would be useful for further protein extraction from the three investigated legumes.

#### Water and oil holding capacities

Water holding capacity of flours plays an important role in the food preparation process because it influences other functional and sensory properties. Furthermore, the range of application of flours as food ingredients is dependent, to a large extent, on their interaction with water (Sreerama *et al.*, 2012b). The water and oil holding capacities (WHC and OHC) flours are presented in figure 3 (a) and (b). They were expressed in g by 100 g fresh sample. Regarding WHC, Generally, there was significant difference between the three samples at different temperatures with pea values being the highest, followed by chickpea and lentil. Mean WHC of all flour samples increased with temperature, and

ranged between 106.4 g/100g in chickpea at 25°C and 206.5 g/100g in pea at 75°C. These results are supported by Ma *et al.* (2011), who found that boiling of legume flours improved their WHC. This effect might be due to protein denaturation, and starch damage; water molecules become linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin, which causes an increase in WHC (Singh, 2011). The swelling of crude fiber during heating might also contribute to increase WHC (Ma *et al.* 2011). Our results are comparable with those reported by (Ma *et al.*, 2011; Sreerama *et al.*, 2012b) for raw legume flours under ambient conditions. It is known that polar amino acid residues of proteins have an affinity for water molecules and differences in WHC of different legumes could be due to the content of these amino acids in legumes (Sreerama *et al.*, 2012b). In addition, carbohydrate composition (fiber and starch) also influence the hydration properties of flours (Farooq and Boye, 2011). Since these constituents contain hydrophilic parts, such as polar or charged side chains too (Wani *et al.*, 2013). Flours with high WHC could be good ingredients in bakery applications, such as bread formulations, since a higher WHC enables bakers to add more water to the dough, thus improving the handling characteristics and maintaining freshness in bread. Furthermore, WHC is a critical property of proteins in viscous foods, e.g. soups, dough, custards and baked products, because these are supposed to imbibe water without dissolution of protein, thereby providing body, thickening and viscosity (Sreerama *et al.*, 2012b). The binding of oils depends on the surface availability of hydrophobic amino acids and other non-polar side chains as dietary fiber components (Benítez *et al.*, 2013). Regarding results, there was a general tendency for OHC to increase when temperature increase. Chickpea flour has the highest OHC at the three temperatures, of 74.8%, 79.5% and 85.93% at 25°C, 50°C et 75°C respectively, followed by pea and lentil. The basic subunits of the 11S are very hydrophobic in nature and are situated inside the globulin macromolecular assembly, while the less hydrophobic acidic domains are situated at the surface. The balance of forces holding the subunits together is altered during heating, which in turn may affect the protein surface hydrophobicity (Taherian *et al.*, 2011). Additionally, the physical structural differences of the boiled flours may have induced greater porosity allowing greater entrapment of fat compared to the raw and roasted flours (Ma *et al.*, 2011). Our results suppose that chickpea have more non polar side chains and hydrophobic amino acids. OHC is important since fats act as a flavor retainer

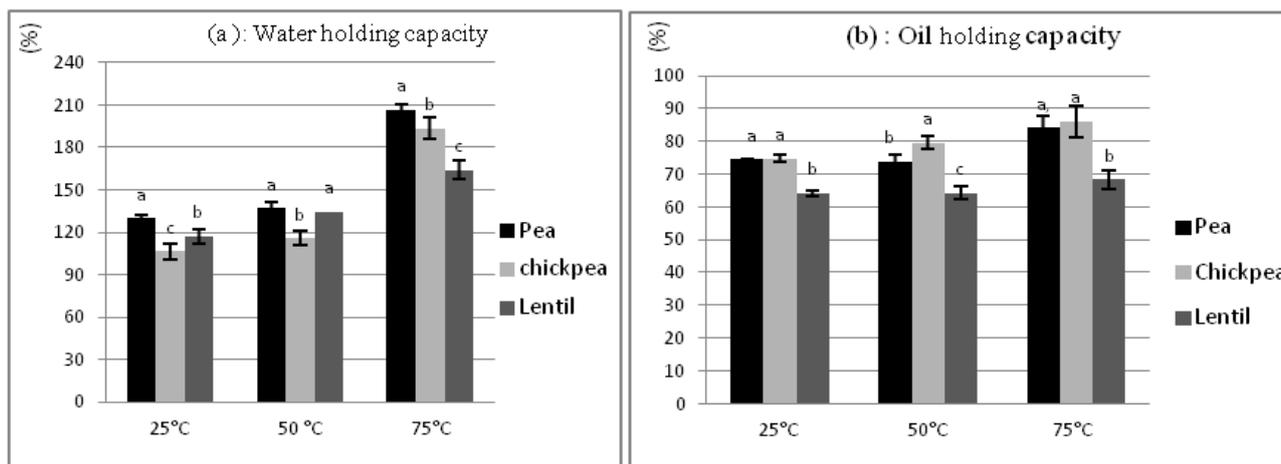


Figure 3(a). Water holding capacity, (b): Oil holding capacity

Values expressed is mean  $\pm$  standard deviation. Means in the same temperature with different superscript are significantly different at  $p = 0.05$

and increase the mouth feel of food (Elkhalifa and Bernhardt, 2010). In this study, legume type and temperature appeared to have an impact on the WHC and OHC.

