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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Effect of roasting on physicochemical and functional properties of flaxseed flour

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Abstract: An investigation was carried out on the physical, physicochemical, and functional properties of flaxseed. Physical properties viz. seed shape and size, geometric and arithmetic mean diameter, sphericity, aspect ratio, bulk and true density, porosity, angle of repose, and static friction coefficient were determined. Geometric and arithmetic mean diameter were 2.19 and 3.51 mm while average sphericity and aspect ratio were 40.34 and 62.58%. The average true density, bulk density, and porosity were 1.34 g/cm³, .66 g/cm³, and 51.56%. Angle of repose was 19.40° and coefficient of static friction obtained on glass, stainless steel, plywood perpendicular, and plywood parallel was .32, .36, .33, and .33, respectively. Flaxseeds were roasted and compositional and functional properties like water absorption capacity (WAC), oil absorption capacity (OAC), foaming capacity, foaming stability, sedimentation value, and least gelation concentration of roasted and unroasted flaxseed flour were performed. Foaming capacity (9.23%) and foaming stability (54.43%) were significantly higher for unroasted flaxseed than roasted flaxseed flour (7.82 and 48.60%). Roasted flour was observed to have highest values of WAC, bulk density, WSI, ash, fiber, carbohydrate, and lowest values of moisture, protein, fat, OAC, tap density, porosity, angle of repose, WAI, and sediment value as compared to unroasted flour.

Subjects: Engineering & Technology; Food Engineering; Food Science & Technology

Keywords: flaxseed; roasting; physical; functional; physicochemical; Environmental sustainability engineering

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PUBLIC INTEREST STATEMENT

The physical properties of flaxseeds were evaluated to understand structural and functional behaviour of the flaxseed flour. The results of the experimental investigation may help to optimize engineering parameters of separation and processing equipments like in the processing of flaxseed flour and extraction of flaxseed oil. Roasting of flaxseed enhanced the nutty flavour and flaxseed flour sample being a rich source of good quality protein, minerals and fat can be used for utilization in bakery industry as a composite flour to improve the nutritional quality of products. Great potential, therefore, exists for incorporating flaxseed into human food products like cookies, cake, buns etc., as a fat supplement and a functional agent in a variety of formulated foods. Flaxseed products will boost the economy and status of bakery industry by providing essential nutrients in addition to phytochemical constituents for malnutrition, arthritis, cardiovascular and other diseases. Hence, greater use of the flaxseed as food is recommended.

1. Introduction

Flaxseed belongs to the family *Linaceae* and is an economically important multipurpose oilseed crop that yields ample amount of tiny smooth and flat seeds with a hard shiny shell that is light to reddish brown in color. The seeds possess wide range of health benefits due to the presence of omega-3 fatty acid especially alpha-linolenic acid, which prevents heart disease, inflammatory bowel disease, arthritis etc. and are thus consumed in whole, milled, and oil form. The seeds have been consumed from ancient times for its medicinal purposes to relieve abdominal pains and also as energy source (Oplinger, Oelke, Doll, Brundy, & Schuler, 1989). The oil percentage in Flaxseed is in the range of 28–42% depending on the variety and cultivation condition.

Roasting helps in the formation of desired flavor, and the quality of roasted nuts and oilseeds highly depends on roasting conditions as it improves the flavor, brown color, texture, and overall acceptability of the product (Özdemir & Devres, 2000a; Pittia, Dalla Rosa, & Lericci, 2001). However, the developed roasted flavor and aroma depends upon the temperature and time of roasting besides the type of nuts and techniques applied. Moreover, roasting results in lipid damage due to oxidation reactions, but the damage is less due to the antioxidant nature of phytochemicals present like tocopherols and polyphenols which play an important role for protection of nuts and oilseeds against fat deterioration (Chun, Lee, & Eitenmiller, 2005). Roasting also results in the formation of melanoidins due to Maillard's reaction, that are known to possess pronounced antioxidant properties, thereby improving the oxidative stability of nuts and seeds (Rizzi, 2003). Maillard reaction also plays an important role in the formation of typical color and flavor during roasting (Ziegleder, 1991). The roasting treatment has also resulted in loosening the shell of beans roasted (Krysiak & Motyl-Patelska, 2006).

The physical properties of agricultural produce are important in designing and constructing equipment and structures for handling, transportation, processing, storage, and also for assessing the product quality (Kashaninejad, Mortazavi, Safekordi, & Tabil, 2006; Sirisomboon, Pornchaloempong, & Romphopphak, 2007). Physical and mechanical properties of fruit, nut, seed, and kernel are important to design equipment for dehulling, nut shelling, drying, oil extraction, and other processes like transportation and storage (Sirisomboon, Kitchaiya, Pholpho, & Mahuttanyavanitch, 2007). Physical properties such as size, shape, sphericity, aspect ratio, true density, bulk density, and porosity, and mechanical properties such as coefficient of friction, angle of repose as well as fracture resistance are very important in the design of processing machines for major agricultural crops (Owolarafe, Olabige, & Faborode, 2007). Many studies have been reported on the chemical and physical-mechanical properties of fruits and kernels, such as apricot kernel, berries, cherry laurel, cornelian cherry, fresh okra fruit, orange, rose fruit, wild plum etc. The objective of this study was to determine the physical properties of flaxseed and effect of roasting on the physical, physicochemical, and functional properties of flaxseed flour in comparison to wheat flour.

2. Material and methods

2.1. Materials

Flaxseeds (*Linum usitatissimum*) were purchased from local market of Parbhani, Maharashtra, India. The wheat flour (Brand name Rajdhani) was purchased from local market of Sangrur, Punjab, India. The seeds were cleaned and used as basic raw material for the study. For roasting, 50 g seeds were placed in a single layer on Petri dishes and were roasted in convection oven (Memmert, UNB 500) at 180°C for 10 min. After roasting, the seeds were allowed to cool at room temperature. After cooling (30 min), roasted samples were immediately ground. The raw and roasted samples were grinded using laboratory blender (Waring, USA) at low speed.

