Food Chemistry **48** (1993) 109–114

Flaxseed proteins—a review

B. D. Oomah & G. Mazza

Crops Utilization Laboratory, Agriculture Canada Research Station, Morden, Manitoba, R0G 1J0, Canada

(Received 28 August 1992; received in revised version 11 January 1993; accepted 11 January 1993)

The literature on the protein content, amino-acid composition, fractionation, and functional properties of flaxseed proteins is reviewed and summarized. The discussion on the fractionation centers on the methods for isolation of the various protein fractions and on the physico-chemical characteristics of high- and low-molecular-weight fractions. Most interesting are the favorable functional properties of flaxseed proteins and the wide range of potential products in which they can be incorporated.

INTRODUCTION

Flax (*Linum usitatissimum* L.) cultivated commercially as a field crop is generally considered a non-edible oilseed. The high level of linolenic acid (57% of total fatty acid) in flaxseed oil is commercially exploited in the manufacture of several industrial products, such as paints and plastics. Linseed oil is one of the few non-edible oils that can be processed into edible-grade products either by genetic improvement (Green, 1989) or through processing into hydrogenated fats. The defatted cake is generally unfit for any food applications and is used to a limited extent in livestock feed, particularly for ruminants.

The presence of biologically active phytochemicals believed to possess cancer-preventive properties has generated increased interest in flaxseed (Caragay, 1992) and oilcake (meal), which has traditionally been used for animal feed.

World flaxseed production was approximately 2·3 million tonne in 1990–91 compared with 23·8 million tonne for rapeseed and 105·5 million tonne for soybean. Production in 1991–92 increased to 2·7 million tonne. The annual world production of linseed oil and meal has been stable at 0·6 and slightly above 1 million tonne, respectively. Factors such as reliability of supply, variability in quality, and the presence of antinutritional components, especially cyanogenic glycosides (Oomah *et al.*, 1992), have limited the use of flaxseed meal in the formulation of feed rations. Many of these constraints have hindered new opportunities for greater exploitation of this under-used protein source.

TOTAL PROTEINS

The protein content in flaxseed has been reported to range from 10·5% (Baijpai *et al.*, 1985) to 31% (Salunkhe & Desai, 1986). The protein and oil contents of flaxseed from the most important cultivars grown in Canada are presented in Table 1. Protein values are generally well above 36%. Differences can be attributed to both genetics and environment. As in other oilseeds, a negative correlation is observed between the oil and protein contents of the seeds (Naqvi *et al.*, 1987; Bajpai *et al.*, 1985). However, the relationship between protein and oil contents in the same populations varies from year to year and from location to location (Table 1). Thus, whereas an increase in oil percentage may lead to a decrease in protein percentage, it does not result in a decrease in the protein content of the oil-free meal (Rowland, 1982).

Higher seed-protein levels can be achieved by increasing the application of nitrogen fertilizer. Gad and El-Farouk (1978) reported that increasing the N availability to 45 kg/ha increased the flaxseed-protein content as well as the oil concentration. Singh and Singh

Table 1. Protein and oil contents of flaxseed from the most important cultivars grown in Canada in 1987, 1988, and 1989

Cultivar	Protein* (%)			Oil† (%)		
	1987	1988	1989	1987	1988	1989
Linott	32·5	34·9	36·5	43·2	42·0	43·2
Noralta	31·4	33·9	35·8	42·1	40·5	41·0
Dufferin	31·4	34·1	na	44·8	42·8	na
McGregor	31·3	33·8	34·7	43·9	41·8	42·4
NorLin	32·0	34·0	35·7	43·6	41·8	42·2
NorMan	32·5	34·6	36·2	44·6	42·7	43·3
Vimy	31·3	34·1	36·2	44·6	43·0	43·9
Andro	32·8	34·6	36·4	43·2	41·8	42·6
Somme	32·4	34·4	36·3	43·5	42·1	42·7
Flanders	32·5	34·6	36·0	44·7	42·9	43·7
AC Linora	na	34·7	36·7	n/a	43·0	43·9

* N × 6·5, oil-free, moisture-free basis.
† Dry-weight basis.
na, Data not available.

