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CHEMICAL COMPOSITION, PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF LUPIN (*Lupinus albus*) SEEDS GROWN IN ETHIOPIA

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ABSTRACT

White lupin (*Lupinus albus*) seeds collected from the local markets of Debretabor (DT) and Dembecha (DB) in Ethiopia were studied for their chemical composition, physicochemical and functional properties. Moisture, total ash, crude protein, crude fat, crude fiber and minerals were determined. Mean values for protein, crude fat, total carbohydrates, crude fiber, and crude ash content of the two samples were 40.22, 8.92, 47.73, 10.08 and 3.15 g/100g, respectively on dry weight basis. The mean values of minerals such as phosphorus, iron, zinc and calcium contents for the samples were 248.90, 12.51, 4.68 and 82.56 mg/100g, respectively on dry weight basis. There was significant difference ($p < 0.05$) on physicochemical properties such as seed mass, seed volume, hull content, hydration coefficient, swelling capacity, cooking time, and seed hardness. However, the mean diameter, bulk density, sphericity, water absorption, swelling coefficient and swelling index were not significantly different between the two lupin seed samples. There was strong positive correlation between calcium content and the cooking time of lupin. The lower calcium concentration leads to a better cook ability and shorter cooking time. Hardness was negatively correlated with water absorption, and positively correlated with cooking time of the lupin seed. The flour obtained from Dembecha lupins was found to be superior to that of Debretabor in terms of the foaming capacity and bulk density. Lupin flour from Debretabor exhibited significantly higher dispersibility and water absorption than Dembecha, while the oil absorption was practically the same for the two lupins. Furthermore, a relationship exists between a water absorption capacity and the least gelation concentration. The results of chemical composition, physicochemical and functional properties for both lupin samples indicated that lupins can be used as a raw material for various food products manufacturing and provide consistency in food processing, analogous to other food legumes. Therefore, the research findings can be used by food companies in recipe development of lupin-based processed foods, including fortified food products to combat the protein-energy malnutrition (PEM) problem in Ethiopia and other East African countries.

Key words: Lupin, Chemical composition, Functional properties

INTRODUCTION

Although humans rely on a diverse range of cultivated plant species for various purposes, only a few staple crops produce the majority of the food supply and many species such as lupins are underestimated and underutilized [1]. Lupins are highly valued as animal feed but have been underutilized as human food yet the seeds are reported [2] to be a rich source of protein (33 - 47%) and oil (6 - 13%). There are also claims that the seeds are rich in dietary fiber and beneficial phytochemicals. Lupins are now receiving national and international interest as a future source of food ingredients that could be used to enhance the nutritional profile of existing food products [3].

Lupin flour can be used in production of different products. It can be added to pasta, crisps, bread and emulsified meat products to increase nutritional value, aroma as well as modify the texture of the end products. Moreover, protein isolate produced from lupin seeds can be utilized for milk and meat imitation products. In the Middle East, lupin seeds are consumed as a snack after they are soaked in water, scalded and dehulled. Additionally, in some European counties, pickle is produced from lupin seeds [4].

Lupinus albus (white lupin) seeds grown in Ethiopia and locally known as '*Gibto*', is used as roasted bean '*kolo'* and to prepare local alcoholic drink '*katikala*' and other food products especially in the northwestern part of the country, after debittering by roasting and soaking the seeds in a river/spring water for 3-7 days (Personal communication with the local people). The high-lysine, low-methionine content of lupin complements that of wheat flour proteins, which are poor in lysine and relatively high in the sulphur-containing amino acids [5]. In addition to their utilization in bakery products, value added products such as pasta, crisps, milk and yogurt analogues, meat analogues, lupin protein isolate for the enrichment of vegetable and fruit based foods can be produced from the lupin flour after removal of the antinutritional factors present in the lupin seeds.

Little is known about the nutritional value, physicochemical and functional properties of locally grown lupins in Ethiopia. This information gap does not allow intensive and extensive utilization of lupin as a value added product (food/feed) in the country. There is little information available for farmers, processors and end-users in utilization of the resource capacity of lupin seeds in the Ethiopian context. It is upon this background that this study sought to investigate the chemical composition, physicochemical and functional characteristics of lupins grown in Ethiopia.