2.2. Proximate composition

Moisture content, ash, fat, fiber, and protein were determined using the method of Association of Official Analytical Chemists (2000) and total carbohydrate was determined by difference method of Raghuramulu, Nair, and Kalyanasundaram (1983). The energy value of the sample was calculated

applying factors 4, 9, and 4 for each gram of protein, lipid, and carbohydrate, respectively (Shrestha & Noomhorm, 2002)

$$\text{Energy value (Calories)} = 4(\text{protein}) + 9(\text{fat}) + 4(\text{carbohydrate})$$

2.3. Determination of physical properties

2.3.1. Color characteristics

Color analysis was done by standard method using Hunter Lab Color Spectrophotometer (Gretag Macbeth, I-5, USA)

2.4. Determination of geometrical properties

2.4.1. Determination of shape

The shape was expressed in terms of its sphericity index and aspect ratio. The higher the sphericity value, the closer is the shape to a sphere. For the sphericity index (ϕ), the dimensions obtained for the 10 selected seeds used to compute the sphericity index based on the equation (Karababa, 2006) as:

$$\phi(\%) = \frac{(X \cdot Y \cdot Z)^{\frac{1}{3}}}{X}$$

where, X = length (L) in mm; Y = width (mm); and Z = thickness.

For the aspect ratio same seeds were selected for conducting the experiment. The aspect ratio (R_a) was calculated as recommended by Maduako and Faborode (1990):

$$R_a(\%) = \frac{Y}{X} \times 100$$

2.4.2. Arithmetic and geometric mean diameter

The arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of seeds were calculated from the geometrical dimensions by the formula given by Goyal, Kingsly, Kumar, and Walia (2007). Both arithmetic and geometric mean are expressed in mm and calculated by the following equation:

$$D_a = \frac{X + Y + Z}{3}$$

$$D_g = (X \cdot Y \cdot Z)^{\frac{1}{3}}$$

2.4.3. Surface area

Surface area (S) was estimated by the formula corresponding to the geometrical shape. The surface area of seed was determined by using the following equation (Goyal et al., 2007):

$$S (\text{mm}^2) = \pi D_g^2$$

where, D_g = geometrical mean diameter (mm).

2.4.4. Thousand kernel weight

Thousand kernel weight was determined by counting 100 seeds randomly and weighing them in an electronic balance (.001) and then multiplied by 10 to give the mass of 1,000 kernels.

Thousand kernel weight was expressed in grams (g).

2.5. Determination of gravimetric properties

2.5.1. Determination of bulk and true density

The bulk density is the ratio of the mass of the sample to its container volume occupied. For bulk density measurement, an empty cylindrical container was filled with seeds to a known volume. Tapping during the filling was done to obtain uniform packaging and to minimize the wall effect, if any. The filled sample was weighed and the bulk density was calculated using the below equation Mohsenin (1980);

$$\text{Bulk density} \left(\frac{\text{g}}{\text{cm}^3} \right) = \frac{M}{V}$$

where, M = mass of the sample (g); V = volume of the filled sample (cm^3).

The true density is defined as the ratio of mass of the sample to its true volume. It was determined by the toluene displacement method in order to avoid absorption of water during experiment. Five grams of sample was weighed and immersed into a 100 ml measuring cylinder containing 50 ml of toluene (Mwithiga & Sifuna, 2006). It was ensured that the seeds were submerged during immersion. The net volumetric displacement was recorded from the graduated scale of the cylinder. The true density was then calculated using equation below:

$$\text{True Density}(\text{g}/\text{cm}^3) = \frac{\text{Weight of seed (g)}}{\text{Rise in toluene level (cm}^3\text{)}}$$

2.5.2. Determination of tap density

The tap density of a material can be used to predict the flow properties and compressibility of a particular material. The tap density of a sample was determined by the method of Deshpande and Poshadri (2011) as;

$$\text{Tap density} \left(\frac{\text{g}}{\text{cm}^3} \right) = \frac{\text{weight of sample}}{\text{volume of tapped sample}}$$

2.5.3. Determination of porosity of seed

Porosity, ϵ (%) indicates the amount of pores in the bulk material and was calculated as per Mohsenin (1980). The porosity of the seed was calculated from the average values of bulk density and true density using the relationship.

$$\epsilon(\%) = \left[1 - \frac{\rho_b}{\rho_t} \right] \times 100$$

where, ρ_b = bulk density (g/cm^3); ρ_t = true density (g/cm^3)

2.6. Determination of frictional properties

2.6.1. Angle of repose

The angle of repose is the angle with the horizontal at which the material will stand when piled. The cylinder was placed over a plain surface and flaxseeds were filled in. Tapping during filling was done to obtain uniform packing and to minimize the wall effect if any. The tube was slowly raised above the floor so that whole material could slide and form a natural slope. The height of heap above the floor and the diameter of the heap at its base were measured and the angle of repose (Φ) was calculated by following equation;

$$\Phi = \frac{h}{R}$$

or

$$\Phi = \tan^{-1} \frac{2h}{D}$$

where, Φ = angle of repose ($^{\circ}$); h = height of the pile (cm); and D = diameter of the pile (cm).

2.6.2. Coefficient of static friction

The coefficient of static friction (μ) was determined from three structural materials namely glass, stainless steel, and plywood. A plastic cylinder of 30 mm diameter and 35 mm height was placed on an adjustable tilting flat plate faced with the test surface and filled with the sample. The cylinder was raised slightly without touching the surface. The structural surface with the cylinder resting on it was inclined gradually, until the cylinder starts to slide down. The angle of tilt was noted from a graduated scale (Dutta, Nema, & Bhardwaj, 1988) with the following equation;

$$\mu = \tan \theta$$

2.7. Determination of functional properties of flour

2.7.1. Color characteristics

A Hunter Lab Color Spectrophotometer (Gretag Macthbeth, I-5, USA) was employed to measure the color of the flour samples. A white and black standard tile was used for calibration. The color values were expressed as L^* (whiteness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness). For the color analysis, the flour samples were packed in a transparent zip bag and placed against the light source to measure the color. Three measurements were analyzed for each substitution level and were analyzed at three different locations.

