J. Agric. Sci. Mansoura Univ., 28 (10): 7557 - 7569, 2003

COMPARATIVE STUDY ON FLAXSEED PROTEIN PRODUCTS PREPARED BY DIFFERENT METHODS.

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ABSTRACT

Flaxseed has gained attention lately due to its content of functional ingredients. This work deals with the preparation of refined protein products from flaxseed flour. Three protein isolates namely , flaxseed protein isolate I ,prepared by the alkali-extraction isoelectric precipitation of the protein, isolate II, prepared by alkali extraction of the protein then spray drying. Isolate III same as isolate II, but freeze dried. Two flaxseed protein concentrates were also prepared. Concentrate I, prepared by acid washing at the IEP of the protein and concentrate II, prepared by 80% ethanol washing. Results revealed that flaxseed protein isolate I was superior to isolate II and III, regarding its protein content, protein digestibility and functional properties. Concentrate I was better than concentrate II. Amino acid analysis of the flaxseed protein products revealed that lysine was the first limiting amino acid followed by threonine. Chemical score of individual amino acids also confirm the amino acid content (resulting from analysis) of flaxseed protein products. Essential amino acid index and biological value were higher for all flaxseed protein products than that for soybean flour. All protein product were rich sources of sulphur amino acids. Protein products exhibited poor nitrogen solubility as indicated by the nitrogen solubility index, but had favorable water absorption capacity, oil absorption capacity and emulsifying capacity.

Keywords : flaxseed , isolate , concentrate , functional propertise.

INTRODUCTION

Flaxseed (*Linum usitatissimum* L.) is cultivated since 3000 B.C., flax can be traced back to approximately 10,000 years to the stone age people of Switzerland (Anon, 1984). Flax is generally cultivated for its fiber and oil. The ancient Egyptians have consumed linseed oil in their traditional food from the time of the pharaohs to the present day. In Ethiopia, they consume the seed often roasted in a stew (Wat), as a porridge (Gumfo) and a drink (Chilka). People of India and China consume flaxseed in the diet mainly as oil. The extensive, long standing culinary use of flaxseed and domestically produced flax oil strongly suggest a history of safety in those large middle and far Eastern populations. Flaxseed contains generally over 38% oil , which is usually recovered by pressing. The pressed oil cake contains about 8 to 18% residual oil. To obtain an oil free meal, pressing should be followed by solvent extraction. The defatted flaxseed meal contains from 30-36% protein (Oomah and Mazza, 1993). Amino acid composition of flaxseed protein is comparable to those of soybean and canola protein (Bhatty and Cherdkiagtumachai, 1990, Wanasundara and Shahidi, 1994). Pressed and crushed flaxseeds has been mainly used as a fodder especially for ruminants due to its relatively high protein content and favorable digestibility. It has generally been considered unsuitable for food applications, partly due to cyanogenic glycosides contained in flax seed (Oomah and Mazza, 1993). Moist and dry

heat treatments as well as ethanol extraction removes cyanogenic glycosides (Madhusudhan and Singh, 1985, Kozlowska, 1989). As early as 1946, the possibility of isolating proteins from defatted flax meal by an alkali extraction process followed by acid precipitation has been reported (Smith *et al.*, 1964). Other authors described solubilization and isolation of flaxseed proteins by salt or alkali solutions (Sosulski and Bakal, 1969, Madhusudhan and Singh, 1983). The extractability of proteins from Canadian flaxseed cultivars by changing the pH and ionic strength of the medium, and meal to solvent ratio was described (Oomah et al, 1994). Optimization of hexametaphosphate assisted extraction of flaxseed proteins using response surface methodology was also reported (Wanasundara and Shahidi, 1996). Interest in flax proteins has increased because their functional properties such as water binding, oil absorption and emulsifying activity are comparable to soy protein (Dev and Quensel, 1986, Oomah and Mazza, 1993).

In this work different protein products were prepared from flaxseed meal namely: protein isolates and protein concentrates. The conditions of the preparation for the three isolates and two concentrates were different and their effect on the chemical composition, essential amino acids, *in vitro* protein digestibility and functional properties were examined.