MATERIALS AND METHODS

Materials

Samples of lupin (*L. albus*) seeds were procured from the local markets of Dembecha (DB) and Debretabor (DT) in Amhara region (Northern part of Ethiopia) with different agronomic and material handling practices. All the samples were cleaned manually to remove foreign matter, immature and damaged seeds. The seeds were later ground in

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100-mesh flour, packed in colored glass containers and stored at 4 ^{0}C until analysis. The seed flour obtained was analyzed for proximate chemical composition, physicochemical properties and functional properties. Analytical grade reagents and chemicals were used for laboratory analyses.

METHODS

Proximate composition of lupins

Proximate chemical composition of the seed flour including moisture, crude fat, crude protein, total ash and crude fiber were determined using AOAC official methods of 925.09, 4.5.01, 979.09, 923.03 and 962.09; respectively [6]. Total carbohydrates and utilizable carbohydrate content in the lupin samples were calculated following the methods described by Samati and Rajagopal [7]. Calorie content (kJ) of the seeds was estimated by multiplying the percentage of crude protein, crude fat and carbohydrates by the energy values for gross nutrients conversion factors, 16.76, 37.71, and 15.71, respectively [6]. Seed contents of Ca, Fe and Zn were determined using Atomic Absorption Spectrometer (Model: Spectr AA. 20 plus, Varian Australia) [8]. Phosphorus content was assayed colorimetrically using visible Spectrophotometer (Model: BECKMAN, DU-64 Spectrophotometer).

Physicochemical properties

Unprocessed lupin seed samples were analyzed for seed weight, bulk density, volume, hydration and swelling coefficient, water absorption, swelling capacity and index, seed coat content, pH value, cooking time and texture measurements.

Hundred grain mass, seed dimensions and sphericity

One hundred seed mass was determined by counting 100 seeds manually and weighing them thrice. The final weight as expressed as the mean of triplicate determination. Thirty randomly selected seeds were used to measure length, width and thickness using electronic digital caliper and mean values were calculated. The geometric mean diameter and the sphericity were calculated [9].

Seed volume and density

The bulk density of the lupin seeds was calculated using the standard method of Bishnoi and Khetarpau [10]. 100g of the sample seeds were transferred to a measuring cylinder, which had 100 ml distilled water at 20 ^{o}C. Seed volume (ml/100g seeds) was obtained after subtracting 100 ml from the total volume (ml). The bulk density was then calculated and recorded in g/ml.

Hydration and swelling coefficient

Hydration and swelling coefficients were determined using the typical Youssuf method [11]. The raw lupin seeds were soaked in distilled water for 24 hours and the volume of the lupin seeds was estimated before and after soaking by determination of displaced water. The hydration coefficient was calculated as the percentage increase in weight of lupins. The swelling coefficient was calculated as the percentage increase in volume of lupin after soaking.

Water absorption

Water absorption was determined by soaking 100 g of lupin seed samples in deionized water at a ratio of 1:1. It was left overnight at room temperature. After the water was drained, the soaked seeds were blotted dry and weighed. Water absorption was then calculated from equation:

$$Wa\ (g/g) = \frac{W_2 - W_1}{W_1}$$

Where: W_1 - the initial weight; W_2 - weight after water absorption; Wa – water absorption

Swelling capacity and index

Seeds, weighing 100 g, were counted, their volume noted and soaked overnight. The volume of soaked seeds were noted in a graduated cylinder [10]. Swelling capacity was calculated as change in volume per number of seeds and swelling index was determined as the ratio of swelling capacity per seed to the volume of one seed (ml).

Seed coat content

An accurately weighed sample of 10g was soaked in distilled water for 16 hours at room temperature. After the water was drained, the soaked lupins were blotted dry and the seed coat was removed with tweezers. The seed coats collected were dried in an oven at 60 ^{0}C for 24 h, followed cooling in a desiccator. It was then weighed and the percentage of seed coat was calculated.

pH value

The pH values of the seed flours were determined using AOAC official method 14.022 [12]. Sample suspensions of 20% (w/v) lupin flour were prepared in 10 ml distilled water and the pH of the homogenate was measured at 22 ^{o}C using a pH meter (HANNA instruments, pH 301, Portugal).