The color difference (ΔE) was calculated by applying the equation;

$$\Delta E = \left[(L^* - L_s)^2 + (a^* - a_s)^2 + (b^* - b_s)^2 \right]^{1/2}$$

The whiteness index values that combine lightness and yellow-blue into a single term was calculated as described by Hsu, Chen, Weng, and Tseng (2003) as follows:

$$WI = 100 - [(100 - L)^2 + a^2 + b^2]^{1/2}$$

2.7.2. Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI of flour were determined as described by Singh, Sandhu, and Kaur (2005). Flour sample (2.5 g) was dispersed into 30 ml of distilled water, using a glass rod, and heated at 90°C for 15 min in a water bath. The cooked paste was cooled to room temperature and transferred to tarred centrifuge tube, and centrifuged at $3,000 \times g$ for 10 min. The supernatant was transferred into a tarred evaporating dish for determination of dry solid content by evaporating the supernatant overnight at 110°C while the sediment was weighed. Triplicate determinations were carried out. WSI and WAI were calculated by the equations;

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

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

2.7.3. Water absorption capacity

WAC of flour was measured by the centrifugation method of Sosulski (1962). Sample (3.0 g) was dispersed in 25 ml of distilled water and placed in pre-weighed centrifuge tube. The dispersions were stirred occasionally, held for 30 min, followed by centrifugation for 25 min at $3,000 \times g$. The supernatant was poured in pre-weighed Petri dish and dried in hot air oven for 25 min at 50°C and the solids remained after drying were weighed. Triplicate determinations were carried out and the water absorption capacities were expressed as gram of water bound per gram of the sample on a dry basis.

$$\text{WAC} \left(\frac{\text{g}}{\text{g}} \right) = \frac{(\text{wt of tube with sample after drying} - \text{wt of tube}) - \text{Sample weight}}{\text{Sample weight}}$$

2.7.4. Oil absorption capacity

For the determination of oil absorption capacity (OAC), the method of Lin, Humbert, and Sosulski (1974) was used. Sample (.5 g) was mixed with 6 ml of corn oil in pre weighed centrifuge tube. The contents were stirred for 1 min with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at $3000 \times g$. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil prior to weighing. Triplicate determinations were carried out and the oil absorption capacities were expressed as gram of oil bound per gram of the sample on a dry basis.

$$\text{OAC} \left(\frac{\text{g}}{\text{g}} \right) = \frac{(\text{weight of tube with sample after removing oil} - (\text{tube weight} + \text{Sample weight}))}{\text{Sample weight}}$$

2.7.5. Least Gelation Concentration

Gelation properties were studied in triplicates by employing the method of Sathe, Deshpande, and Salunkhe (1981). Test tubes, containing suspensions of 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20% (w/v) of material in 5 ml distilled water were heated for 1 h in boiling water, followed by rapid cooling in ice cold water. The tubes were further cooled at 4°C for 2 h. The least gelation concentration (LGC) was determined when the sample in the inverted test tube did not fall down or slip. The results were expressed as no gelation, gel, firm gel, and very firm gel.

2.7.6. Foaming properties

Foaming properties were determined according to the method of Okaka and Potter (1977). One gram of flour was dispersed in 50 ml of distilled water, in a capped test tube, by shaking vigorously for 5 min followed by immediate pouring into a 250-ml graduated cylinder. The volume of the foam formed was then recorded as the foam capacity (%). A final observation was made after 60 min for recording the foam stability (%).

$$\text{Foaming capacity}(\%) = \frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume before whipping}}$$

$$\text{Foaming stability}(\%) = \frac{\text{Foam Volume after 1hour}}{\text{Initial foam volume}} \times 100$$

2.7.7. SDS-sedimentation volume test

Sodium dodecyl sulfate (SDS) sedimentation volume of flour samples was estimated according to the procedure of Axford, Mcdermott, and Redman (1978). Flour (5 g, 14% moisture basis) was added to water (50 ml) in a cylinder, a stopclock was started, and the material was dispersed by rapid shaking for 15 s. The contents were re-shaken for 15 s after 2 and 4 min. After shaking, SDS-lactic acid reagent (50 ml) was added and mixed by inverting the cylinder four times before re-starting the clock. The SDS-lactic acid reagent was prepared by dissolving SDS (20 g) in distilled water (1 L) and then adding a stock diluted lactic acid solution (20 ml; 1 part lactic acid plus 8 parts distilled water by volume). Inversion (four times) was repeated at 2, 4, 5, and 6 min before finally starting the clock once again. The contents of the cylinder were allowed to settle for 40 min before reading sedimentation volume.

2.8. Statistical analysis

The reported data in Table 1 are an average of 10 observations and in rest of the tables are an average of 3 observations. The significant differences were obtained by a one-way analysis of variance followed by Duncan's multiple range test ($p < .05$).

Table 1. Physical properties of flaxseed

Parameters	Flaxseed
<i>Moisture content</i>	
Moisture content (%w.b.)	7.66 ± .52
Moisture content (%d.b.)	8.29 ± .62
<i>Color values</i>	
L^*	46.63 ± .25
a^*	8.21 ± .37
b^*	8.96 ± .01
<i>Geometrical properties</i>	
Length X(mm)	5.43 ± .25
Width Y(mm)	3.39 ± .15
Thickness Z (mm)	1.69 ± .24
Geometric mean diameter D_g (mm)	2.19 ± .03
Arithmetic mean diameter D_o (mm)	3.51 ± .17
Sphericity ϕ (%)	40.34 ± 1.38
Surface area S (mm ²)	15.08 ± .49
<i>Gravimetric properties</i>	
Bulk density, ρ_b (g/cm ³)	.66 ± .08
True density, ρ_s (g/cm ³)	1.34 ± .09
Porosity, ϵ (%)	51.56 ± 4.72
Aspect ratio, R_o (%)	62.58 ± 3.25
Thousand kernel weight (g)	7.14 ± .26
<i>Friction properties</i>	
Angle of repose (°)	19.40 ± 1.27
<i>Static coefficient of friction</i>	
Glass	.32 ± .01
Stainless steel	.36 ± .02
Plywood perpendicular	.33 ± .01
Plywood parallel	.33 ± .01

Note: Results are expressed as mean ± SD of triplicate observations.