MATERIALS AND METHODS

1. Material

Flaxseed was supplied by the Ministry of Agriculture (Season 2002). The oil was first extracted by pressing the oil cake in a laboratory hydraulic press which yielded an oil cake containing 10% oil. This oil cake was further extracted in a soxhlet apparatus using n-hexane until the residual oil did not exceed 1%. The resulting flaxseed flour was spread to dry then finally ground to pass 80 mesh screen.

2. Methods

2.1 Chemical composition

Moisture, oil, protein, ash and crude fiber were determined according to AOCS methods of analysis (1998). Nitrogen solubility index (NSI) also according to AOCS (1987), water absorption capacity as described by Huber (1982), oil holding capacity according to Lee *et al.* (1992) and emulsifying capacity was measured by the method of Swift *et al.* (1961). Nitrogen solubility according to Lyman *et al.* (1953). Amino acid analysis was carried out according to Moore *et al.* (1958) and Spackman *et al.* (1958).The protein sample were hydrolyzed with constant boiling aqueous 6N HCl at 110°C for 24 hours, for tryptophan determination, samples were hydrolyzed with 5M KOH at 110°C for 18 hours. The chemical score CS of essential amino acids, essential Amino Acid Index (EAAI) and Biological value (Bv) were calculated according to Oser (1959).*In vitro* protein digestibility according to Hsu *et al.* (1977).

2.2. Solubilization of flaxseed protein

To determine the normality of sodium hydroxide for optimum solubilization of the protein, flaxseed was solubilized in sodium hydroxide

solutions with different normalities ranging between 0.01 to 0.06 N-NaOH according to Lyman *et al.* (1953). The flaxseed protein was solubilized in 0.03 N sodium hydroxide solution,(proved to be the most efficient normality) at a meal to solvent ratio 1 : 25 using an ultraturrax stirrer for 30 minutes. The protein solution was then subjected to centrifugation at 4000 xg for 20 minutes. The supernatant was saved for further studies while residue was discarded.

2.3. Isoelectric precipitation of the flaxseed protein

The protein extract resulting from 2.2. was subjected to isoelectric precipitation to determine the isoelectric point of the protein (IEP) .The isolelectric point was determined as described by Taha et al (1981) by subjecting protein extract to isoelectric precipitation as follows. Aliquots of the protein extract 40 ml were subjected to pH adjustment using drops of 6 N-HCl (from pH 3 to 6) after pH adjustment the protein extract were centrifuged at 3000 x g for 30 minutes and the volume of supernatant was recorded. Aliquots of supernatant (0.5 ml) were taken for the determination of non-precipitated protein. The percentage of precipitated protein was plotted against the pH in order to determine the isoelectric point of the protein.

2.3.1. Preparation of protein isolates

Flaxseed flour protein was extracted with 0.03 N-NaOH as described in 2.2. The pH of the protein extract was adjusted to its (IEP) determined in 2.3. The precipitated protein was washed twice with acetone, then diethyl ether and finally was spread to dry at room temperature (Taha *et al.*, 1981) isolate (I).

2.3.2. Preparation of Isolate II

In this procedure the protein extract from 2.2 was directly subjected to spray drying (Buchi 190 : 40°C and 400 Vacuum) to yield isolate (II).

2.3.3. Preparation of Isolate III

Here the protein extract from 2.2 was dried in a freeze dryer (EdwardsModulyo – : -40°C and 0.1 Vacuum) to give isolate (III).

2.4. Preparation of protein concentrates

The protein concentrates were prepared by two methods.

2.4.1. By acid wash :

The flaxseed flour was extracted at the IEP (pH 4.5) of the protein, at a flour to solvent ratio of 1:10 for 15 minutes using ultra turrax stirrer, then centrifuged at 4000 x g for 20 min. The supernatant was discarded and the precipitate washed twice with acetone followed by diethyl ether and finally was spread to dry at room temperature (Taha *et al.* 1981) This resulted in concentrate I.