Food Chemistry 0308-8146/93/$06.00 © 1993 Elsevier Science Publishers Ltd, England. Printed in Great Britain

(1978) obtained higher seed-protein contents at the expense of the seed-oil level with increased application of N and P fertilizers. Similarly, Anderson and Spencer (1950) reported that nitrogen deficiency lowers the concentration of total and non-protein nitrogen in flaxseed, and sulfur deficiency increases the concentration of protein nitrogen.

AMINO-ACID COMPOSITION

Few data on the amino-acid composition of flaxseed are available. The amino-acid profiles of seed from a brown-seeded NorLin and two yellow-seeded Foster and Omega flax cutivars are presented in Table 2 together with the amino acid composition of laboratory defatted flaxseed flour and soy flour as reported by Dev *et al.* (1986) and Friedman and Levin (1986), respectively. Generally, the amino-acid pattern of flaxseed is comparable with that of soy, with both oilseeds having relatively high levels of aspartic acid, glutamic acid, leucine, and arginine. Sosulski and Sarwar (1973) reported results similar to those presented in Table 1.

PHYSICO-CHEMICAL PROPERTIES

Nitrogen solubility

The effect of parameters such as pH, meal-to-solvent ratio, composition of the solvent, salt concentration, heat treatment, etc., on the nitrogen extractability of defatted linseed meal has been reported (Dev *et al.*, 1986; Madhusudhan & Singh, 1985*a*). The broad pattern of the nitrogen extractability of linseed at varying pH and ionic strength is comparable with other defatted oilseed meals. The minimum extractability of nitrogenous matter from oil-free flaxseed meal was observed by Smith *et al.*, (1946) at pH 3·8 and by Painter and Nesbitt (1946) at pH 3·5–4·0. Madhusudhan & Singh (1983), however, recently reported a much broader pH range of least nitrogen solubility (pH 3·0–6·0) for demucilaged, defatted, and dehulled flaxseed meal. About 20–24% of the total nitrogen is soluble at the isoelectric point (Dev *et al.*, 1986; Madhusudhan & Singh, 1985*b*), and this is due, to a large extent, to the presence of high levels of non-protein nitrogen (Bhatty *et al.*, 1973; Sosulski & Bakal, 1969), which is not recoverable by a protein-isolation process involving the use of alkali extraction and acid precipitation.

The solubility of nitrogen from defatted flax flour has been investigated in several solvent systems. Of the total meal nitrogen, 42–52% was found to be water-soluble, 34–47% soluble in 5% NaCl, 1–2% soluble in 70% ethanol, and 3–3·5% soluble in 0·2% NaOH (Sosulski & Bakal, 1969). However, Panford (1989) later observed that water extracted only 25% whereas NaCl, 70% ethanol and 0·1N NaOH extracted 29·4 and 42% of the total meal nitrogen, respectively.

Table 2. Amino-acid composition of NorLin, Foster, and Omega flaxseed

Amino acid*	NorLin	Foster	Omega	Flaxseed flour†	Soy flour‡
Aspartic acid	9·3	10·0	9·7	8·3	11·7
Threonine	3·6	3·8	3·7	3·1	3·6
Serine	4·5	4·7	4·6	4·1	4·9
Glutamic acid	19·6	20·0	19·7	22·8	18·6
Proline	3·5	3·8	3·5	3·0	5·2
Glycine	5·8	5·9	5·8	4·9	4·0
Alanine	4·4	4·7	4·5	4·3	4·1
Cystine	1·1	1·8	1·1	nd	1·1
Valine	4·6	5·1	4·7	4·9	5·2
Methionine	1·5	1·4	1·4	3·0	1·2
Isoleucine	4·0	4·1	4·0	4·6	4·7
Leucine	5·8	6·0	5·9	6·5	7·7
Tyrosine	2·3	2·4	2·3	4·6	3·4
Phenylalanine	4·6	4·8	4·7	6·5	5·1
Histidine	2·2	2·1	2·3	5·9	2·5
Lysine	4·0	4·0	3·9	6·0	5·8
Arginine	9·2	10·0	9·4	10·4	7·3

* In g/100 g protein.
† From Dev et *al.*, 1986.
‡ From Friedman and Levin, 1989.
nd, Not reported.