3. Results and discussion

3.1. Physical properties

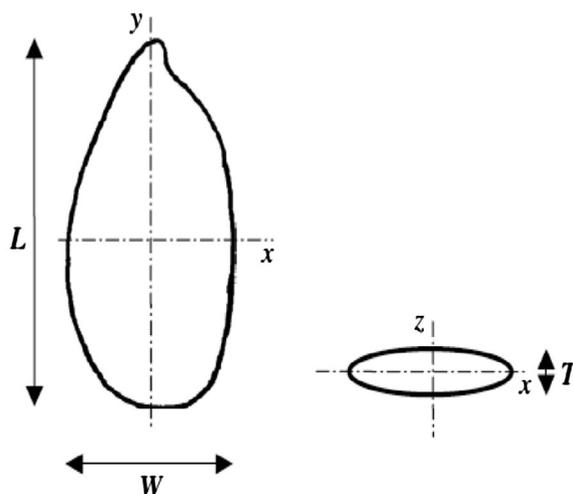
The results of the determined physical parameters of the flaxseed are shown in Table 1. Moisture content of flaxseed was observed as 7.66% on wet basis and 8.29% on dry basis (Table 1). Flaxseed with low moisture content 7.66% is suitable for long-term storage as higher moisture content could cause decomposition of fatty acids by microbial action.

Color parameters including L^* , a^* , and b^* were observed to be 46.63, 8.21, and 8.96, respectively, as shown in Table 1. Based upon color, flaxseed is commercially divided into two parts viz. golden yellow flaxseed and brown color flaxseed. Golden flaxseed is having less omega-3 content as compared to brown color flaxseed. However, brown color flaxseed is preferable for bakery products like cookies, bun, bread etc., and is also utilized in oil processing industry due to high omega-3 content.

3.2. Geometrical properties of flaxseed

Basic geometric characteristics of the flaxseed in terms of length, width, thickness, geometrical mean diameter, arithmetic mean diameter, sphericity, and surface area are presented in Table 1,

Figure 1. Dimensional representation of flaxseed.



and graphical representation is shown in Figure 1. These parameters depend upon the size of the seed, with bigger size seeds having higher values (Owolarafe et al., 2007). Selvi, Pinar, and Yeşiloğlu (2006) reported the length of linseed in the range of 4.58–4.7 mm, and no change in the width and thickness for the moisture range from 8.25 to 11.75% dry basis (d.b.). The sphericity of the flaxseed was 40.34%, which indicates that the shape of the seeds is flat and thus makes it difficult to roll on surface as flat seeds slide easier than spherical seeds, which roll on structural surfaces. Thus, the flat shape of the seeds enables them to slide, and this property is important in the development of hopper and dehuller designs for flaxseed. This is very important in design of hoppers for machines (Omobuwajo, Sanni, & Balami, 2000). The geometric mean diameter of flaxseed was found to be lower than pumpkin, sunflower, and guna seeds, and higher than that of sesame seeds (Gupta & Das, 1997; Joshi, Das, & Mukherjee, 1993).

3.3. Gravimetric properties of flaxseed

Bulk density of flaxseed is presented in Table 1, and the value of bulk density was found to be .66 g/cm³. Coşkuner and Karababa (2007) has reported the bulk density values of 726.6–555.6 kg/m³ for the moisture range of 6.09–16.81% (d.b.), whereas Selvi et al. (2006) observed the bulk density of 690.5–545.0 kg/m³ for the moisture range of 6.09–16.81% (d.b.) for the commercial variety of linseed. The decrease in bulk density of flaxseed may be due to the increase in seed size with moisture content which gives rise to decrease in quantity of seeds occupying the same bulk volume. The true density of flaxseed was observed to be 1.34 g/cm³ and was found to be higher than sunflower kernel (Gupta & Das, 1997) and guna seed (Aviara, Gwandzang, & Haque, 1999). Porosity depends on size, shape, and boldness of seeds, and includes the air spaces in between the seeds during storage. The flaxseed was having porosity value of 51.56% (Table 1). According to Hettiarachchy, Hareland, and Ostenson (1990), presence of more voids in between the seeds leads to accumulation of moisture thereby decreasing the storage stability of flaxseeds. Porosity of the mass of seeds determines the resistance to airflow during aeration and drying procedures. The aspect ratio (R_v) was found to be 62.58%. The 1000 kernel weight was found to be higher as 7.14 gm than reported by Selvi et al. (2006), which was 6.0 g at 8.25% (d.b.) moisture content for linseed.

3.4. Friction properties of flaxseed

The angle of repose indicates the cohesion among the individual units of a material. The higher the cohesion, higher is the angle of repose. Coefficient of static friction of seeds was higher on stainless steel and lowest on glass surface, i.e. $.36 \pm .02$ and $.32 \pm .01$, respectively. Values of the coefficient of static friction of the flaxseed grains on four surfaces are given in Table 1. The results showed higher coefficients for the rough surface such as stainless steel and plywood than that of the smooth surface such as glass. Change in moisture content has a pronounced effect on the friction coefficient of

flaxseed. The angle of repose of flaxseed was 19.40°. The angle of repose of flaxseed is influenced by the moisture content present in the seeds, and seeds with higher moisture content have higher values for angle of repose. The angle of repose of flaxseed was found higher than fenugreek seeds (Altuntaş, Özgöz, & Taşer, 2005) and faba bean grains (Altuntaş & Yıldız, 2007).