2.4.2. Washing with ethanol :

Flaxseed flour was extracted with 80% ethanol at flour to solvent ratio of 1:10 for 30 minutes using a magnetic stirrer. The extract was then filtered

and the precipitate was spread to dry at room temperature. (Bhatty and Cherdkiagtumachai, 1990)This procedure gave concentrate II.

Experiments were replicated twice while all analysis were carried out in triplicates.

RESULTS AND DISCUSSION

The main components of flaxseed are oil and protein, the latter is concentrated in the defatted meal or flour. Although flaxseed oil has gained interest because of its content of α-linolenic acid (Cunnane and Thompson (1995) untill now, a few comprehensive studies have been published on the meal and its protein products.

1. Solubilization of flaxseed protein:

Table 1 gives the chemical compostion of the flaxseed flour. In order to extract the protein from flaxseed flour, it was necessary to determine the effective normality of sodium hydroxide solution that results in maximum protein extraction. Table 2 shows that maximum protein was extracted with 0.03 N-NaOH, where 98.44% protein was extracted.

The use of sodium hydroxide solution for protein extraction from other oilseed meals was recommended by several investigators (Taha *et al.*, 1981, Lyman *et al.*, 1953, Dev and Quensel, 1986).

Table 1. Proximate composition of flaxseed flour and protein products prepared thereform*

Flaxseed protein products	Protein %	Oil %	Ash %	Crude fiber %	NFE** %	Digestibility %
Flour	41.9	1.03	6.9	15.6	34.6	71.0
Protein isolate I	76.9	1.00	0.9	8.3	12.4	83.0
Protein isolate II	59.6	0.90	1.2	14.2	24.0	74.7
Protein isolate III	57.6	1.01	1.3	14.9	25.4	76.9
Protein concentrate I	63.2	0.90	0.6	6.3	29.0	80.9
Protein concentrate II	58.6	0.90	0.8	6.4	33.3	81.8

*** All values are given on moisture free basis.**

**** NFE: nitrogen free extract calculated by difference.**

Table 2. Nitrogen solubility of flaxseed proteins in different normalities of sodium hydroxide.

Normality of NaOH	N-Solubility %
0.01	10.16
0.02	54.19
0.03	98.44
0.04	87.50
0.05	86.60
0.06	87.50

2. Precipitation of flaxseed protein:

In order to establish the condition for the precipitation of flaxseed protein from the protein extracts (prepared by extracting protein with 0.03 N-

NaOH at 1 : 25, flour : solvent ratio, for 30 min.), the isoelectric point was determined. Figure 1 illustrates the precipitation curve of flaxseed protein and it is evident that maximum precipitation takes place at pH 4-5 where 88% precipitation was affected. Least nitrogen solubility at a broad range pH 3.0-6.0 for flaxseed protein was reported in the literature (Madhusudhan and Singh, 1983).