Cooking time and texture measurements

Cooking time was determined according to Mattson method [13] and later modified by Jackson and Variano-Martson [14] using Mattson cooking device. A lupin sample (50 g) was soaked-in deionized water (100 ml) for 24 hours at room temperature before cooking, the soaked samples were then positioned into each of the 25 cylindrical holes found in the cooker so that the piercing up of the 82 g rod was in contact with the surface of the lupins. The cooker was placed into a 2 l metal beaker containing 1.5 l of boiling water. The lupins were considered as “cooked” when the tip of the brass rod passed through the seed. Cooking time (time required to cook 50% of the sample) was then recorded from the point of contact between cooker and boiling water.

Approximately 10 g of the cooked lupin samples were loaded on to the sample holder in a single layer and compressed to 75% of the original height with a texture analyzer (LLOYD instruments, TA plus Ametek, UK 2007) as shown in Figure 1 according to the Wang *et al* [15], with slight modification on the load cell capacity which was increased to 2500 N of force. Aluminum polished compressing plate with a diameter of 45 cm and a load cell capacity of 500 N at a crosshead speed of 7 mm min^{-1} was applied to compress the cooked lupins. The maximum compression force was measured, recorded and expressed as the maximum compression force per gram of cooked sample (N force per g of cooked sample). The hardness of the cooked lupins was defined as the maximum force required compressing the lupins.

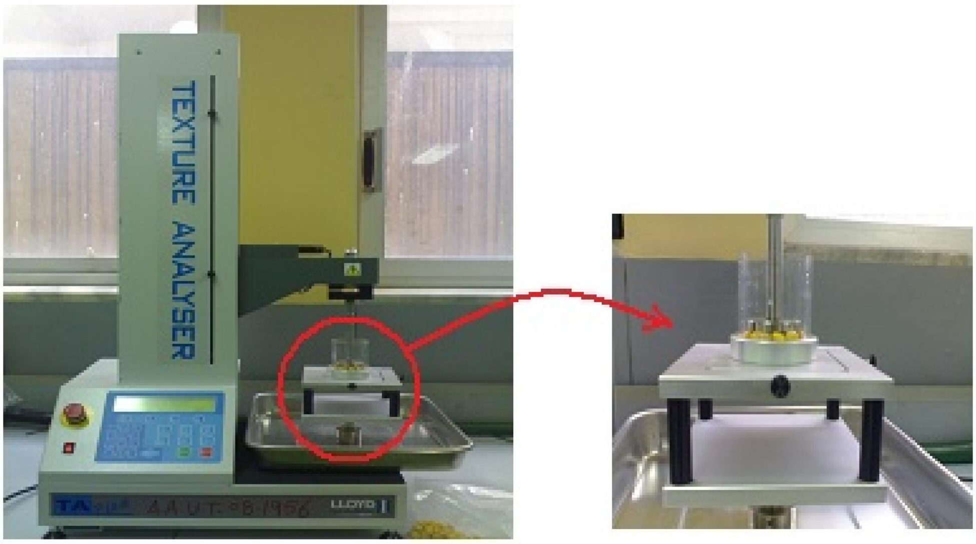

Figure 1: Texture analyzer (LLOYD Instruments, TA plus Ametek, UK 2007)

Functional Properties

Water and oil absorption capacity

The centrifugal Beuchat method [16] was employed to determine the water and oil absorption capacity of the lupin flour. Precisely weighed 1 g of the sample was mixed with 10 ml distilled water and or oil for 30 seconds in a mixer. The samples were then allowed to stand at room temperature for 30 min, and were centrifuged at 5000 x g (DYNAC II Centrifuge, Clay Adams, USA) for 30min. The volume of the supernatant was noted in a 10ml graduated cylinder. Density of water was assumed to be 1g/ml and that of the oil (fully refined soybean oil, Hatun, Turkey) 0.911 g/ml. The results were expressed on a dry weight basis.

Emulsion activity and stability

The emulsion activity and stability were both determined using the methods described by Yasumatsu *et al.* [17]. The emulsion (2 g sample, 20 ml distilled water and 20 ml soybean oil) was prepared in a calibrated centrifuge tube. The emulsion was centrifuged at 2000 x g (DYNAC II Centrifuge, Clay Adams, USA, 1989) for 10 min. The emulsion activity (%), were calculated as the ratio of the height of the emulsion layer to the total height of the mixture. Emulsion stability was determined using the same samples that were prepared for determination of emulsifying activity. Samples were heated at 80 ^{o}C for 30 min in a water bath (BUCHI Water bath B-480, Switzerland), followed 15 min cooling under running tap water and finally centrifuged at 2000 x g for 15 min.