3.5. Physical properties of wheat flour and flaxseed samples

Physical properties of wheat flour and flaxseed samples are presented in Table 2. The bulk density of flaxseed is important in relation to its packaging as it determines the capacity of storage, packaging, and transport system (James, 2005). The maximum bulk density value of .49 g/cm³ was found in WF followed by .48 g/cm³ in RFF and .47 g/cm³ in URFF, respectively. It is revealed from the results that roasting significantly increased the bulk density. The lower values of bulk density could be due to low volumes of flaxseeds. The variation in density of flaxseed may be due to the effect of random harvesting of seeds at different maturity stages. A decreased bulk density would be an advantage in infant food formulation. Highest tap density of .81 g/cm³ was found in URFF followed by .77 g/cm³ in RFF and .60 g/cm³ in wheat flour, respectively. It was concluded from the data that true density was significantly affected by treatment and maximum true density was observed in URFF i.e. 1.77 g/cm³ followed by 1.58 g/cm³ in RFF while minimum value was found in WF (1.40 g/cm³). Porosity is a measure of the voids between the solid particles in a material. Pore space can be filled with fluids including gas and/or water. Air filled porosity allows gases to move within the material. URFF was having the maximum porosity of 73.01% while minimum value was found in WF (64.44%). Angle of repose is directly affected by moisture content or fat content of the sample. Higher the moisture content, higher is the angle of repose and was found to be maximum in URFF i.e. 39.71° followed by 36.56° in RFF and 33.60° in wheat flour, respectively. A significant difference in WSI and WAI was observed between wheat flour and different flaxseed samples with a maximum value of WAI i.e. 5.96 g/g in URFF while minimum value was found in WF (4.89 g/g). WAI was found to be higher in URFF samples as compared to RFF samples. Water solubility index is measure of soluble starch content in flour. It was observed that RFF was having highest WSI i.e. 10.83% while minimum value of 4.24% was found in WF.

Table 2. Physical and functional properties of wheat and flaxseed flour

Parameters	WF	URFF	RFF
Bulk density (g/cm ³)	.49 ± .01 ^a	.47 ± .01 ^a	.48 ± .01 ^a
Tap density (g/cm ³)	.60 ± .03 ^b	.81 ± .01 ^a	.77 ± .06 ^a
True density (g/cm ³)	1.40 ± .13 ^b	1.77 ± .19 ^a	1.58 ± .13 ^{ab}
Porosity (%)	64.44 ± 3.72 ^b	73.01 ± 2.80 ^a	69.09 ± 2.99 ^{ab}
Angle of repose (°)	33.60 ± 1.25 ^c	39.71 ± .52 ^a	36.56 ± .26 ^b
WAI (g/g)	4.89 ± .18 ^b	5.96 ± .05 ^a	5.33 ± .57 ^{ab}
WSI (%)	4.24 ± .26 ^c	6.61 ± .20 ^b	10.83 ± .74 ^a
<i>Functional properties</i>			
WAC (g/g)	.63 ± .04 ^b	1.47 ± .17 ^a	1.61 ± .27 ^a
OAC (g/g)	1.14 ± .03 ^a	1.08 ± .19 ^a	.96 ± .20 ^a
Foaming capacity (%)	30.40 ± .76 ^a	9.23 ± .23 ^b	7.82 ± .02 ^c
Foaming stability (%)	56.05 ± 5.56 ^a	54.43 ± 1.07 ^{ab}	48.60 ± .51 ^b
Sedimentation value (ml)	23.56 ± 1.25 ^a	24.93 ± .58 ^a	23.60 ± .50 ^a

Notes: Mean ± SD with different superscripts in a row differ significantly ($p < .05$) ($n = 3$). WF = wheat flour.

URFF = unroasted flaxseed flour; RFF = roasted flaxseed flour. WAI: water absorption index.

WSI: water solubility index; WAC: water absorption capacity; OAC: oil absorption capacity.

Table 3. Physicochemical properties and color of wheat and flaxseed flour

Parameters	WF	URFF	RFF
Moisture (%)	13.55 ± .25 ^a	4.71 ± .23 ^b	4.13 ± .58 ^b
Protein (%)	11.46 ± 1.25 ^b	23.78 ± 2.19 ^a	22.83 ± 2.40 ^a
Crude Fat (%)	1.30 ± .43 ^b	32.27 ± .39 ^a	31.05 ± 1.05 ^a
Ash (%)	.78 ± .05 ^b	3.16 ± .05 ^a	3.29 ± .085 ^a
Crude fiber (%)	.57 ± .19 ^b	9.34 ± .22 ^a	9.63 ± .29 ^a
Carbohydrate (%)	71.47 ^a	26.72 ^b	29.06 ^b
Energy value (Cal/100 g)	346.84 ^b	492.51 ^a	487.04 ^a
<i>Color</i>			
L*	92.65 ± .28 ^a	45.40 ± .31 ^b	34.43 ± .11 ^c
a*	2.13 ± .07 ^c	7.61 ± .15 ^a	6.95 ± .05 ^b
b*	9.89 ± .15 ^b	10.72 ± .07 ^a	9.27 ± .06 ^c
ΔE	-	47.57 ± .30 ^b	58.42 ± .10 ^a
Whiteness index	87.48 ^a	43.84 ^b	33.41 ^c

Notes: Mean ± SD with different superscripts in a row differ significantly ($p < .05$) ($n = 3$). WF = wheat flour. URFF = unroasted flaxseed flour; RFF = roasted flaxseed flour.

3.6. Physicochemical properties of wheat flour and flaxseed samples

3.6.1. Color characteristics

Color is an important quality factor that typically relates to the acceptability, marketability, and wholesomeness of foods (Berrois, Wood, Whitehand, & Pan, 2004). Color characteristics of wheat flour and flaxseed samples are presented in Table 3. The L^* value of 92.65 was found for wheat flour, 45.40 for URFF, and 34.43 for RFF, respectively. Wheat flour was having highest L^* value, lowest a^* value, while lowest L^* value was found in RFF. ΔE value for URFF and RFF was found to be 47.57 and 58.42, respectively. Whiteness index value was found to be highest in wheat flour i.e. 87.48 followed by 43.84 in URFF and 33.41 in RFF, respectively.