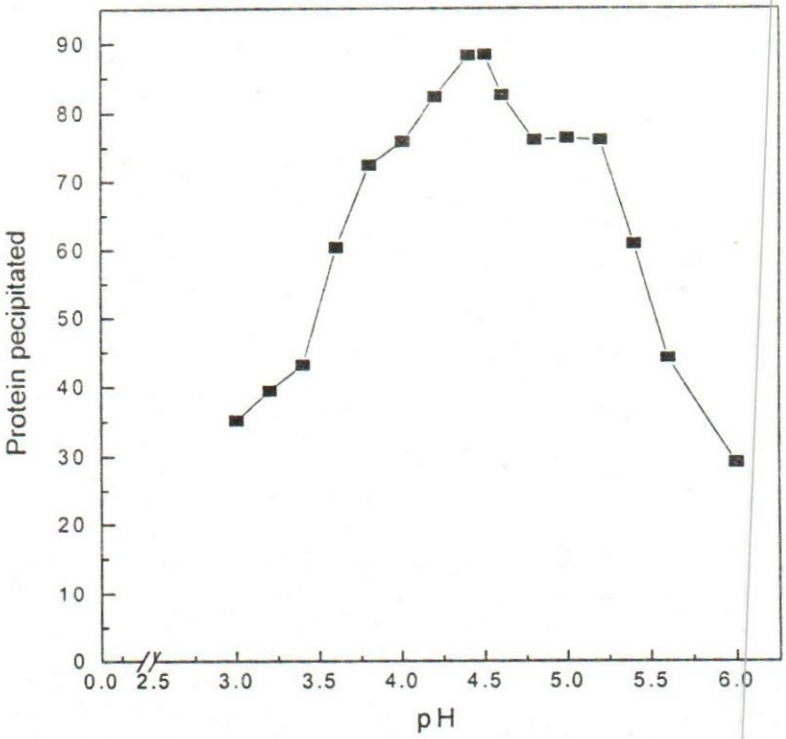

Fig 1. Iso-Electric Precipitation Curve of Flaxseed Proteins.

3. Proximate composition of flaxseed protein products

Table 1 gives the chemical composition of flaxseed protein products, namely, protein isolate I, protein isolate II, protein isolate III, protein concentrate I and protein concentrate II.

Protein contents of isolates I, II and III are 76.9%, 59.6% and 57.6%, respectively. Protein content of isolates prepared from other oilseeds by alkali extraction and isoelectric precipitation range between 90-100% (Taha *et al.*, 1981, Abbasy *et al.* 1981, Taha *et al.*, 1987).

The low protein content of the flaxseed isolates is attributed to the high content of mucilage in the seed hulls. As early as 1964, Smith *et al.* attempted the possibility of isolating flaxseed protein by alkali extraction-acid precipitation, separation and drying of precipitated curd, but results were not as expected. This method although suitable for soybean protein was not effective for flaxseed, since flaxseed hulls are rich in polysaccharide gums

which interfere with the settling and isolation of proteins (Mazza and Biliaderis, 1974). Dev and Quensel (1988) used isoelectric precipitation for the preparation of flaxseed proteins with varying mucilage content and the protein content of these preparations ranged from 56 to 86%.

Protein isolate II and III which were alkali extracted then spray dried or freeze dried, respectively, contain less protein than the acid precipitated isolate, probably because the extracted protein and mucilage are dried together yielding less protein content in the isolates. However spray drying and freeze drying are rather expensive, techniques for the industry and were used only for researches.

Although the presence of mucilage is a disadvantage to the protein content and purity of the isolates, yet these isolates containing mucilage will probably have improved functional properties, also the presence of mucilage exhibits good health effects as reported by (Cunnane and Thompson 1995).

Protein concentrate I prepared by acid washing contained 63.2% protein which is within the normal range of protein concentrates. Dev and Quensel (1989) reported a flaxseed protein concentrate to have 65.5% protein, flaxseed mucilage was reported to be extracted from a hull fraction by use of acidified water at pH 4.5 (Bolley and McCormack, 1952).

Protein concentrate II that was washed with 80% ethanol has protein content less than concentrate I, This may be due to some of the mucilage was not washed out with the soluble sugars and remain with protein. The fact that lower alkanols precipitate mucilage that inevitably, remain with protein , was reported by (Antilla *et al.*, 1999).

4. Essential amino acids, chemical scores and biological value (B.V.) of Flaxseed protein products

Results of amino acid analysis in table 3 reveal that the amino acid composition of flaxseed protein is comparable to that of soybean protein. Comparing the amino acids composition of all flaxseed protein products to the FAO/WHO/UNU pattern (1991) for human adults, it is clear that the first limiting amino acid is lysine followed by threonine. Meanwhile all flaxseed protein products are rich sources of sulphur amino acids. As conformation to these results, it was reported that the protein fraction of flaxseed contains a favourable ratio of amino acids, with lysine, thereonine and tyrosine as limiting amino acids, yet it is considered as a good source of sulphur amino acids namely, methionine and cystine (Oomah and Mazza, 1998). Tables 4 and 5 are self explanatory, they show the calculated chemical score (CS) of each individual amino acids based on egg protein as reference, as well as the essential amino acid index (EAAI) and biological value (BV) of each flaxseed protein products and soybean flour, for comparison. The value of individual amino acids in Table 3 are in agreement with their CS in Table 4. Sosulski and Sarwar (1973), reported that the protein score based on most limiting amino acid relative to FAO nutritional requirements for flaxseed meal is 82 compared to 67 for soybean flour. EAAI for flaxseed flour is 104.05 and is the highest of all the flaxseed protein products, which had EAAI between 86-100, soybean flour show an EAAI of 97. Again Sosulki and Sarwar (1973) reported on EAAI for flaxseed meal 69 compared to 79 and 75 for soybean and canola

