Chemical, Physicochemical, and Nutritional Evaluation of Plantago (*Plantago ovata* Forsk)

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ABSTRACT

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Plantago ovata F. are small tan-colored seeds with ≈30% weight husk. Plantago's husk high content of soluble fiber makes it a good lubricant of the intestinal track with demonstrated effects in lowering plasma cholesterol levels in humans and experimental animals. Plantago seeds grown in Northern Mexico were analyzed for proximate composition, combustion heat, soluble and insoluble dietary fiber, fatty acids, amino acids, and protein fractionation. In vitro digestibility and digestibility of dry matter, apparent and true digestibility, and net protein ratio (in vivo) were also analyzed. Plantago seeds had 17.4% protein, 6.7% fat, 24.6% total dietary fiber, 19.6% insoluble fiber, 5.0% soluble fiber, and a combustion heat of 4.75 kcal/g. Osborne fractionation (based on solubility) yielded albumin 35.8%, globulin 23.9%, and prolamin 11.7%. The oil from plantago seeds had a high percentage of linoleic acid (40.6%) and oleic acid (39.1%) and a minor proportion of linolenic acid (6.9%). In vitro protein digestibility of the plantago seed was 77.5%, suggesting a highly digestible protein. Lysine content was 6.82 g/100 g of protein, higher than wheat and oats (2.46 and 4.20 g/100 g of protein, respectively). Rat bioassays showed values of 89.6% digestibility of dry matter, 86.0% apparent digestibility, 88.1% true digestibility, and 4.40 net protein ratio corrected (NPRc). The importance of these findings is that plantago whole grain shows favorable nutritional quality when compared with cereals and legumes.

Farmers from two agricultural regions in Northern Mexico (Valle del Yaqui and Valle del Mayo) are actively searching for alternative crops that are well adapted to semiarid conditions. Lack of water and wide fluctuation in prices of traditional crops has increased this interest. Currently, India is the number one producer of plantago in the world market (Gupta 1982; Chakrabortty et al 1992).

The *Plantago ovata* seeds were introduced in the late 1950's in the northern region of Mexico and there has been a gradual increase in production ever since. There are many advantages associated with the production of plantago including the international demand for this seed and the intrinsic characteristics of the plant that permit its production in this arid region of Mexico. About 250 cultivars of plantago are known, but only two species, *Plantago ovata* and *P. psyllium*, are economically feasible. The first one is a more valuable crop due to its large content of husk, ≈30% by weight (Gupta 1982), which is used to produce the commercial psyllium product.

The beneficial effects of psyllium husk in reducing plasma cholesterol concentrations have been demonstrated in numerous clinical trials, including normal lipid men, pre- and postmenopausal women (Vega-Lopez et al 2001), hyperlipidemic individuals (Romero et al 1998), and diabetic patients (Anderson et al 1999). Psyllium husk is also effective in reducing plasma cholesterol when used in combination with low fat diets (Anderson et al 2000). A diet containing 10% psyllium husk also demonstrated strong reduction of the tumorigenicity of 1,2-dimethylhydrazine (DMH) in rats (Roberts-Andersen et al 1987).

Although the hypocholesterolemic properties of psyllium husk have been well characterized in animals and humans, there is limited information regarding the effects of the seeds on plasma lipids. In a previous report, it was demonstrated that the seeds also exert a hypocholesterolemic action in guinea pigs (Romero et al 2002), which is related to alterations in hepatic cholesterol homeostasis and lipoprotein metabolism.

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The purpose of this study was to evaluate some physical, chemical, and nutritional properties of *P. ovata* seeds that can be used to estimate its potential use for human consumption when compared with cereals and legumes.

MATERIALS AND METHODS

Seed Source

The *P. ovata* seeds were a gift from Foundation Produce Sonora, A.C. (Hermosillo, Mexico). Whole meal flour was obtained by using a grinder mill (Pulvex model 200, Mexico D.F.). Samples were packed into polyethylene bags and stored at –20°C until needed for analysis.