Foaming capacity and stability

The capacity and stability of foam were determined following method described by Lin *et al.* [18]. Exactly 50 ml of 3% (w/v) dispersion of material in distilled water was homogenized for 5 min at speed of 1600 rpm. The mixture was immediately transferred into a 250 ml graduated cylinder and the foam volume was measured. The foaming capacity was expressed as the percentage volume increase (v/v,%). Foaming stability was expressed as foam volume remaining after 15, 30, 45, 60, 90 and 120 min.

Gelation property

Lupin flour dispersions in deionised water with concentration of 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% (w/v) were prepared in test tubes. The dispersions were heated in a water bath (BUCHI Water bath B-480, Switzerland) at 80 ^{0}C for 1 h, followed by rapid cooling under running cold water. The test tubes were set at 4 ^{0}C for 2 h. The least gelation concentration was then determined as the concentration at which the sample from the inverted tube did not fall or slip [19].

Bulk density and dispersibility of flours

Bulk density of flour was determined according to the method described by Narayana and Narasinga [20]. An empty calibrated tube was weighed and filled with a sample to 5 ml by constant tapping until there was no further change in volume. Bulk density was calculated as the mean of the triplicate determination of the weight determined by difference per unit volume of the sample. Dispersibility of lupin flour in water was also determined using the described by Kulkarni *et al.* [21]. Accurately weighed 10 g of each flour sample was placed in a 100 ml measuring cylinder followed by addition of distilled water up to the 100 ml mark. The sample was vigorously stirred, mixed and next allowed to settle for 3 h. The volume of the settled particles was recorded and subtracted from 100 to give a difference which is considered as percentage dispersibilty.

Statistical Analysis

Data were analyzed in triplicate using Statistical Package for Social Scientists (SPSS 15, Chicago, Ill, USA) software for windows. Independent sample *t*-test was used for comparison of means and significance was accepted at 0.05 level of probability ($p < 0.05$).

RESULTS

Proximate chemical compositions

The results of the chemical compositions of the two *L. albus* seeds are presented in Table 1. The lupin from Debretabor showed higher levels of moisture, crude fat, carbohydrates, zinc and calcium than the one lupin from Dembecha. Conversely, lupin those from Dembecha showed higher levels of crude protein, total ash, crude fiber, food energy, phosphorus and iron. Variation in the moisture content of the lupin seeds was high, 8.99 % in DB and 12.27 % in DT due to storage and post harvest seed handling management practices of the farmers. Mean protein, crude fat, total carbohydrates, crude fiber, and crude ash contents of the two samples were found to be 40.22, 8.92, 47.73, 10.08 and 3.15 g/100g, respectively on dry weight basis. The protein content of the lupins was 37.24 % for DT and 43.20 % for DB and closely resembled that of soybean. Furthermore, the crude fiber content was 9.67 % and 10.49 % for DT and DB lupin flour, respectively. The mean phosphorus, iron, zinc and calcium contents for the samples were 248.90, 12.51, 4.68 and 82.56 mg/100g, respectively on dry weight basis. The iron and zinc levels were 8.52 and 5.22 mg/100g for DT and 16.49 and 4.13 mg/100g, respectively.

Physicochemical properties
Results of physicochemical properties of lupin samples from DT and DB are summarized in Table 2. The volume of the two seed samples, (88.33 ml) for DT and (90.67 ml) for DB, also showed significant difference. Generally, there were significant differences ($p < 0.05$) between the seed mass, seed volume, hull content, pH, hydration coefficient, swelling capacity, cooking time, and seed hardness. Nevertheless, no significance differences were noted between the two lupin seed samples in terms of mean diameter, sphericity, water absorption, swelling coefficient and swelling index. Furthermore, calcium content was found have direct positive correlation with the cooking time of lupin. Hardness was found to be negatively correlated with water absorption, and positively correlated with cooking time of the lupin seed.