FRACTIONATION OF PROTEINS

Several methods have been used for the isolation of flaxseed proteins. The earlier methods were of the classical type, namely, extraction of the meal with salt solution and precipitation of the protein by removal of the salt by dialysis (Osborne, 1892). Because Osborne's method of protein isolation is commercially impractical, the possibility of isolating the protein from oil-free meal by alkaline extraction, acid precipitation, separation, and drying of the precipitated curd was explored by Smith *et al.* (1946). This method, which is suitable for the isolation of soybean protein, was not effective for flaxseed, since flaxseed hulls are rich in polysaccharide gums (Mazza & Biliaderis, 1989), which interfere with the settling and isolation of the protein. To overcome this problem, Smith *et al.* (1946) attempted to improve protein extraction by removing the hull with graded sieves and air separation. The protein yield of solvent-extracted dehulled flaxseed meal was 44%, with a 75% nitrogen recovery for three successive extractions.

Mandokhot and Singh (1979) degummed flaxseed by soaking the seed in 1% HCl for 16 h, decanting, and subsequently washing with 1% HCl and water. The protein content of the degummed and defatted meal was 55·6% (N × 6·25). The solubility of the nitrogen present in this product was lowest at the pH 3–6 range and highest at pH 8 and above. About 85% of the total nitrogen of the degummed flaxseed protein was extracted with 1M NaCl at pH 7·0. These authors also demonstrated a shift in the minimum nitrogen solubility of the degummed flaxseed protein in the presence of NaCl to the acidic side, pH 0·5–4·5.

Protein can be separated from defatted flaxseed meal by isoelectric precipitation. Sosulski and Bakal (1969)

isolated protein from hexane-defatted ground flaxseed with 0·2% sodium hydroxide (1 : 20 meal-to-solvent ratio) and then precipitated by adjusting the pH to the isoelectric point of 4·5. The low nitrogen content of the isolated protein, in spite of its high extraction rate of 91–96% of meal nitrogen, led these authors to conclude that much of the extracted protein was not precipitated at pH 4·5. However, from an alkaline extract (0·5M NaOH, pH 10·0) of defatted flaxseed flour, only 77% of extracted protein was precipitated at pH 4·1 (Dev *et al.*, 1986). Dev and Quensel (1988) used isoelectric precipitation for the preparation of flaxseed proteins with varying gum content. The crude-protein content of these preparations ranged from 56 to 86%.

Several attempts have been made to extract flaxseed protein with buffered salt solutions. Vassel and Nesbitt (1945) described the isolation of a major flaxseed protein that they termed linin. In their procedure, fat-free flaxseed meal was extracted with a 0·2M phosphate buffer (pH 7·2)–ethylene glycol mixture (1 : 1·4 buffer-to-ethylene-glycol ratio). The glycol extract was then brought to alkaline pH 10·0 and diluted with water, and the gum was precipitated by adding dioxane. The supernatant was first diluted and then acidified to pH 4·5 to precipitate the proteins. Youle and Huang (1981) extracted protein by grinding flaxseed in 0·035M phosphate buffer (pH 7·5) in 1M NaCl. Their low-molecular weight proteins, mostly albumins, 2*S*, accounted for 42%, whereas the globulin (11*S*) protein made up 58% of the total salt-to-soluble proteins. Dev and Sienkiewicz (1987) extracted total proteins from oil-free flaxseed meal, which had been passed through a 0·25-mm screen, with 0·66M Sörensen phosphate buffer (pH 7·6) containing 1·0M NaCl by using a meal-to-solvent ratio of 1 : 20. The protein was further separated on a Sephadex G-200 column by eluting with phosphate buffer (0·66M, pH 7·6) into three distinct peaks. Madhusudhan and Singh (1983) extracted the protein from degummed, defatted, and dehulled flaxseed meal with 1M NaCl. About 85% of the total nitrogen was extracted with 1M NaCl at pH 7·0. Gel filtration on Sepharose 6B separated this protein into three fractions accounting for 3, 67, and 30% of the total content. Ion-exchange chromatography on DEAE- Sephadex eluted the total protein between 0 and 0·5M NaCl into four peaks. The presence of these four proteins was also confirmed by the sedimentation-velocity patterns in 1M NaCl of $S_{20,w}$ of 1·4, 5·0, 9·0, and 14·0*S* in relative proportions of 20, 10, 66, and 4%, respectively.