Table 3. Essential amino acid composition of flaxseed flour and protein products prepared thereform, together with soy flour and FAO pattern for comparison (g/16 g N).

Amino acid	Flaxseed flour	Flax isolate I	Flaxseed isolate II	Flaxseed isolate III	Flaxseed concentrate I	Flaxseed concentrate II	Soybean flour*	FAO Pattern**
Lysine	4.2	5.2	5.0	5.0	4.9	4.9	6.6	5.8
Histidine	3.1	5.6	5.3	5.4	5.8	5.6	3.1	
Valine	5.6	5.8	5.6	5.7	5.7	5.5	4.9	3.5
Threonine	5.1	3.9	3.6	3.5	4.4	4.2	4.2	3.4
Methionine and cystine	5.0	6.6	6.2	6.3	5.8	5.8	3.0	2.5
Leucine	6.8	6.5	6.2	6.3	7.0	7.2	7.8	6.6
Isoleucine	5.0	5.4	5.5	5.5	5.4	5.0	4.7	2.8
Phenylalanine and tyrosine	9.2	10.1	10.0	10.0	9.9	9.7	8.3	6.3
Tryptophan	1.7	1.2	1.0	1.0	1.0	1.0	1.1	1.1

* Bresani (1981).
** FAO/WHO/UNU pattern (1991).

Table 4: Chemical Score [CS].of flaxseed flour and protein products prepared thereform, together with soy flour pattern.

Amino Acids	Flaxseed flour	Isolate I [normal]	Isolate II [spray dryer]	Isolate III [Freeze dryer]	Concentrate IV [normal]	Concentrate V [alcohol]	Soybean flour VI
Lysine	90	105.5	90.9	104.5	100.9	100	1450.5
Valine	96.3	96.3	85.93	97.8	96.3	96.3	88.9
Threonine	125.0	94.7	77.0	83.3	103.96	101.0	104.2
MethionineCystine	100.9	129.3	110.3	129.3	113.8	115.5	63.8
Leucine	90.9	82.4	72.7	82.4	90.3	94.3	107.95
Isoleucine	106.4	109.0	102.7	115.5	110.9	104.5	105.5
Phenylalanine Tyrosine	113.7	118.95	108.95	121	115.8	115.8	105.3
Tryptophan	114.3	77.0	57.0	57.0	65.7	57.1	77.14

meal, respectively. Our work show the Biological value (BV) of flaxseed flour protein to be 101.69 . Other flaxseed protein products had BV above 90%. Flaxseed protein isolate II had the lowest CS, EAAI and BV of all the protein products investigated probably due to the heat encountered in the process of spray drying during the preparatio0n of the isolate. Dev et al (1986) and Sambucetti et al (1973), reported BV of flaxseed to be 61.6-77.4.

5. In vitro protein digestibility (PD):

Even though the amino acid profile is important in evaluating the nutrition quality of a protein, yet the digestibility of that protein is the primary determinant of the availability of its amino acids. Table 1 shows the PD of the prepared flaxseed protein products. The PD of all protein products prepared from flaxseed flour are higher than that of the flour. Values for PD were in the following decreasing order : Isolate I (83%) > concentrate II (81.8%) >concentrate I (80.9%) > Isolate III (76.9%) > Isolate II (74.7%) > flour (71%). A value of 90% PD was reported for low mucilage flaxseed protein isolate (Wanasundara and Shahidi (1997). Bresani (1981) reported that PD for defatted say flour between 84-90% and for soy isolate between 79-93%.