Chemical and Physical Tests

Moisture, protein, fat, and ash were evaluated in the whole meal flours according to Approved Methods 44-40, 46-13, 30-25, and 08-02 (AACC International 2000). Total dietary fiber, soluble and insoluble, and protein fractions were extracted according to previously reported methods (Landry et al 1980; Prosky et al 1988). Oil extraction was performed using chloroform-methanol (Daugherty et al 1983). Fatty acid profiles were determined according to Method Ce 2-66 (AOCS 1998) utilizing a gas chromatograph (Varian model Star 3400 GX, Palo Alto, CA) with a capillary column Sp 256 (100 m × 0.25 mm, i.d.), detector FID at 250°C with a hydrogen flux of 30 mL/min, 300 mL/min of air, and 28 mL of nitrogen. Nitrogen was used as a carrier gas with a flux of 30 mL/min and a heptadecanoic acid (17°C) internal standard. Caloric content was measured using a bomb calorimeter (Raymond et al 1957).

TABLE I
Composition of Diets (g/100 g of diet) Used for Nutritional Evaluation of *Plantago ovata* Forsk

Component	Plantago	Casein	Nitrogen Free Diet
Plantago whole meal	12.0	–	–
Casein[a]	11.7	11.7	–
Starch	58.3	58.3	70.0
Corn oil[a]	8.0	8.0	8.0
Cellulose[a]	–	12.0	12.0
Sucrose	5.0	5.0	5.0
Mineral mix[a]	3.5	3.5	3.5
Vitamin mix[b]	1.5	1.5	1.5

[a] ANRC, Dyets Inc., Bethlehem, PA.
[b] Test Diet, Richmond, IN.

The amino acid profile was analyzed in defatted whole meal flour on a high-performance liquid chromatograph (Varian model 9010) with a short Microsorb column, (10 cm × 4.6 mm, i.d.) and a fluorometric detector (OPA filter) at 25–27°C and with a flux at 1.5 mL/min. The internal standard was α-amino butyric acid. Before quantification, amino acids were derivatized with oftaldehyde for 2 min to produce fluorescent compounds, primary and secondary amines, which were excited and detected at 360–450 nm (Vazquez-Ortiz et al 1995).

Nutritional Evaluation

In vitro protein digestibility was performed using the method described by Satterlee et al (1982). Biological assays (in vivo) such as dry matter digestibility, apparent and true digestibility, and net protein ratio were conducted utilizing Sprague Dawley rats according to Barron et al (1993). Rats weighing 45–55 g were housed in a room with controlled temperature (25°C) and relative humidity (67–80%); water and food were provided ad libitum. For each diet, a group of eight rats (4 female and 4 male) was used and the analysis was performed in duplicate on a separate test date using the same number of rats. Observations represent the average of two independent analyses. Experimental diets contained the material to be tested supplemented with 1.5% vitamins, 3.5% minerals, 8% fat, and 5% sugar. Sufficient protein (casein ANRC, Cat# 400626, Dyets, Bethlehem, PA) was added to the diet mix so that the total protein equaled 10% in all diets.

The composition of the diets is reported in Table I. Diets were prepared by mixing all the ingredients in powder form (model A5 2001, Hobart Corp., Troy, OH) to homogenize the mix. The prepared diets were packed in polyethylene bags and stored at 4°C until needed.

Statistical Analysis

A Statisical Analysis System (JMP v. 4.04, SAS Cary, NC) was used for analysis of variance of the biological data. The Tukey's procedure for mean comparison (P <0.05) was also used.

RESULTS AND DISCUSSION

Chemical Composition

The energy and chemical composition of *P. ovata* Forsk whole meal flour compared with wheat, corn, oats, and pinto beans *(Phaseolus vulgaris)* is shown in Table II. The plantago sample had higher energy and fat than most of the compared samples, except for similar fat content compared with oats. The total dietary fiber was 24.6% and the remaining carbohydrate was 48.6%. In comparison, cereals and legumes have higher percentages of carbohydrates other than dietary fiber. The carbohydrate composition in plantago has been reported to contain mainly D-xylose (63.6%), L-arabinose (20.4%), L-rammonose (6.5%), and D-galacturonic acid (9.0%) (Chakrabortty et al 1992). The composition of carbohydrate in cereals is mainly starch (Serna et al 1991; Mohamed et al 1995).

Protein content of plantago seeds (17.4%) was similar to oats (17.1%) but lower than pinto beans (26.3%). These results suggest plantago seeds as a potential protein source. Higher protein values (20 and 29.3% of crude protein for seed and defatted flour, respectively) have been reported from a *P. ovata* cultivar grown in India (Chakrabortty et al 1992). It is well known that protein content differs among cultivars due to differences in genotype and environment during developing and maturation of the grain.