High-molecular-weight fraction

Initial attempts to isolate the 12*S* protein from flaxseed by differential isoelectric precipitation at pH 5·7 were made by Vassel and Nesbitt (1945). The purified linin was shown to be homogeneous, with an isoelectric point of pH 4·75, containing 17% nitrogen, 0·6% sulphur, and 0·54% carbohydrate. Madhusudhan and Singh (1985*b*) isolated and characterized the major fraction of linseed protein by ammonium sulfate (20%) fractionation, and purification on a Sepharose 6B column by elution with 0·05M phosphate buffer, pH 7·6. The major protein fraction eluting at 0·24M NaCl on DEAE Sephadex accounted for nearly 66% of the total proteins. The protein prepared by this method was found to be homogeneous by gel filtration, ion-exchange chromatography, PAGE, and ultracentrifugation. The protein contained less than 0·5% carbohydrate and no phosphorus. Dev and Sienkiewicz (1987) extracted the protein in 0·066 M phosphate buffer, pH 7·6, in 1 M NaCl. The supernatant was cryoprecipitated at 4°C and purified on a Sephadex G-200 column by eluting with phosphate buffer. In the analytical centrifuge, this protein displayed a sedimentation coefficient ($S_{20,w}$) of 11·45.

Madhusudhan and Singh (1985*c*) have characterized the physico-chemical and hydrodynamic properties from the major fraction of flaxseed protein (12*S*) (Table 3). The protein has an $S_{20,w}$ of 12 in the presence of 1M NaCl although *S* values of 11·45, 11·0, and 9·0 have been reported (Dev & Sienkiewicz, 1987; Youle & Huang, 1981; Madhusudhan & Singh, 1983). In the absence of NaCl, the 12*S* protein dissociates into 10*S* and 7*S* components in a 90 : 10 ratio by ultracentrifuge peak area, respectively. The intrinsic viscosity of the protein in phosphate buffer is 0·031 dl/g, indicating it to be globular. The molecular weight of the protein as determined by various approaches varies from 252 000

Table 3. Physico-chemical properties of 11*S* (high-molecular-weight) and 2*S* (low-molecular-weight) protein fractions from flaxseed

Property	11*S**	Carmin†	2*S*‡
Total protein (%)	66	65	20
Extinction coefficient			
(*E*, 1%, cm, 280)	7·6	11·2	
Sedimentation coefficient ($S_{20,w}$)	12	12·7	1·6
Diffusion coefficient			
($D_{20,w} \times 10^{7}$, cm^2/s)	3·7	5·5	10·74
Molecular weight			
Archibald method	294 000		17 000
Sedimentation diffusion	298 000	240 000	16 000
From viscosity data	252 000	290 000	
Gel filtration			15 000
Fluorescence emission maximum (nm)	320	323	340
Secondary structure (%)			
α-Helix	3 ± 1	3 ± 2	26
β-Structure	17	15 ± 3	32
Aperiodic	80	82 ± 5	42
Sub-unit Composition			
SDS–PAGE	5	6	1
Urea–PAGE	6		
Stokes radius (Å)	58·3	40 ± 3	
Intrinsic viscosity (dl/g)	0·031	0·037	
Frictional ratio (f/f_0)	1·32	1·05	
Hydrophobicity and related parameters			
Average hydrophobicity (cal/residue)	881	824	
NPS (frequency of non-polar side chains)	0·27	0·26	
P (ratio of volume occupied by polar to non-polar residues)	1·22	1·69	
Total number of amino acids per 100 000 g of protein	871	885	

* From Madhusudhan and Singh (1985*c*).
† From Prakash and Narasinga Rao (1986).
‡ From Madhusudhan and Singh (1985*d*).