3.6.2. Chemical composition

The wheat flour, roasted and unroasted flaxseed flour samples were analyzed for physicochemical properties. The proximate composition of the samples is presented in Table 3. As observed from the data, the moisture content was minimum in RFF and maximum in URFF samples, but both the samples were having less moisture content as compared to wheat flour. The protein content was found to be highest in flaxseed than in wheat flour. The protein content of URFF was observed to be 23.78% highest than 22.83% in RFF. The results for decreased protein content may be due to the fact that roasting may have destroyed some of the protein content. These results are in accordance with those described by Flax council of Canada (2004) and Broihier (1999). The crude fat content of URFF was higher than RFF samples as shown in table 3. The values for crude fat content were 32.27% in URFF and 31.05% in RFF and the decreased fat content is due to the destruction of fat during the treatment process. The ash content of wheat flour was found to be minimum i.e. .78% as compared to other flaxseed samples. The highest ash content was observed in RFF (3.29%) followed by URFF (3.16%) and no significant difference was seen between the ash content of URFF and RFF. The crude fiber content of wheat flour (.57%) was significantly different from both the flaxseed samples and no significant difference was observed in the crude fiber content of URFF and RFF. The carbohydrate content of wheat flour was observed to be maximum (71.47%) and significantly different from flaxseed flour samples. Among the flaxseed samples, maximum carbohydrate content was found in RFF i.e. 29.06% followed by URFF 26.72%, respectively. The decrease in the carbohydrate content of URFF is due to increased fat, protein, and ash content of the sample. The energy value was calculated on the basis of protein, fat, and carbohydrate content of the sample and the energy value of URFF was

found to be maximum, i.e. 492.51 Cal/100g, followed by the energy value of RFF and wheat flour, respectively.

3.7. Functional properties of flour

The functional properties of wheat, roasted and unroasted flaxseed flour samples are presented in Table 2. It was revealed from the results that RFF was having the highest water absorption capacity (WAC) of 1.61 g/g, followed by URFF and WF i.e. 1.47 g/g and .63 g/g, respectively. Flour with high water-binding capacity is associated with more hydrophilic constituents like polysaccharides, non-starch components mainly mucilage (Aboubakar, Njintang, Scher, & Mbofung, 2008). The WAC of wheat flour was found significantly different from flaxseed flour samples. The higher WAC of Flaxseed samples may be due to the presence of hull mucilage polysaccharides which adsorb water and swell (Dev & Quensel, 1986) or due to the existing differences in the conformational characteristics of its proteins. Moreover, gelation of carbohydrates and swelling of crude fibers may also influence the water adsorption of oilseed samples (Narayana & Narasinga Rao, 1982). The OAC is a prominent factor in food formulations as it improves flavor and increases the mouth feel of foods. The OAC was observed to be highest in WF i.e. 1.14 g/g followed by URFF (1.08 g/g) while RFF was having lowest value of .96 g/g. Oil binding capacity of food component is important for various applications because it relies mainly on this capacity to physically entrap oil by a complex capillary attraction process and this property of flour leads to better flavor retention, a consistency trait and an increase in mouth-feel (Khattab & Arntfield, 2009). The foaming capacity of wheat flour (30.40%) was found to be highest and significantly different from flaxseed flour samples. Foaming properties depend on the proteins and carbohydrates present in the flour (Sreerama, Sashikala, Pratape, & Singh, 2012). Among the flaxseed samples, maximum foaming capacity was observed in URFF i.e. 9.23% followed by RFF 7.82%, respectively. Foaming stability of WF was found to be maximum (56.05%), and minimum value was observed in RFF i.e. 48.60%. The higher foam capacity and stability of wheat flour suggests the presence of higher amount of solubilized native protein in the sample. Owing to a large increase in the surface area in the liquid/air interphase, proteins denature and aggregate during whipping and are important for flour to be used in leavened food products such as baked goods, cakes, and biscuits (Sreerama, Sasikala, & Pratape, 2008). Foaming properties are important in the maintenance of the texture and structure of different food products like bakery and ice cream products. The foamability of the flour depends on the presence of the flexible protein molecules which may decrease the surface tension of water (Sathe & Salunkhe, 1982). It was observed from the results that the foam capacity and stability of RFF was less as compared to URFF and may be due to loss of surface proteins during roasting process. Sedimentation value is the indirect measurement of quality and composition of gluten proteins. The sedimentation value was observed to be highest (24.93 ml) in URFF.

Table 4. Least gelation concentration of wheat flour and different flaxseed samples

Flour conc. (%)	WF	URFF	RFF
2	No gel	No gel	No gel
4	No gel	No gel	No gel
6	No gel	No gel	Gel
8	No gel	Gel	Gel
10	No gel	Firm gel	Firm gel
12	Gel	Firm gel	Firm gel
14	Gel	Very firm gel	Firm gel
16	Firm gel	Very firm gel	Very firm gel
18	Firm gel	Very firm gel	Very firm gel
20	Very firm gel	Very firm gel	Very firm gel

Notes: WF = wheat flour; URFF = unroasted flaxseed flour; RFF = roasted flaxseed flour.

3.7.1. Least gelation concentration

LGC of wheat flour and flaxseed samples is presented in Table 4. The ability of proteins to form gels is measured by LGC. No gel formation was observed in WF up to the concentration of 10% while gel was formed in URFF at 8% and in RFF at 6%.

4. Conclusion

The physical properties including seed shape, size, geometric mean diameter, sphericity, bulk density, porosity, surface area, static coefficient of friction and angle of repose, physicochemical and functional properties were investigated. The study reveals that engineering properties including physical and mechanical properties of flaxseed may be useful in designing equipment for postharvest handling and processing operations like deshelling of seed, oil extraction, and pulverization of seed kernel into flour etc. These properties are necessary for the design of equipment for harvesting, separating, processing, packing, and transportation.

This study also provides insight on the physicochemical and functional properties of roasted and un-roasted flaxseed flour in comparison to wheat flour. Statistical analysis showed significant difference between the properties of flaxseed and wheat flour studied. The findings showed that flaxseed is rich in protein and fat, and possess good physicochemical properties that could be exploited for nutrition and food formulation. Flaxseed also possesses good functional properties that may be useful in food systems where they can play many functional roles. The water absorption and OAC of flaxseed flour make it useful for various products that require water and oil retention for their textural integrity like oil retention capability helps retain flavor and provides good mouth feel. Hence, flaxseed can be incorporated in commercial flours which are low in protein as composite flour that can be utilized in bakery products like cookies, muffins, biscuits, and buns. Consumption of foods formulated or fortified with flaxseed flours would be an important step toward relieving protein malnutrition in the poor countries of the world.