Crude fat (6.7%) and ash (2.7%) content from plantago seeds were similar to those from oats (6.4 and 3.2%, respectively). These values were higher when compared with other cereals and legumes but lower than those reported in a cultivar of *P. ovata* Forsk grown in India that has 8.6% total fat (Chakrabortty et al 1992). The germ of plantago seed is rich in oil and protein, while oat is the only cereal that contains significant quantities of lipids in the endosperm (Serna et al 1991).

Dietary Fiber Content

Dietary fiber content is reported in Table II. Plantago seeds had higher total dietary fiber (24.6%) than cereals and beans. The dietary fiber of oats has been extensively investigated due to its high soluble fiber (6.6%), composition (>50% β-glucans), and physiological effects (Asp et al 1992; Braaten et al 1994). Studies on normal and hypercholesterolemic men consuming diets rich in soluble fiber from oats or psyllium showed lower total cholesterol level (18.3%) and LDL-cholesterol (26.1%) with a diet rich in oats, and 14.2% of total cholesterol and 22% of LDL-cholesterol with a diet rich in psyllium (Romero et al 1998).

Soluble and insoluble dietary fiber of plantago seed were 5.0 and 19.6%, respectively (Table II). These values are higher than those found in wheat (1.7 and 10.4%) and corn (1.1 and 11.7%). The plantago sample had 24.4% lower soluble fiber than oats; the insoluble fiber was 3.3× higher than oats. Soluble and insoluble dietary fiber have different effects on digestion and metabolism (Wisker et al 1985). Soluble fiber is associated with cholesterol and glucose reduction in plasma and it is related to reduction of the risk of cardiovascular disease. Insoluble fiber affects the intestinal transit and absorption rate of nutrients and minimizes the exposition of carcinogenic agents in the intestinal lumen, which acts as protector against colon cancer (Serna et al 1991; Weisburger et al 1993).

Protein Fractions

Protein class fractionation of plantago according to Osborne's classical separation based on solvent solubility is reported in Table III. Albumin and globulin were the major protein fractions

TABLE II
Chemical Composition Content of *Plantago ovata* Forsk Compared with Selected Cereals and Legumes[a]

Parameter	Plantago[b]	Wheat[c]	Corn[c]	Oat[c]	Pinto Beans[d]
Energy (kcal)	4.75 ± 0.06	3.70	3.48	3.82	3.25
Protein (%)	17.4 ± 0.02	14.4	9.1	17.1	26.3
Fat (%)	6.7 ± 0.02	2.3	4.4	6.4	2.0
Ash (%)	2.7 ± 0.01	1.9	1.7	3.2	3.2
Carbohydrate[e] (%)	48.6	69.3	72.0	60.8	49.0
Total dietary fiber[f] (g/100 g)	24.6	12.1	12.8	12.5	19.5
Soluble fiber (g/100 g)	5.0 ± 0.09	1.7	1.1	6.6	7.4
Insoluble fiber (g/100 g)	19.6 ± 0.25	10.4	11.7	5.9	12.1

[a] All values are reported in dry weight basis.
[b] Values are means (± standard deviation) of three determinations.
[c] Serna et al (1991).
[d] Dreher (1999).
[e] Carbohydrate by difference.
[f] Sum of soluble and insoluble fiber.

TABLE III
Protein Fractions of *Plantago ovata Forsk* Compared with Selected Cereals and Legumes

Protein Fraction	Plantago[a] (%)	Wheat[b] (%)	Corn[b] (%)	Oats[c] (%)	Pinto Beans[d] (%)
Albumin	35.8 ± 3.1	6.4	7.0	–	4.0
Globulin	23.9 ± 1.0	–	5.0	–	67.0
Albumin + Globulin	59.7	6.4	12.0	67.0	71.0
Glutelin	14.1 ± 0.2	41.9	25.0	23.0	29.0
Prolamin	11.7 ± 0.2	48.5	52.0	9.0	–
NPN[e]	9.6 ± 0.4	–	6.0	1.0	–
Total	95.1	96.8	95.0	100.0	100.0

[a] Values are means (± standard deviation) of three determinations.
[b] Singh et al (1981).
[c] Serna et al (1991).
[d] Duffus et al (1985).
[e] Nonprotein nitrogen.