to 298 000. The secondary structure consists of 3–4% α-helix, 17% β-pleated, and nearly 80% aperiodic structure and closely resembles that of carmin, the high-molecular-weight protein of safflower (Prakash & Narasinga Rao, 1986). The amino-acid composition indicates the protein to be rich in aspartic and glutamic acids as well as basic amino acids. The average hydrophobicity value of 880, calculated according to Bigelow's (1967), and Waugh's (1954) NPS of 0·27 suggests that the protein is globular and that most of the non-polar residues are buried inside the protein molecule. Comparison of the hydrophobicity and related parameters of the high-molecular-weight proteins of flaxseed and soybeans suggests close similarity of their functional properties, especially surface properties, i.e. surface tension, emulsion, etc. (Prakash & Narasinga Rao, 1986). The 11*S* protein consists of at least five non-identical polypeptide chains differing in their molecular weights as determined by SDS–PAGE, i.e. 11 000, 18 000, 29 000, 42 000 and 61 000. From the mobility of the bands in Urea–PAGE, the protein is assumed to contain one acidic, two neutral, and three basic sub-units. The solubility of the high-molecular-weight proteins in water, 0·05M NaCl and 0·5M NaCl solutions showed that 82% of the protein was soluble in 0·5 M NaCl whereas only 41% was water- soluble (Youle & Huang, 1981).

Low-molecular-weight protein

Procedures for the isolation of the low-molecular-weight-protein fraction (2*S*) of flaxseed have been described by Youle and Huang (1981) and Madhusudhan and Singh (1985*d*). The earliest report on the separation of the low-molecular-weight protein, conlinin, was furnished by Vassel and Nesbitt (1945), who isolated conlinin from a dioxane-treated glycol extract of flaxseed meal. Youle and Huang (1981) extracted the 2*S* protein from flaxseed in 0·035M sodium phosphate buffer, pH 7·5, in 1M NaCl. The solubilized protein was centrifuged in a sucrose gradient from 5 to 30% sucrose in the same buffer. The 2*S* protein extracted according to this procedure accounted for 42% of the total seed protein.

The major low-molecular-weight-protein fraction from defatted flaxseed meal was isolated to homogeneity by CM-Sephadex C-50 Chromatography (Madhusudhan & Singh, 1985*d*). The protein had a sedimentation coefficient of 1·6 and a molecular weight of 15 000–18 000. The N-terminal amino acid was alanine, and the C-terminal amino acid was lysine. The fraction exhibits a high content of β-structure and helical conformation of 51% and 26–32%, respectively (Table 3). The protein consists of a single polypeptide chain. The amino-acid composition of the protein is characterized by a large amount of lysine, cysteine, glutamic acid, and glycine. About 93% of the protein was found to be soluble in water and 99% was soluble in 0·05M NaCl (Youle & Huang, 1981). The basic nature of the protein is consistent with low-molecular-mass-storage proteins of Brazil nut, castor bean, sunflower seed, and rapeseed (Schwenke, 1990).

FUNCTIONAL PROPERTIES OF FLAXSEED PROTEINS

The solubilities of flaxseed proteins in the Osborne series of solvents are unique relative to other oilseeds but comparable with those of sunflower (Panford, 1989). About 25% of the seed nitrogen was soluble in distilled water, about 30% solubilized by 1M NaCl, and the major fraction (42%) extracted with 0·1N NaOH. Only 4% of the residue was soluble in 70% ethanol. Globulins constituted 70–85% of flaxseed proteins, of which two-thirds had a molecular weight of 250 000 and the remainder was of low molecular weight (Madhusudhan & Singh, 1983).

The poor water-solubility of flaxseed proteins is confirmed in the nitrogen-extractability curve, flaxseed meal proteins being only 20–24% soluble between pH 2 and 6 (Dev & Quensel, 1986, 1988; Madhusudhan & Singh, 1985*a*). Flaxseed-protein isolate prepared by an alkali-extraction–acid-precipitation method showed a greater acid- and alkali-solubility than soy-protein isolate (Dev & Quensel, 1986), and moderate-to-high solubility in low and high concentrations of sodium chloride. In the presence of NaCl, the solubility minima are shifted to lower pH values. The buffer capacity of flaxseed protein is a maximum at acid pH below the isoelectric region and minimum in the alkaline region.