6. Functional properties of flaxseed protein products

The functional properties of protein products must be taken into account quite apart from its nutritional properties as stated by Finch (1970). Pour-El (1981) has broadly defined functionality as any property of a food or food ingredient except its nutritional ones that affected its utilization.

Table 5: Essential amino acid index(EAAI) and biological Value (B.V.) of flaxseed flour and protein products prepared therefrom

Samples	EAAI	BV
Flaxseed flour	104.05	101.69
Flaxseed Isolate I	100.3	97.59
Flaxseed Isolate II	86.3	82.33
Flaxseed Isolate III	96.02	92.93
Flaxseed Concentrate I	98.36	95.48
Flaxseed Concentrate II	96.18	93.1
Soybean flour	97.18	94.2

6.1. Solubility

Among the functional properties of proteins, solubility is of primary impcrtance due to its significant influence on the other functional properties of proteins (Halling, 1981). In general, proteins used for functionality are required to have high solubility, in order to provide good emulsion, foam, gelation and whipping properties. Nitrogen solubility index (NSI) is generally taken as a measure for the solubility of the protein. Table 6 indicate that NSI of all flaxseed protein products are low ranging between 10.4 to 14.9% compared to soybean 16.5%.

The poor water solubility of flax seed protein is documented (Dev and Quensel, (1986),(1988), Oomah and Mazza, 1993).

Table 6. Functional properties of flaxseed flour and protein products prepared therefrom.

Functional property	Flax flour	Flaxseed isolate I	Flaxseed isolate II	Flaxseed isolate III	Flaxseed concentrate I	Flaxseed concentrate II	*Soybean flour
Nitrogen solubility index (NSI %)	13.38	14.30	11.70	14.09	14.92	10.40	16.48
Water absorption capacity (WAC %)	585.00	580.00	590.00	495.00	480.00	460.00	300.00
Oil holding capacity (OHC g/g meal)	3.50	3.80	3.60	1.58	1.50	4.00	1.88
Emulsifying capacity (EC ml oil/100 g)	18.60	21.80	20.80	21.70	22.00	21.60	20.50

*Taha and Ibrahim 2002.

6.2. Water absorption capacity (WAC)

Since most conventional food products contain more than 50% water, good water holding capacity is important. Consumers tend to avoid products that show free water in the package, such as in fresh meat trays, yoghurt etc. In general water held within a protein structure (gel or powder) can be divided into two categories: water bound to the protein molecule (absorbed) and the water trapped within the protein matrix (retained water) water holding determines the acceptability of a given food regarding texture, juiciness,and mouth feel.

Table 6 indicate the high water absorption capacity of flaxseed protein products probably due to the mucilage content of the products. WAC for all products range from 590 to 460% compared to 300% for soybean flour. It is reported that flaxseed products generally exhibit favourable water absorption (Dev and Quensel, 1986). The high absorption capacity of flaxseed protein products make it suitable for incorporation in baked foods, pasta products, doughnuts and others.

6.3. Oil holding capacity (OHC)

The oil holding capacity of a protein based food as the water holding capacity not only determines the acceptability of given food product (texture, juiciness, mouth feel) but also the profit margin. Formulations that result in poor water and fat holding capacity directly translate to liquid losses during processing (cooling, freezing,....etc).

Results in table 6 reveal superior oil holding capacity of flaxseed protein products over soybean flour. OHC values range from 1.50 to 4.0 g/g sample.

Dev and Quensel (1986) demonstrated that in general flaxseed protein exhibit favorable oil absorption and that the alkali extracted acid precipitated flaxseed protein isolates held four times less oil than soybean isolate. The good OHC of the products suggest their use in the meat industry.

6.4. Emulsifying capacity (EC)

One of the primary functional requirements of several food systems is the ability to form emulsion.

An emulsion is defined as a suspension of two immiscible liquids, but the structure of most food emulsion is much more complex.