TABLE IV
Amino Acids Profile (g/100 g of protein) of *Plantago ovata* Forsk Compared with Selected Cereals and Legumes

Amino Acid	Whole Plantago Flour[a]	Whole Wheat Flour[b]	Pinto Beans (*Phaseolus vulgaris* L.)[b]	Whole Oats[c]	Reference Protein[d]
Aspartic	9.25 ± 0.69	4.81	12.16	–	–
Glutamic	29.66 ± 3.72	30.62	13.80	–	–
Serine	6.66 ± 0.04	3.98	6.07	–	–
Histidine	3.74 ± 0.23	2.42	3.34	2.40	–
Glycine	8.55 ± 0.93	3.41	3.96	–	–
Threonine	5.58 ± 0.59	2.41	4.90	3.30	4.0
Arginine	10.82 ± 1.18	4.26	8.05	–	–
Alanine	6.75 ± 0.50	2.52	3.27	–	–
Tyrosine	6.85 ± 0.55	2.78	3.67	–	–
Methionine	2.61 ± 0.40	1.42	1.20	2.30	2.2
Valine	6.10 ± 0.45	3.82	4.99	5.80	5.0
Phenylalanine	4.78 ± 0.79	4.39	6.00	5.40	2.8
Isoleucine	5.82 ± 0.47	3.20	4.78	4.20	4.0
Leucine	8.91 ± 0.73	7.65	8.50	7.50	7.0
Lysine	6.82 ± 0.58	2.46	9.24	4.20	5.5

[a] Values are means (± standard deviation) of three determinations.
[b] Instituto Nacional de la Nutrición (1996).
[c] Serna et al (1991).
[d] FAO (1973).

in plantago, 35.8 and 23.9% respectively, with minor proportions of glutelin and prolamin at 14.1 and 11.7%, respectively. Overall similar values have been reported from a plantago cultivar from India with albumin 42.3%, globulin 19.2%, glutelin 16.2%, and prolamin 7.8% (Chakrabortty et al 1992).

Plantago seeds and legumes have high albumin and globulin content. These proteins are mainly enzymes (amylases), nucleoproteins, and glycoproteins that play critical roles during seed germination. Among cereals, oats have the highest percentage of albumin and globulin (Table III). Wheat and corn have high percentages of prolamin and glutelin protein fractions (Serna et al 1991).

Amino Acid Profile

The amino acid profile of plantago compared with the FAO/WHO protein reference is presented in Table IV. Plantago exceeded the requirement of essential amino acids and appears to be a good source of lysine and methionine (6.82 and 2.61 g/100 g of protein, respectively). These values are higher than that reported for a plantago cultivar from India with 4.14 and 1.7 g/100 g of protein for lysine and methionine, respectively (Chakrabortty et al 1992). Genotypic and environmental differences could account for the observed differences.

Fatty Acid Profile

The saturated and unsaturated fatty acid contents of the plantago seed sample are shown in Table V. The saturated fatty acid content in the plantago seed sample was similar to corn oil (12%), which is considered good quality oil and commercially acceptable. Unsaturated fatty acids in plantago (≈87%) have composition similar to soybeans and oat oils, although the linolenic acid is significantly lower in oats (1.9%) compared with plantago and soybean oil (6.9 and 8%, respectively). These observations compare well with literature values reporting oleic, linoleic, and linolenic contents of 48, 37.7, and 2.1%, respectively, in *P. ovata* Forsk seed from India (Chakrabortty et al 1992). Plantago and oat oil could be considered of good quality due to the low content of saturated fatty acids.

In Vitro Protein Digestibility

The digestibility of protein in vitro uses a model of mammalian digestion and is a fast and efficient enzymatic method that can be used as an indicator of protein quality (Singh et al 1981; Satterlee et al 1982; Rasco 1994;). The in vitro digestibility of plantago is presented in Table VI. Lower digestibility value was obtained from plantago compared with the casein control (77.5 and 90.9%, respectively) but higher than previous reports for corn (62.5%). Differences in protein digestibility could suggest differing susceptibility to enzymatic hydrolysis in the digestive system. However, as discussed later, the biological (in vivo) assays indicate that plantago has digestibility similar to casein. Compared with literature reports, the in vitro digestibility of plantago reported here was higher than that reported for raw soybean and similar to dehulled and heat-treated soybeans, averaging 68.9 and 78.3%, respectively (Maforimbo 2001).