Dev and Quensel (1986, 1988) demonstrated that, in general, flaxseed products exhibit favorable water absorption, oil absorption, emulsifying activity, and emulsion stability compared with the corresponding soybean products (Table 4). However, the alkali-extracted–acid-precipitated flaxseed-protein isolates have higher water-absorption properties and bound four times as much oil as the soybean isolate. The emulsifying properties of flaxseed proteins are pH-dependent and are adversely influenced by NaCl. Flaxseed proteins also show high foaming characteristics. The incorporation of sodium chloride increases the foam stability of flaxseed-protein isolate from a half-life of 22 min to over 600 min.

It appears that flaxseed proteins are structurally more lipophilic than soybean proteins. Their hydrophilic properties are influenced by the presence of polysaccharide gums in flaxseed-protein preparations (Table 4). The gum in flaxseed has been implicated in enhancing the viscosity and the water-binding, emulsifying, and foaming properties of linseed-protein products (Dev & Quensel, 1986; Mazza & Biliaderis, 1989).

Modification of flaxseed proteins by heat treatment effectively increases water absorption, but reduces fat absorption, nitrogen-solubility, and foaming and emulsion characteristics (Madhusudhan & Singh, 1985*b*).

PRODUCT APPLICATIONS

Flaxseed-protein products containing different levels of polysaccharide gums have been evaluated as additives in food systems such as canned-fish sauce, meat emulsion, and ice cream (Dev & Quensel, 1989). Generally,

Table 4. Functional properties of linseed products*

Functional property	LMF	LMPC	HMPC-S	HMPC-EC	LMPI	SI
Water absorption (%)†	366	303	419	470	610	485
Moisture adsorption (%)	8·3	7·2	16·8	13·2	14·2	5·8
Oil absorption (%)	313	141	95	95	459	100
Bulk density (g/ml)	0·21	0·39	0·36	0·31	0·13	0·38
Viscosity (mPa s)						
1·0% dispersion	—¶	—¶	2·75	2·68	2·54	
2·5% dispersion	—¶	—¶	8·27	7·77	6·48	
Emulsifying activity (%)	50	51	96	98	69	57
Emulsion stability (%)	72	79	90	94	84	54
Least gelation concentration (%)	12	12	12	12	8	
Foaming capacity (%)	27	10	226	166	80	35
Foam half-life (min)	60	70	50	9	22	1·5

* From Dev and Quensel (1988).
† Expressed on a dry-weight basis.
¶ Not determined.

LM—low-mucilage flour.
LMPC—low-mucilage protein concentrate.
HMPC-S—high-mucilage protein concentrate from seeds.
HMPC-EC—high-mucilage protein concentrate from expeller cake.
LMPI—low-mucilage protein isolate.
SI—soybean isolate (Dev & Quensel, 1986).

flaxseed-protein products were found to have emulsion-stabilizing effects comparable with those of gelatin. The incorporation of flaxseed-protein products at 3% level produced a smooth and creamy fish sauce devoid of any undesirable flavor and a marked reduction in its red color.

Extending meat emulsions with flaxseed-protein products may lead to a reduction in fat losses during cooking and a reduction in the firmness of cooked emulsions and meaty flavor owing to their poor gelling properties. Supplementation of flaxseed-protein products in ice-cream mixes increased product viscosity, specific gravity, and overrun but reduced melt-down times with an increasing level of additions from 0·5 to 1%. Thus flaxseed-protein products have potential as emulsifiers and stabilizers in food systems.

Increased commercial utilization of flaxseed proteins, particularly in food products, will depend on whether proteins with specific functional requirements for incorporation in various products can be produced. A range of functional properties may be achieved either through genetic manipulation of the plant material or, more probably, through chemical modification of the proteins. Genetic variation in protein composition, such as that encountered in soybeans, can have a significant effect on the processing characteristics of the end-product. Similarly, chemical/processing modifications designed to modify composition and functional properties of the protein have received considerable attention in the case of cereals and soybeans (Fligner & Mangino, 1991; Pour-El, 1981), but relatively little has been done with flaxseed proteins. To date, for instance, no economically feasible method for the separation of flaxseed-protein components is available. Likewise, protein modifications involving succinylation, acylation, or incorporation of lipophilic molecules that are known to improve surface properties of the protein (Nakai & Li-Chan, 1988) have not been investigated, and no research has been carried out on the relationship between the structure and functional properties of the flaxseed proteins. In our opinion, progress in the utilization of flaxseed proteins will continue to be slow until these issues are addressed and properly resolved.