Functional properties
The most important functional properties of the lupin seed flour in food formulations were characterized in Figure 2, Table 3 and 4. Lupin seeds from Dembecha had significantly ($p < 0.05$) higher bulk density than lupin from Debretabor. Flour obtained from Dembecha lupins was found to superior to that of Debretabor in terms of foaming capacity and bulk density, whereas; lupin flour from Debretabor was better in water absorption and dispersibilty of the flour. The bulk density of lupin flour was 0.61g/ml and 0.75g/ml for DB and DT, respectively. The dispersibility for the DT flour was 56.75% and 51.5% for DB flour. A relationship exists between a water absorption capacity and the least gelation concentration (LGC). LGC for the two lupin flours ranged between 12 to 20 % as shown in Table 4. Figure 2 shows foaming stability of DT and DB lupin flour dispersions.

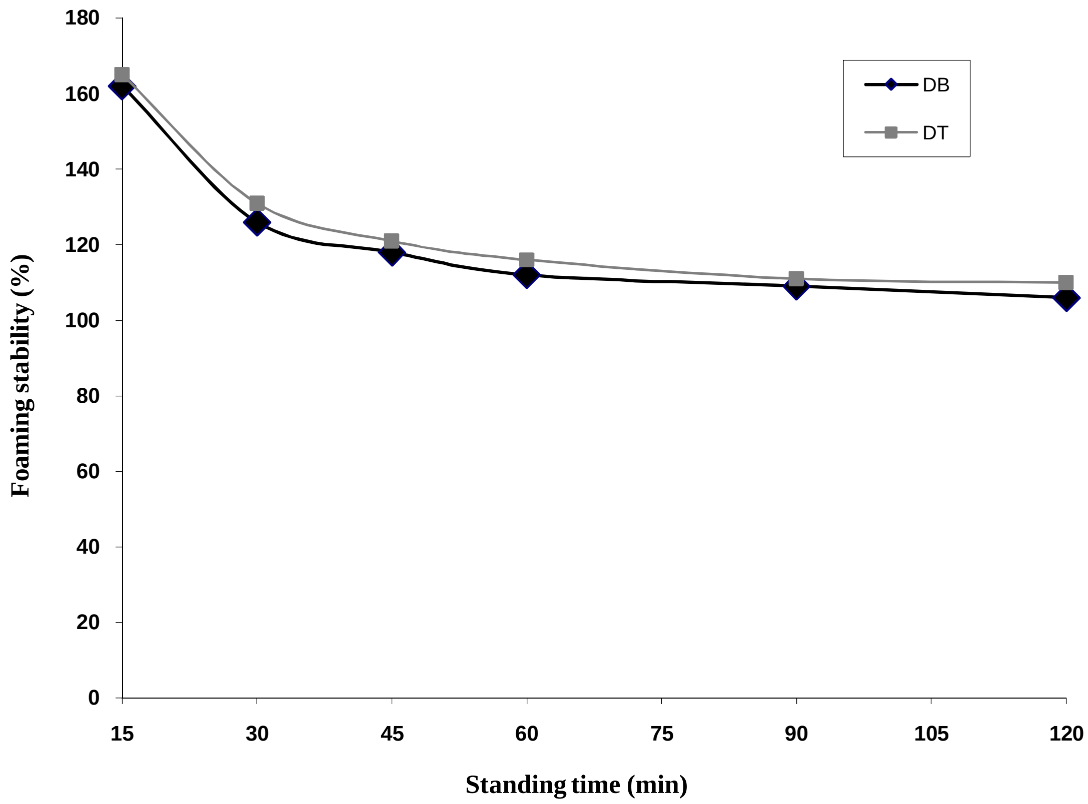

Figure 2: Foaming stability of DB and DT lupins

DISCUSSION

Proximate Composition

Variations in moisture content of the lupin seeds were high. The crude fat content of the lupins was 9.42 % and 8.41 % for DT and DB, respectively. The fat content of the two lupin seed samples were higher as compared with Turkey lupins (5.95%) [22], but less than the 13.63 % crude fat as reported by Solomon [23]. The protein content of the lupins closely resembled that of soybean. Similar results for *L. albus* seed flour were reported [22] in Turkey. A range of 28.6-32.4 % protein in four cultivars of *L. angustifolius* and 40 % protein in one cultivar of *L. luteus* was also reported [24]. This variation was attributed to the characteristics of the growing conditions and the soil types [25]. Lupin generally contains about twice the protein found in those legumes normally consumed by humans. Therefore, based on the recommended average human protein intake of 23-50 g/day lupins could contribute significantly to alleviate the protein malnutrition problem in Ethiopia.