Biological Assays

Dry matter digestibility. This is an in vivo assay that provides information on the absorption of all nutrients present in the food product tested, its probable assimilation, and an indication of the

TABLE V
Fatty Acids Profile (%) of *Plantago ovata* Forsk Compared with Selected Oilseeds and Cereals

Fatty Acids	Plantago[a,b]	Soybean[c]	Sunflower[c]	Corn[c]	Oats[d]
Saturated	12.4	14.0	7.0	12.0	21.1
Miristic	0.1 ± 0.01	–	–	–	0.6
Palmitic	9.0 ± 0.32	10.0	5.0	10.0	18.9
Stearic	3.0 ± 0.35	4.0	2.0	2.0	1.6
Arachidic	0.3 ± 0.03	–	–	–	–
Unsaturated	86.6	86.0	93.0	88.0	78.8
Oleic	39.1 ± 0.22	24.0	17.0	31.0	36.4
Linoleic	40.6 ± 0.27	54.0	76.0	56.0	40.5
Linolenic	6.9 ± 0.34	8.0	–	1.0	1.9

[a] Experimental data obtained by cold extraction and gas chromatography.
[b] Values are means (± standard deviation) of three determinations.
[c] Tequida (1995).
[d] Serna et al (1991).

TABLE VI
Protein Quality Evaluation of *Plantago ovata* Forsk by In Vitro and In Vivo Assays[a]

Assay	Plantago	Casein (Control)	Corn[b]	Wheat[c]
In vitro digestibility (%)	77.5 ± 1.69a	90.9 ± 0.64b	62.5	–
Dry matter digestibility (%)	89.6a	90.3a	–	–
Apparent nitrogen digestibility (%)	86.0a	87.5a	87.3	90.0
True nitrogen digestibility (%)	88.1a	89.7a	–	96.0
Net protein ratio (corrected)	4.4a	4.3a	2.24	–

[a] Tukey's procedure. Values are means of 16 determinations and data was adjusted to 10% protein. Means (± standard deviation) with different letter within a row are significantly different at $P < 0.05$.
[b] Canett (2000).
[c] Serna et al (1991).

nutritional capacity of the foods (Bender 1982, 1994, 2005). The digestibility of dry material for the diet of plantago was not significantly different ($P < 0.05$) to that of the casein control (89.6 and 90.3%, respectively) (Table VI). Both diets, plantago and casein, were prepared with 12% dietary fiber. The results suggest that the high fiber content of plantago whole meal flour does not have an adverse effect on the digestibility of the dry material measured during 14 days of bioassays with rats.

Apparent and true nitrogen digestibility. The nitrogen digestibility is an important biological test in the quality of foods and an indicator of the nutritional quality defined as the proportion absorbed from the digestive tract (Bender 1994). True and apparent nitrogen digestibility of the whole meal plantago and casein control diets are reported in Table VI. Plantago and casein control diets had similar ($P < 0.05$) apparent and true nitrogen digestibility (86 and 87.5% and 88.1 and 89.7%, respectively). No aversion or rejection of the plantago-based diet was observed in the laboratory rats.

Net protein ratio. The values of net protein ratio corrected (NPRc) are reported in Table VI. Similar to dry matter digestibility and apparent and true nitrogen digestibility, the NPRc of plantago whole meal diet was not significantly different ($P < 0.05$) from the casein control diet (4.4 and 4.3, respectively). These results suggest that the protein in plantago whole meal flour is highly utilized by rats and the high content of fiber in the plantago sample does not have an adverse effect in the utilization of the protein. The diet containing plantago had higher NPRc value compared with wheat and corn diets reported in the literature (Canett 2000).