REFERENCES

Anderson, A. J. & Spencer, D. (1950). Sulfur and nitrogen metabolism of legumes and non-legumes. *Aust. J. Sci. Res. Ser. B*, **3** 431–49.

Anon. (1991). *World Oilseed Situation and Outlook*. United States Department of Agriculture. Foreign Agricultural Service Circular Series FOP 1–91, January, 1991, 5–25.

Bajpai, M., Pandey, S. & Vasishtha, A. K. (1985). Spectrum of variability of characteristics and composition of the oils from different genetic varieties of linseed. *JAOCS*, **62**, 628.

Bhatty, R. S., Sosulski, F. W. & Wu, K. K. (1973). Protein and nonprotein nitrogen contents of some oilseeds and peas. *Canad. J. Plant Sci.*, **53**, 651–7.

Bigelow, C. C. (1967). On the average hydrophobicity of proteins and the relation between it and protein structure. *J. Theor. Biol.*, **16**, 187.

Caragay, A. B. (1992). Cancer-preventive foods and ingredients. *Food Technol.*, **46**, 65–8.

Dev, D. K. & Quensel, E. (1986). Functional and microstructural characteristics of linseed (*Linum usitatissimum* L.) flour and a protein isolate. *Lebensm.-Wiss. u.-Technol.*, **19**, 331–7.

Dev, D. K., Quensel, E. & Hansen, R. (1986). Nitrogen extractability and buffer capacity of defatted linseed (*Linum usitatissimum* L.) flour. *J. Sci. Food Agric.*, **19**, 199–205.

Dev, D. K. & Sienkiewicz, T. (1987). Isolation and subunit composition of 11*S* globulin of linseed (*Linum usitatissimum* L.). *Die Nahrung*, **31**, 767–9.

Dev, D. K. & Quensel, E. (1988). Preparation and functional properties of linseed protein products containing differing levels of mucilage. *J. Food Sci.*, **53**, 1834–7, 1857.

Dev, D. K. & Quensel, E. (1989). Functional properties of linseed protein products containing different levels of mucilage in selected food systems. *J. Food Sci.*, **54**, 183–6.

Fligner, K. L. & Mangino, M. E. (1991). Relationship of composition to protein functionality. In *Interactions of Food Proteins*, ed. N. Parris & R. Barford. American Chemical Society, Washington, DC, USA.

Friedman, M. & Levin, C. E. (1989). Composition of jimson weed (*Datura stramonium*) seeds. *J. Agric. Food Chem.*, **37**, 998–1005.

Gad, A. Y. & El-Farouk, M. (1978). Influence of seeding rates and nitrogen levels on yield and some technological characters of flax. *Agric. Res. Rev.*, **56**, 79–91.

Green, A. G. (1989). Genetic modification of polyunsaturated fatty acid composition in flax (*Linum usitatissimum* L.). In *Proc. of World Conf. on Biotechnology*. American Oil Chemists Society, Champaign, IL, USA, pp. 55–7.

Madhusudhan, K. T. & Singh, N. (1983). Studies on linseed proteins. *J. Agric. Food Chem.*, **31**, 959–63.

Madhusudhan, K. T. & Singh, N. (1985*a*). Effect of detoxification treatment on the physicochemical properties of linseed proteins. *J. Agric. Food Chem.*, **33**, 1219–22.

Madhusudhan, K. T. & Singh, N. (1985*b*). Effect of heat treatment on the functional properties of linseed meal. *J. Agric. Food Chem.*, **33**, 1222–6.

Madhusudhan, K. T. & Singh, N. (1985*c*). Isolation and characterization of the major fraction (12*S*) of linseed proteins. *J. Agric. Food Chem.*, **33**, 673–7.