Nomenclature

x	Length (mm)
Y	Width (mm)
Z	Thickness (mm)
D_g	Geometrical mean diameter (mm)
R_a	Aspect ratio (%)
D_r	Density ratio (%)
ϕ	Sphericity (%)
D_a	Arithmetic mean diameter (mm)
ρ_t	True density (g/cm^3)
ρ_b	Bulk density(g/cm^3)
ε	Porosity (%)
Φ	Angle of repose ($^\circ$)
h	Height of the pile (cm)
D	Diameter of the pile (cm)
μ	Coefficient of static friction
S	Surface area (mm^2)

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References

- Aboubakar, Njintang.Y. N., Scher, J., & Mbofung, C. M. F., (2008). Physicochemical, thermal properties and microstructure of six varieties of taro (*Colocasia esculenta* L. Schott) flours and starches. *Journal of Food Engineering*, 86, 294–305. <http://dx.doi.org/10.1016/j.jfoodeng.2007.10.006>
- Altuntaş, E., & Yıldız, M. (2007). Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. *Journal of Food Engineering*, 78, 174–183. <http://dx.doi.org/10.1016/j.jfoodeng.2005.09.013>
- Altuntaş, E., Özgöz, E., & Taşer, Ö. F. (2005). Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. *Journal of Food Engineering*, 71, 37–43. <http://dx.doi.org/10.1016/j.jfoodeng.2004.10.015>
- Association of Official Analytical Chemists. (2000). Official methods of analysis (14th ed.) Arlington, VA. Retrieved from http://www.fspublishers.org/published_papers/41283_pdf
- Aviara, N. A., Gwandzang, M. I., & Haque, M. A. (1999). Physical properties of guna seeds. *Journal of Agricultural Engineering Research*, 73, 105–111. <http://dx.doi.org/10.1006/jaer.1998.0374>
- Axford, D. W. E., Mcdermott, E. E., & Redman, D. G. (1978). Small-scale tests of bread making quality. *Milling Feed and Fertilizer*, 161, 18–20.
- Berros, J. D. J., Wood, D. F., Whitehand, L., & Pan, J. (2004). Sodium bicarbonate and the microstructure, expansion and color of extruded black beans. *Journal of Food Processing and Preservation*, 28, 321–335.
- Broihier, K. (1999). Just the flax. Retrieved August 2, 2004, from <http://www.egginnovations.com/pdf/smartchx.pdf> updated on 2004 January 6, 2004
- Chun, J., Lee, J., & Eitenmiller, R. R. (2005). Vitamin E and oxidative stability during storage of raw and dry roasted peanuts packaged under air and vacuum. *Journal of Food Science*, 70, 292–297.
- Coşkun, Y., & Karababa, E. (2007). Some physical properties of flaxseed (*Linum usitatissimum* L.) *Journal of Food Engineering*, 78, 1067–1073. <http://dx.doi.org/10.1016/j.jfoodeng.2005.12.017>
- Deshpande, H. W., & Poshadri, A. (2011). Physical and sensory characteristics of extruded snacks prepared from Foxtail millet based composite flours. *International Journal of Food Research*, 18, 751–756.
- Dev, D. K., & Quensel, E. (1986). Functional properties and microstructural characteristics of linseed flour and protein isolate. *LWT-Food Science and Technology*, 19, 311–317.
- Dutta, S. K., Nema, V. K., & Bhardwaj, R. K. (1988). Physical properties of gram. *Journal of Agricultural Engineering Research*, 39, 259–268. [http://dx.doi.org/10.1016/0021-8634\(88\)90147-3](http://dx.doi.org/10.1016/0021-8634(88)90147-3)
- Flax council of Canada. (2004). Flax nutrition. Retrieved August 11, 2004, from <http://www.flaxcouncil.ca/pdf/smartchx.pdf> updated on February 2, 2004
- Goyal, R. K., Kingsly, A. R. P., Kumar, P., & Walia, H. (2007). Physical and mechanical properties of aonla fruits. *Journal of Food Engineering*, 82, 595–599. <http://dx.doi.org/10.1016/j.jfoodeng.2007.03.019>
- Gupta, R. K., & Das, S. K. (1997). Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research*, 66, 1–8. <http://dx.doi.org/10.1006/jaer.1996.0111>
- Hettiarachchy, N. S., Hareland, G. A., & Ostenson, A. (1990). Chemical composition of 11 flaxseed varieties grown in North Dakota. *Proc. Flax Institute*, 53, 36–39.
- Hsu, C. L., Chen, W., Weng, Y. M., & Tseng, C. Y. (2003). Chemical composition, physical properties, and antioxidant activities of yam flours as affected by different drying methods. *Food Chemistry*, 83, 85–92. [http://dx.doi.org/10.1016/S0308-8146\(03\)00053-0](http://dx.doi.org/10.1016/S0308-8146(03)00053-0)
- James, G. B. (Ed.). (2005). *Food processing handbook* (p. 27). Weinheim: Wiley.
- Joshi, D. C., Das, S. K., & Mukherjee, R. K. (1993). Physical properties of pumpkin seeds. *Journal of Agricultural Engineering Research*, 54, 219–229. <http://dx.doi.org/10.1006/jaer.1993.1016>
- Karababa, E. (2006). Physical properties of popcorn kernels. *Journal of Food Engineering*, 72, 100–107. <http://dx.doi.org/10.1016/j.jfoodeng.2004.11.028>
- Kashaninejad, M., Mortazavi, A., Safekordi, A., & Tabil, L. G. (2006). Some physical properties of Pistachio (*Pistacia vera* L.) nut and its kernel. *Journal of Food Engineering*, 72, 30–38. <http://dx.doi.org/10.1016/j.jfoodeng.2004.11.016>
- Khattab, R. Y., & Arntfield, S. D. (2009). Functional properties of raw and processed canola meal. *LWT – Food Science and Technology*, 42, 1119–1124.
- Krysiak, W., & Motyl-Patelska, L. (2006). Effects of air parameters on changes in temperature inside roasted cocoa beans. *Acta Agrophysica*, 7, 113–127.
- Lin, M. J. Y., Humbert, E. S., & Sosulski, F. W. (1974). Certain functional properties of sunflower meal products. *Journal of Food Science*, 39, 368–370. <http://dx.doi.org/10.1111/jfds.1974.39.issue-2>
- Maduako, J. N., & Faborode, M. O. (1990). Some physical properties of cocoa pods in relation to primary processing. *Journal of Technology*, 2, 1–7.
- Mohsenin, N. N. (1980). *Physical properties of plant and animal materials* (p. 407, 2nd ed.). New York, NY: Gordon and Breach Science.
- Mwithiga, G., & Sifuna, M. M. (2006). Effect of moisture content on the physical properties of three varieties of sorghum seeds. *Journal of Food Engineering*, 75, 480–486. <http://dx.doi.org/10.1016/j.jfoodeng.2005.04.053>
- Narayana, K., & Narasinga Rao, M. S. (1982). Functional properties of raw and heat processed winged bean (*Psophocarpus tetragonolobus*) flour. *Journal of Food Science*, 47, 1534–1538. <http://dx.doi.org/10.1111/jfds.1982.47.issue-5>
- Okaka, J. C., & Potter, N. N. (1977). Functional and storage properties of cowpea powder-wheat flour blends in breadmaking. *Journal of Food Science*, 42, 828–833. <http://dx.doi.org/10.1111/jfds.1977.42.issue-3>
- Omobuwajo, T. O., Sanni, L. A., & Balami, Y. A. (2000). Physical properties of sorrel (*Hibiscus sabdariffa*) seeds. *Journal of Food Engineering*, 45, 37–41. [http://dx.doi.org/10.1016/S0260-8774\(00\)00039-X](http://dx.doi.org/10.1016/S0260-8774(00)00039-X)
- Oplinger, E., Oelke, E., Doll, J., Brundy, L., & Schuler, R. (1989). *Flax: alternative field manual* (pp. 114–126). St. Paul, MN: University of Wisconsin, Corporate Extension.
- Owolarafe, O. K., Olabige, M. T., & Faborode, M. O. (2007). Physical and mechanical properties of two varieties of fresh oil palm fruit. *Journal of Food Engineering*, 78, 1228–1232. <http://dx.doi.org/10.1016/j.jfoodeng.2005.12.049>