The total ash, which is an indirect indicator of the mineral content of foodstuffs, was found to be 3.01 % for lupins from Debretabor and 3.28 % from Dembecha, slightly higher than the value (2.9 %) as reported by Erbas *et al.* [22]. The ash level of lupins was somewhat variable and has been reported to be dependent on the soil type where the plant was grown. The crude fiber content (9.67% and 10.49 % for DT and DB lupin) was much lower than the value (16.2 %) reported by Erbas *et a.l* [22]. Fibers have many desirable properties, including white color, high water-holding capacity and beneficial effects on human health. Therefore, lupin flour can be incorporated into a wide range of foods to make dietary products. The phosphorus and calcium levels (248.77 and 97.98 mg/100g, respectively) in DT and (249.02 and 67.13 mg/100g, respectively) in DB were less than 400 and 190 mg/100g, respectively reported for *L. albus* seed in Australia [26]. However, the Ca level is still higher than many other crop foodstuffs including wheat, maize and soybean. Therefore, lupins can thus be considered as good sources of dietary calcium and phosphorus. The iron and zinc levels for DB were greater than that reported by Hung *et al.* (4.3 and 3.8 mg/100g) [26] . In a nutshell, mineral composition of lupin favorably compares with that of other dry beans showing that it can help to mitigate the micronutrient malnutrition of the developing regions of the world. The difference in the composition of the DT and DB seeds in this study could be attributed to the growing conditions, agronomic profile and cultivar differences.

Physicochemical Properties

The 100-seed mass showed significant ($p < 0.05$) differences between the two samples, as samples from DT exhibited higher 100-seed weight. The mean diameter and sphericity of DT and DB seed samples were not significantly different. The mean diameter was 7.04 and 7.71 mm, and the sphericity was 0.74 and 0.78 for DT and DB samples, respectively. These values are comparable with the findings of Solomon [23] for white lupin where the mean diameter and sphericity were 7.41 mm and 0.77. The morphology of the seed such as size, uniformity of seed size and seed shape are varietals character that are key factors affecting the dehulling process of pulses [27]. These properties thus play a vital role in the selection of sieves and dehulling machines.

In pulses, a tough, single seed coat tightly envelopes the cotyledons. The percentage seed coats of the whole seeds were found to be 15.8% for DT and 16.97% for DB. This is comparable with the seed coats of chickpea and pigeon pea which was reported to be between 12 and 15% [28]. In some pulses, such as cowpea, green gram and lentil, the seed coat is thin, forming only about 5-10% of the grains [28]. The pH of the lupin flour was 5.37 for DT and 5.30 for DB and showed no significant difference. The pH of haricot bean flour (*Phaseolus vulgaris*) from Ethiopia was higher than the lupin flours' pH, which was reported to be between 6.44 and 6.58 for three cultivars [29]. Soaking forms an integral part of pulse processing operations like germination, cooking and fermentation. On this note, water absorption, swelling coefficient and swelling index of the two lupin seeds were not significantly different, whereas, the hydration coefficient and swelling capacity were significantly different. Hydration coefficient, swelling coefficient and swelling index of DT was less than that of DB. This might be a reflection of the relative hardness and impermeability of DT seed coat as compared to DB seeds. The swelling capacity of DT was higher than that of DB lupin. This could be attributed to the higher seed weight of DT than DB.

Cooking time is one of the main considerations used for evaluation of pulse-cooking quality. Longer cooking times result in loss of nutrients, increased energy use and could limit end uses. Although the cooking time of DB (420.00 min) was lower than that of DT (450.48 min) both generally have a long cooking time. Similar investigation on cooking time was reported up to three hours for soybean seed [30]. It is possible that the long cooking time of lupin could be due to the fact that the Ethiopian *L. albus* seed is a wild species that requires further genetic improvement through breeding techniques to reduce the cooking time. Seed mass, thickness and composition of seed coat and cotyledon, genotype, growing conditions, soil type, and postharvest handling may play a role in prolongation of the cooking time of pulses [15].