Madhusudhan, K. T. & Singh, N. (1985*d*). Isolation and characterization of a small molecular weight protein of linseed meal. *Phytochemistry*, **24**, 2507–9.

Mandokhot, V. M. & Singh, N. (1978). Studies on linseed (*Linum usitatissimum*) as a protein source for poultry. I. Process of demucilaging and dehulling of linseed and evaluation of processed materials by chemical analysis and with rats and chicks. *J. Food Sci. Technol.*, **16**, 25–31.

Mazza, G. & Biliaderis, C. G. (1979). Functional properties of flaxseed mucilage. *J. Food Sci.*, **54**, 1302–5.

Nakai, S. & Li-Chan, E. (1988). Importance of hydrophobic interactions in modification of structure and function of food proteins. In *Hydrophobic Interactions in Food Systems*. CRC Press, Boca Raton, FL, USA, pp. 129–78.

Naqvi, P.A., Rai, M. & Vasishtha, A. K. (1987). Association of different components of seed and oil in linseed. *Indian J. Agric. Sci.*, **57**, 231–6.

Osborne, T. M. (1892). Proteins of the flaxseed. *J. Am. Chem. Soc.*, **14**, 629–61.

Oomah, B., D., Mazza, G. & Kanaschuk, E. O. (1992). Cyanogenic compounds in flaxseed. *J. Agric. Food Chem.*, **40**, 1346–8.

Painter, E. P. & Nesbitt, L. L. (1946). Nitrogenous constituents of flaxseed. *Industr. Engng. Chem.*, **38**, 95–8.

Panford, J. A. (1989). Factors affecting wavelength selection for the determination of protein, oil, water and fiber in oilseeds by near-infrared reflectance (NIR) spectroscopy. PhD. thesis. University of Guelph, Canada.

Pour-El, A. (1981). Protein functionality: classification, definitions, methodology. In *Protein Functionality in Foods*, ed. J. P. Cherry. American Chemical Society, Washington, DC, USA.

Prakash, V. & Narasinga Rao, M. S. (1986). Physicochemical properties of oilseed proteins. *CRC Critical Rev. Biochem.*, **20**, 265–363.

Rowland, G. G. (1982). The relationship between protein and oil in flax. *Proc. Flax Inst. USA*, pp. 47–50.

Salunkhe, D. K. & Desai, B. B. (1986). Linseed, niger, and cottonseed. In *Postharvest Biotechnology of Oilseeds*. CRC Press, Boca Raton, FL, USA, pp.171–86.

Schwenke, K. D. (1990). Structural studies on native and chemically modified storage proteins from rapeseed (*Brassica napus* L.) and related plant proteins. *Die Nahrung*, **34**, 225–40.

Singh, R. A. & Singh, H. R. (1978). Effect of nitrogen and phosphorus on yield, quality, and moisture-use pattern of linseed grown on rainfed lands. *Indian J. Agric. Sci.*, **48**, 583–8.

Smith, A. K., Johnson, V. L. & Beckel, A. C. (1946). Linseed proteins: alkali dispersion and acid precipitation. *Industr. Engng. Chem.*, **38**, 353–6.

Sosulski, F. W. & Bakal, A. (1969). Isolated proteins from rapeseed, flax, and sunflower meals. *Canad. Inst. Food Technol. J.*, **2**, 28–32.

Sosulski, F. W. & Sarwar, G. (1973). Amino-acid composition of oilseed meals and protein isolates. *Canad. Inst. Food Technol. J.*, **6**, 1–5.

Vassel, B. & Nesbitt, L. L. (1945). The nitrogenous constituents of flaxseed. II. The isolation of a purified protein fraction. *J. Biol. Chem.*, **159**, 571–84.

Waugh, D. F. (1954). Protein–protein interaction. In *Advances in Protein Chemistry*, Vol. 9, ed. M. L. Anson, J. F. Edsall & K. Bailey. Academic Press, New York, NY, USA, pp. 326.

Youle, R. J. & Huang, A. H. C. (1981). Occurrences of low molecular weight and high cysteine containing albumin storage proteins in oilseeds of diverse species. *Am. J. Bot.*, **68**, 44–8.