- Özdemir, M., & Devres, O. (2000a). Kinetics of color changes of hazelnuts during roasting. *Journal of Food Engineering*, 44, 31–38.
[http://dx.doi.org/10.1016/S0260-8774\(99\)00162-4](http://dx.doi.org/10.1016/S0260-8774(99)00162-4)
- Pittia, P., Dalla Rosa, M., & Lerici, C. R. (2001). Textural changes of coffee beans as affected by roasting conditions. *LWT – Food Science and Technology*, 34, 168–175.
<http://dx.doi.org/10.1006/fstl.2000.0749>
- Raghuramulu, N., Nair, K. M., & Kalyanasundaram, S. (1983). Food analysis. *A Manual of Laboratory Techniques* (pp. 31–136). Hyderabad: National Institute of Nutrition, ICMR.
- Rizzi, G. P. (2003). Free radicals in the Maillard reaction. *Food Reviews International*, 19, 375–395.
<http://dx.doi.org/10.1081/FRI-120025481>
- Sathe, A. K., Deshpande, S. S., & Salunkhe, D. K. (1981). Functional properties of lupin seed protein and protein concentrates. *Journal of Food Science*, 42, 491–492.
- Sathe, S. K., & Salunkhe, D. K. (1982). Functional properties of the great northern bean (*Phaseolus vulgaris* L.) proteins, emulsion, foaming, viscosity and gelation properties. *Journal of Food Science*, 46, 71–81.
- Selvi, K. C., Pinar, Y., & Yeşiloğlu, E. (2006). Some physical properties of linseed. *Biosystems Engineering*, 95, 607–612.
<http://dx.doi.org/10.1016/j.biosystemseng.2006.08.008>
- Shrestha, A. K., & Noomhorm, A. (2002). Comparison of physico-chemical properties of biscuits supplemented with soy and kinema flour. *International Journal of Food Science and Nutrition*, 3, 361–368.
- Singh, N., Sandhu, K. S., & Kaur, M. (2005). Physicochemical properties including granular, morphology, amylose content, swelling and solubility, thermal and pasting properties of starches from normal, waxy, high amylose and sugary corn. *Progress in Food Biopolymer Research Journal*, 1, 44–54.
- Sirisomboon, P., Pornchaloempong, P., & Romphopphak, T. (2007). Physical properties of green soybean: Criteria for sorting. *Journal of Food Engineering*, 79, 18–22.
<http://dx.doi.org/10.1016/j.jfoodeng.2006.01.022>
- Sirisomboon, P., Kitchaiya, P., Pholpho, T., & Mahuttanyavanitch, W. (2007). Physical and mechanical properties of *Jatropha curcas* L. fruits, nuts and kernels. *Biosystems Engineering*, 97, 201–207. <http://dx.doi.org/10.1016/j.biosystemseng.2007.02.011>
- Sosulski, F. W. (1962). The centrifuge method for determining flour absorption in hard red spring wheat. *Cereal Chemistry*, 39, 344–350.
- Sreerama, Y. N., Sasikala, V. B., & Pratapa, V. M. (2008). Nutritional implications and flour functionality of popped/expanded horse gram. *Food Chemistry*, 108, 891–899.
<http://dx.doi.org/10.1016/j.foodchem.2007.11.055>
- Sreerama, Y. N., Sashikala, V. B., Pratapa, V. M., & Singh, V. (2012). Nutrients and antinutrients in cowpea and horse gram flours in comparison to chickpea flour: Evaluation of their flour functionality. *Food Chemistry*, 131, 462–468.
<http://dx.doi.org/10.1016/j.foodchem.2011.09.008>
- Ziegleder, G. (1991). Composition of flavor extracts of raw and roasted cocoas. *Journal of Food Control and Research A*, 192, 521–525.



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