This study showed that DT with a calcium content of 97.98 mg/100g had a longer cooking time, while DB with lower calcium content (67.13mg/100g) showed a shorter cooking time. The lower calcium concentration leads to a better cook ability and shorter cooking time. A significant difference was observed between the hardness of DB and DT lupins, with that of DB (188.51 N/g) being lesser than that of DT (198.40 N/g). Cooked lupin hardness was found to be positively correlated with cooking time and similar correlation trends between hardness and cooking time was reported [15].

Functional Properties

The DT flour exhibited significantly higher dispersibility and water absorption than DB, while the oil absorption was practically the same for the two lupins. Water absorption trends 2.65 and 2.05 g/g for DT and DB flours, respectively, were higher than oil absorption trends 1.82 and 1.64 g/g for DT and DB flours, respectively. A number of factors such as hydrophilic-hydrophobic balance of amino acids molecular size and shape influence the water absorption of flours. There are economic benefits in adding water to a product which is priced according to its weight, and a positive impact on the shelf life, hence food manufacturers prefer to incorporate food ingredients with high water absorption capacities in their formulations. An oil absorption capacity is due to binding of fat by non-polar side chains of proteins. High oil absorption of the protein is required in ground meal formulation, meat replacers and extenders, doughnuts, baked goods and soups. The water and oil absorption for three cultivars of haricot bean flour were reported with mean values of 2.14 - 2.45 g/g and 2.49 - 3.52 g/g, respectively [29].

The emulsifying properties, activity and stability, of the two lupin flours were in the same range. The emulsion activity, which reflects the ability of the proteins to aid formation and stabilization of newly created emulsion, was found to be 53.2% and 55% in the DT and DB flours, respectively. Some food proteins are capable of forming good foams, and their capacity to form and stabilize foams depends on the type of protein, degree of denaturation, pH, temperature and whipping methods. The egg white is one of the most commonly used food ingredients for foaming properties. The foaming capacity of DB and DT lupin flour was found to be 68 and 65%, respectively. Since foam capacity appears to be due to solubilized protein, higher values will enhance its functionality in its uses for the production of cakes and whipping toppings where foaming is an important property.

Foam stability is important since success of a whipping agent depends on its ability to maintain the whip as long as possible. The foam stability at room temperature decreased markedly within the first 15 min and next the decrease was gradual up to 90 min and almost stable after that and DB had higher foam stability than DT which is similar with the research report [31]. Bulk density of flour is related to the textural characteristics and eases of rehydration. Dispersibility of flour in water shows the ease of break up of agglomerates which allow particles to sink below the surface and disperse rapidly in a liquid.

Protein gels can be formed when subjected to heat, salts, acids, alkalis and other chemical treatments. Heating and cooling of protein-water systems is one of the most common means of gel formations in food processing. The least gelation concentration (LGC) indicates the gelation capacity and the lower the LGC, the better the gelling ability of proteins. Gelling ability is a function of the ability of the flour to absorb water and swell.

The DB formed a firm and resistant gel at a lower concentration (16%) than DT, which formed such gel at a concentration of 20%. Gelation is not only based on protein quantity but appears to be related to the type of protein as well as to non-protein components. The studied functional properties demonstrate that lupin flour may be used as a good binder and imparts consistency in food preparations such as the semi-solid fermented traditional Ethiopian food '*Siljo*' and other related traditional foods.

CONCLUSIONS

The results of this research exemplified that the white lupins grown in Ethiopia, which are not commonly consumed as other legumes, are very nutritious crops, rich in both the studied macro and micro nutrients. Lupin seeds obtained from Dembecha are better compared to those from Debretabor in crude protein, mineral composition and crude fiber content. Nevertheless, lupins grown at Debretabor are rich in their crude fat, carbohydrates and calorific value.

The results of physicochemical and functional properties for both lupin samples indicated that lupins can be used for various food products manufacturing analogous to other food legumes. Therefore, the research findings can be used by food companies in recipe development of lupin-based processed foods, including fortified food products to combat the protein-energy malnutrition problem in Ethiopia and other East African countries. Follow-up investigations on the phytochemicals composition of lupins as affected by various processing methods of these lupin seeds are required in order to augment the bioavailability of nutrients and trace elements.