Emulsion capacity is the parameter must commonly estimated in various studies where oil-water emulsion are involved. Table 6 show that all flaxseed protein products except flaxseed flour possess higher emulsifying capacity than soybean flour. EC ranges between 18.6 to 22.0 ml oil/100 g sample. Dev and Quensel (1986) reported flaxseed protein products to have good emulsifying activity. Same authors (1989) evaluated flaxseed protein products containing different levels of polysaccharide gums as additives in food systems such as canned-fish sauce, meat emulsion and ice cream. Generally flaxseed protein products were found to have emulsion stabilizing effects comparable with those of gelatin.

7. Comparison between different methods used for the preparation of protein products

Comparing previous results it can be concluded that the preparation of flaxseed protein isolate is more appropriate by alkali extraction and acid precipitation thus isolate (I) which is characterized by higher protein content, better digestibility and functional properties than the other two isolates prepared by spray drying or freeze drying.

With refrence to the concentrates, generally concentrate I prepared by acid washing at the IEP (pH 4-5) can be considered better than concentrate II prepared by alcohol washing.

Thus, the protein isolate I and concentrate I are the most useful protein products prepared from flaxseed flour. They can also be prepared locally, as additives to food systems, from the pressed flaxseed flour resulting from oil production. In addition, some of their specifications meet with and or rank higher than those of soy protein.

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J. Agric. Sci. Mansoura Univ., 28 (10), October, 2003

مقارنة بين نواتج بروتينية لبذرة الكتان تم تحضيرها بطرق مختلفة

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تهدف هذه الدراسة الى انتاج مكونات غذائية تدخل في تركيب الأغذية الوظيفية وذلك من بذرة الكتان لما يحتويه من مكونات غذائية هامة.

لهذا فقد تركزت الدراسة في هذا البحث على تحضير عدد من النواتج البروتينية عالية القيمة الغذائية من دقيق بذرة الكتان بطرق مختلفة وعمل مقارنة بينهم فقد تم تحضير مكونات بروتينية وهي Isolate I , Isolate II and Isolate III المستخلص الأول قد تم تحضيره عن طريق الترسيب بالتعادل الكهربي للمستخلص القلوي أما المستخلصين الآخرين تم تحضيرهما مع اختلاف طريقة التجفيف للمستخلص القلوي لكليهما الثاني تم تحقيقه باستخدام جهاز ال Spray dryer للتجفيف والثالث تم تحقيقه باستخدام ال Freez dryer للتجفيد كما تم تحضير اثنين من المركزات البروتينية لدقيق بذرة الكتان Concentrate I عن طريق الغسيل الحمضي عند درجة التعادل الكهربائي للدقيق والثاني البروتينية Concentrate II عن طريق الغسيل بايثانول ٨٠ % وقد اوضحت النتائج أن المستخلص الأول Isolate I هو أفضل المستخلصات من حيث نسبة البروتين والهضم والتحسن في الخواص الوظيفية وقد وضح ايضا أن المركز الأول Concentrate I أفضل من المركز الثاني Concentrate II وقد ظهر من تحليل الأحماض الأمينية باستخدام جهاز تحليل الأحماض الأمينية أن هناك نقص في كلا من حامض الليسين والثريونين لجميع المستخلصات والمركزات المستخدمة كما اتضح ايضا من النتائج أنها غنية بالأحماض الأمينية الكبريتية ال Chemical score يؤكد محتوى الأحماض الأمينية الناتجة من التحاليل أما بالنسبة ل Essential amino acid Index و Biological value كانت أعلى في جميع النواتج عنها في كسب فول الصويا.

وبدراسة الخواص الوظيفية لهم وضح انخفاض ملحوظ في الذوبانية النيتروجينية والتي دل عليها قيم معامل الذوبانية النيتروجينية (NSI) في حين اظهرت تحسن ملحوظ في كل من القدرة على امتصاص الماء والقدرة على امتصاص الزيت وايضا القدرة على الاستحلاب.

ونتيجة لهذه الدراسة ممكن أن تستخدم هذه النواتج لدقيق بذرة الكتان في انتاج مكونات غذائية وظيفية لبعض الأغذية الوظيفية.