CONCLUSIONS

The plantago seed sample studied had a higher caloric content than wheat, corn, oats, and pinto beans. The oats soluble fiber was 1.3× as high as plantago and the plantago insoluble fiber was 3.3× as high as oats. Thus, the soluble and insoluble fiber content in plantago (5.0 and 19.6%, respectively) could produce beneficial gastrointestinal effects and might be useful for management of weight, diabetes, hypercholesterolemia, and hypertension. The sum of albumin and globulin was 2.3× that of glutelin plus prolamin protein fractions in plantago seeds. Compared to the FAO/WHO reference protein, plantago seeds had higher amino acids content, especially essential amino acids. A relatively high fat content (6.7%) in plantago was offset by its composition of mainly unsaturated fatty acids (86.6%) and high content of oleic and linoleic acids (39.1 and 40.6%, respectively). While the in vitro digestibility of plantago seeds was lower than that of the casein control, the biological tests including dry matter digestibility, apparent and true nitrogen digestibility, and net protein ratio corrected (NPRc) were similar to the casein control diet. These observations suggest that fiber content in plantago did not cause observable adverse effects in protein utilization by experimental rats. Overall, the compositional and nutritional profile of plantago showed potential for utilization in food products and merits further study.

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LITERATURE CITED

AACC International. 2000. Approved Methods of the American Association of Cereal Chemists, 10th Ed. Methods 08-02, 30-25, 44-40, and 46-13. The Association: St. Paul, MN.

Anderson, J. W., Allgood, L. D., Turner, J., Oeltgen, P. R., and Daggy, B. P. 1999. Effects of psyllium on glucose and serum lipid responses in men with type 2 diabetes and hypercholesterolemia. Am. J. Clin. Nutr. 70:466-473.

Anderson, J. W., Allgood, L. D., Lawrence, A., Altringer, L. A., Jerdack, G. R., Hengehold, D. A., and Morel, J. G. 2000. Cholesterol-lowering effects of psyllium intake adjunctive to diet therapy in men and women with hypercholesterolemia: Meta-analysis of 8 controlled trials. Am. J. Clin. Nutr. 71:472-479.