Table 1: Proximate and mineral composition including energy contents of two lupin samples

Samples	Proximate compositions (g/100g DMB[a])							Mineral compositions (mg/100g)				Food energy (kJ/100g)
	Moisture	Crude fat	Crude protein	Total ash	Crude fiber	Total carbohydrates	Utilizable carbohydrate	P	Fe	Zn	Ca	
DT	12.27 ± 0.09	9.42 ± 0.06	37.24 ± 0.16	3.01 ± 0.03	9.67 ± 0.20	50.33 ± 0.21	40.66 ± 0.22	248.77 ± 3.53	8.52 ± 0.06	5.22 ± 0.09	97.98 ± 1.75	1770.06 ± 0.14
DB	8.99 ± 0.42	8.41 ± 0.05	43.20 ± 0.86	3.28 ± 0.08	10.49 ± 0.02	45.12 ± 0.11	34.63 ± 0.16	249.02 ± 5.11	16.49 ± 1.48	4.13 ± 0.01	67.13 ± 1.24	1750.01 ± 0.21

All values are means of triplicates ± SD

[a] Values except moisture content are expressed in dry weight basis (DWB)

Table 2: Physicochemical properties of DT and DB lupin seed samples

Property	Lupin	
	DT	DB
100 seed mass (g/100seeds)	38.80 ± 0.87^{a}	28.65 ± 0.28^{b}
Seed volume (ml/100g)	88.33 ± 0.58^{c}	90.67 ± 1.15^{a}
Bulk density (g/ml)	1.13 ± 0.01^{a}	1.10 ± 0.01^{a}
Mean diameter D_m (mm)	7.04 ± 1.20^{b}	7.71 ± 0.56^{b}
Sphericity (φ)	0.74 ± 0.02^{c}	0.78 ± 0.01^{c}
Hull (% w/w)	15.80 ± 0.37^{a}	16.97 ± 0.05^{c}
pH	5.37 ± 0.02^{d}	5.30 ± 0.03^{d}
Water absorption (g/g)	0.92 ± 0.01^{e}	0.92 ± 0.03^{e}
Hydration coefficient	224.09 ± 0.28^{d}	234.48 ± 1.50^{c}
Swelling coefficient	765.83 ± 5.20^{f}	769.17 ± 2.88^{f}
Swelling capacity (ml/seed)	0.47± 0.02^{b}	0.36 ± 0.00^{c}
Swelling index	1.51 ± 0.01^{g}	1.52 ± 0.08^{g}
Cooking time (min)	450.48 ± 0.14^{d}	420 ± 0.20^{b}
Hardness (N/g) *	198.40± 0.8^{c}	188.51 ± 1.05^{d}

All values are the mean ± SD of three independent determinations.

$^{a\text{-}g}$ Means with the same superscript letters within a raw are not significantly different (P > 0.05)

* Samples were cooked for their respective cooking times determined using the Mattson-cooker.

Table 3: Functional properties of lupin flour

Parameter	Sample	
	DT	DB
Bulk density of the flour (g/ml)	0.61 ± 0.007[a]	0.75 ± 0.011[b]
Dispersibilty of the flour (v/v, %)	56.75 ± 0.35[b]	51.50 ± 0.70[c]
Water absorption (g/g)	2.65 ± 0.07[c]	2.05 ± 0.07[d]
Oil absorption (g/g)	1.82 ± 0.00[c]	1.64 ± 0.26[c]
Emulsion activity (v/v, %)	53.20 ± 0.99[d]	55.00 ± 0.00[d]
Emulsion stability (v/v, %)	43.20 ± 0.99[e]	44.75 ± 0.35[e]
Foaming capacity (v/v, %)	65.00 ± 0.23[f]	68.00 ± 0.51[g]

Values are triplicate means ± SD

[a-g] Means with the same superscript letters within a raw are not significantly different ($P > 0.05$)

Table 4: Least gelation concentration of lupin flour

	Flour concentration (w/v, %)									
Samples	2	4	6	8	10	12	14	16	18	20
DT	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	High
DB	Low	Low	Low	Low	Low	Moderate	Moderate	High	High	High

Values are triplicate means ± SD

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