#### Gelling properties

The ability of flours to form gels on heating is an important functional property in food processing and food formulation. Gelation occurs when proteins and starches form a three-dimensional network that is resistant to flow under pressure. The least gelling concentration (LGC) is often used as an indication of the gelation capacity of food proteins (Boye *et al.*, 2010a). A lower LGC suggests a better gelling capacity (Sridaran *et al.*, 2012). Gelation is affected not only by protein and starch concentration but also by the type of protein and starch and the presence of non protein components, such as minerals (Tchiegane *et al.*, 2006) and fibers. In addition, changes in physicochemical conditions, such as pH and ionic strength, influence gelling properties (Sridaran *et al.*, 2012). Furthermore, the manufacturing processes used to produce flours can have an impact on gelling properties (Farooq and Boye, 2011). Table 2 summarizes the LGC of the legume flours. In our study, no gels were formed at a concentration of 2%, 4% and 6%, (w/v) for the three samples. Chickpea flour formed a strong gel at concentration of 8%. However, the LGC for lentil and pea were at 12%. Difference between samples may be due to the type of protein and starch. These results are lower than those found by Sridaran *et al.*, (2012) for jering flour.

#### Foaming properties

Foams are formed when proteins unfold to form an interfacial skin that keeps air bubbles in suspension

and prevents their collapse (Boye *et al.*, 2010b). Protein-based foams depend upon the intrinsic molecular properties of the protein being used. Thus, amino acid sequence and disposition; molecular size, shape, conformation and flexibility; surface polarity, charge, hydrophobicity, etc., all influence foaming behavior in food systems. These, in turn, are affected by processing history and by the physical and chemical environment in which the protein is being used (Kinsella, 1981). Foaming properties are dependent on the proteins, as well as on other components, such as carbohydrates (Sreerama *et al.*, 2012b). Foam formation is important in food applications such as beverages, mousses, meringue cakes and whipped toppings (Boye *et al.*, 2010b). The foaming properties of the pea, chickpea and lentil flours are presented in Table 2. Foaming capacity ranged between 32.42 % and 50.95%. Our results are comparable to those reported by Sreerama *et al.* (2012b). The FC values of flours differ significantly, and this may be due to the difference of protein content and the amino acids profile. Lentil flour showed markedly higher foam stability (71.36%) after 60 min than did chickpea (46.10%) and pea (41.31%) flours (Table 2). In general, all three legume flours depicted high foam forming and stability and may find application in baked and confectionery products.

#### Emulsifying properties

Emulsifying properties are usually described by: (1) emulsion capacity, or emulsion activity, which reflects the ability of the proteins to aid formation and stabilization of the newly created emulsion, and (2) emulsion stability, which reflects the ability of the proteins to impart strength to emulsion for resistance to stress (Liu *et al.*, 2008). Emulsifying

properties are very important properties that proteins and other amphoteric molecules contribute to the development of traditional or novel foods (Ma *et al.*, 2011). Emulsions of fats and water are thermodynamically unstable because of the positive free energy caused by interfacial tension. Stabilization of emulsified droplets is achieved by the formation of a membrane of film around the droplets by protein, which lowers interfacial energy and physically prevents droplet coalescence (Kinsella, 1979). Carbohydrates such as starch and fiber may also enhance emulsion stability by acting as bulky barriers between the oil droplets, preventing or slowing down the rate of oil droplet coalescence (Ma *et al.*, 2011). The emulsifying capacity (expressed as emulsifying activity index,  $m^2/g$ ) and emulsion stability (expressed as emulsion stability index, min) of the three flours are shown in table 2. Significant differences in the results were observed between samples. Pea flour had the highest emulsifying activity ( $54.65 m^2/g$ ), followed by chickpea ( $47.38 m^2/g$ ) and lentil ( $38.81 m^2/g$ ). Basically, these results are higher than those reported by Boye *et al.* (2010a) for pea chickpea and lentil protein concentrates processed by ultrafiltration and isoelectric precipitation, which ranged between 4.6 and  $5.7 m^2/g$ . The increased EAI of whole flour might be due to the protein-polysaccharide (fiber) interaction which leads to the formation of a strong homogenous biopolymer film at the interfaces (Lam and Nickerson, 2013). Significant differences were observed between the emulsifying stabilities, where pea had the highest value (47 min), followed by chickpea (32.73 min) and lentil (26.1min). Basically, our results are higher than those reported by certain authors for various legume flours (Ma *et al.*, 2011 and Wani *et al.*, 2013). Differences in the emulsifying ability of flours may be related to their protein composition, solubility and conformational stability (Lestari *et al.*, 2011). Hydrophobicity of proteins has been attributed to influence their emulsifying properties (Kaushal *et al.*, 2012). Carbohydrates such as starch and fiber may also enhance emulsion stability by acting as bulky barriers between the oil droplets, preventing or slowing down the rate of oil droplet coalescence (Ma *et al.*, 2011). In general, the three legume flours depicted high emulsifying properties and may find application in formulation as emulsifiers.

## Conclusions

The results of this study indicate that pea, chickpea and lentil whole flours are rich in protein, carbohydrate and poor in fat. These legume flours

could serve as cheap and alternate source of proteins. Their phenolic compounds and antioxidant activity make them useful for inclusion in the human diet for their beneficial health effects, for the formulation of therapeutic supplementary foods for the vulnerable groups; to improve overall nutritional status of functional food. Pea, chickpea and lentil whole flours would have great potential in various food applications due to their functional properties. High levels of water and oil absorption, good gelation, emulsifying and foaming capacities, should make these flours useful in a variety of formulations, such as bakery products, soups, dairy products, gluten-free foods and other new food products. Further studies are in progress about functional and processing characteristics of whole legumes and legumes fractions and their emerging food and nutraceutical applications.

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