AOCS. 1998. Official Methods and Recommended Practices of the American Oil Chemists Society, 5th Ed. The Society: Champaign, IL.
Asp, N. G., Mattson, B., and Onning, G. 1992. Variation in dietary fibre, beta-glucan, starch, protein, fat, and hull content of oats grown in Sweden 1987-1989. Eur. J. Clin. Nutr. 46:31-37.
Barron, J. M., and Espinoza, A. 1993. Fortification of maize tortilla with alkali-treated chickpea flour. Int. J. Food. Sci. Technol. 28:505-510.
Bender, A. E. 1982. Dictionary of Nutrition and Food Technology, 5th Ed. Butterworths and Co.: Boston.
Bender, A. E. 1994. Nutricion y Tecnologia de los Alimentos. Acribia, S.A.: Zaragoza, España.
Bender, A. E. 2005. Dictionary of Food and Nutrition. Available online at http://www.oxfordreference.com (verified May 2005). Oxford University Press: Oxford, U.K.
Braaten, J. T., Wood, P. J., Scott, F. W., Wolynetz, M. S., Lowe, M. K., Bradley-White, P., and Collins, M. W. 1994. Oat β-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. Eur. J. Clin. Nutr. 48:465-474.
Canett, R. 2000. Calidad nutricional de los cereales para desayuno mas consumidos en la ciudad de Hermosillo. MS. Universidad de Sonora: Hermosillo, Mexico.
Chakrabortty, M. K., and Patel, K. V. 1992. Chemical composition of isabgol (*Plantago ovata* Forsk) seed. J. Food Sci. Technol. 29:389-390.
Daugherty, C. E., and Lento, H. G. 1983. Chloroform-methanol extraction method for determination of fat in foods: Collaborative study. J. Assoc. Anal. Chem. 66:927.
Dreher, M. 1999. Fod sources and uses of dietary fiber. Pages 327-371 in: Complex Carbohydrates in Foods. L. Sungsoo Cho, L. Prosky, and M. Dreher, eds. Marcel Dekker: New York.
Duffus, C., and Slaugther, C. 1985. Las semillas y sus usos. 1st Ed. AGT, S.A.: Mexico, D.F.
FAO. 1973. FAO Nutrition Meetings Report Series. Energy and Protein Requirements; Report of a Joint FAO/WHO ad hoc expert committee. FAO/WHO: Rome.
Gupta, R. 1982. Recent advances in cultivation of isabgol (*Plantago ovata* Forsk) in India. Pages 406-417 in: Cultivation and Utilization of Medicinal Plants. C. K. Atal and B. M. Kapar, eds. Jammu-Tawi: India.
Instituto Nacional de la Nutricion Salvador Zubira. 1996. Tabla de Composicion de Alimentos. Anniversary Edition. Mexico, D.F.
Landry, J., and Moreaux, T. 1980. Distribution and amino acid composition of protein groups located in different histological parts of maize grain. J. Agric. Food Chem. 28:1186.
Maforimbo, E. 2001. In vitro relative protein digestibility and lipoxygenase activity used as parameters to test and compare quality in five varieties of soybean meals. J. Food Technol. Africa 6:48-52.
Mohamed, A. A., and Rayas-Duarte, P. 1995. Composition of *Lupinus albus.* Cereal Chem. 72:643-647.
Prosky, L., Asp, N.-G., Schwiezer, T. F., Devries, J. W., and Furda, I. 1988. Determination of insoluble, soluble and total dietary fiber in foods and foods products. J. Assoc. Off. Analyt. Chem. 71:1017-1023.
Rasco, A. B. 1994. Protein quality tests. Pages 233-247 in: Introduction to the Chemical Analysis of Foods. Jones and Bartlett: Boston.
Raymond, W. F., Canaway, R. J., and Harris, C. E. 1957. An automatic adiabatic bomb calorimeter. J. Sci. Instrum. 46:265.
Roberts-Andersen, J., Mehta, T., and Wilson, R. 1987. Reduction of dmh-induced colon tumors in rats fed psyllium husk or cellulose. Nutr. Cancer 10:129-36.
Romero, A. L., West, K., Zern, T., and Fernandez, M. L. 2002. The seeds from *Plantago ovata* lower plasma lipids by altering hepatic and bile acid metabolism in guinea pigs. J. Nutr. 132:1194-1198.
Romero, B. A., Romero, B. J., Galaviz, S., and Fernandez, M. L. 1998. Cookies enriched with psyllium or oat bran lower plasma LDL-cholesterol in normal and hypercholesterolemic men from northern Mexico. J. Am. Col. Nutr. 17:601-608.
Satterlee, L. D., Fendrich, J. G., Marshall, H. F., Jewel, D. K., Ali, R. A., Heckman, M. M., Steinke, H. F., Larson, P., Philips, R. D., Sarwar, G., and Slump, P. 1982. In vitro assay for predicting protein efficiency ratio as measured by rat bioassays: Collaborative study. J. Asoc. Off. Analyt. Chem. 64:798-809.
Serna, S. S. R. O., McDonough, C. M., and Rooney, L. W. 1991. The millets. Pages 271-300 in: Handbook of Cereal Science and Technology, 1st Ed. K. J. Lorenz and K. Kulp, eds. Marcel Dekker: New York.
Singh, U., and Jambunathan, R. 1981. Studies on desi and kabuli chickpea (*Cicer arietinum* L.). Cultivars levels of protease inhibition, level of polyphenolics compounds and in-vitro protein digestibility. J. Food Sci. 46:1364-1367.
Tequida, M. M. 1995. Caracterizacion fisica y quimica de la semilla de canola y su aceite de cinco variedades cultivadas en el estado de Sonora. MS. University of Sonora: Hermosillo, Sonora, Mexico.
Vazquez-Ortiz, F. A., Caire, G., Higuera-Ciapara, G., and Hernandez, G. 1995. High performance liquid chromatography: Determination of free amino acids. J. Liq. Chromatogr. 18:2059-2068.
Vega-Lopez, S., Vidal-Quintanar, R. L., and Fernandez, M. L. 2001. Sex and hormonal status influence plasma lipid responses to psyllium. Am. J. Clin. Nutr. 74:435-441.
Weisburger, J., Reddy, B., Rose, D., Cohen, L., Kendall, M., and Wynder, E. 1993. Protective mechanisms of dietary fibers in nutritional carcinogenesis. Basic Life Sci. 61:45-63.
Wisker, E., Feldheim, W., Pomeranz, Y., and Meuser, F. 1985. Dietary fiber in cereals. Vol. 7. Pages 186-192 in: Advances in Cereal Science and Technology. Y. Pomeranz, ed. AACC International: St. Paul, MN.

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