

Soybean grain conditioning and its effect on antinutrients, protein and lipids

Ana Karen Juárez-Fernández¹

Juan de Dios Guerrero-Rodríguez^{1,§}

Pedro Antonio-López¹

José Luis Jaramillo-Villanueva¹

Francisco Javier Gómez-Montaño²

1 Colegio de Postgraduados-Campus Puebla. Boulevard Forjadores de Puebla núm. 205, Santiago Momoxpan, Puebla. CP. 72760. (karendz73@gmail.com; palopez@colpos.mx; jaramillo@colpos.mx).

2 Tecnológico Nacional de México-Campus San Martín Texmelucan. Camino a la Barranca de Pesos s/n, San Lucas Atoyatenco, San Martín Texmelucan de Labastida, Puebla, México. CP. 74120.

Autor para correspondencia: rjuan@colpos.mx

Abstract

Soybeans are a strategic source of plant protein for animal nutrition; however, the presence of antinutritional factors such as trypsin inhibitors, phytates and saponins limits their utilization when the grain is used unprocessed. The research was conducted in 2025 and evaluated the effects of four postharvest conditioning methods (soaking, boiling, germination and roasting) on antinutritional factors, crude protein and lipid concentrations in six soybean varieties grown in Puebla (HSO, RGNA, BM2, HSVA, Varita and Tamesí). Crude protein, total lipids, phytates, trypsin inhibitors, and saponins were determined and analyzed using a completely randomized design with a two-factor (variety x method) factorial arrangement and Tukey's multiple comparisons ($\alpha=0.05$). The results showed differences between varieties and conditioning methods. The Hoja Seca Original variety stood out for having the highest crude protein content, intermediate and stable total lipid values, and an efficient reduction of the main antinutritional factors after treatments. In contrast, the BM2 variety had the lowest protein content and the greatest sensitivity to heat treatment. Raw grain had the highest concentrations of antinutritional factors. Roasting and boiling achieved the greatest reductions in trypsin inhibitors, while germination and soaking decreased phytates and saponins with less impact on protein content. The varieties differ in chemical composition, but this variation is less than the effect produced by the conditioning method, with roasting being the one that best reduced antinutrients.

Keywords:

family livestock farming, phytates, trypsin inhibitors.



License (open-access): Este es un artículo publicado en acceso abierto bajo una licencia **Creative Commons**

Introduction

Soybeans are the most important plant protein source for the livestock industry because of their high protein and energy content, essential amino acid profile, and highly digestible oil. In Mexico, their use is strategic in animal nutrition, particularly for poultry, cattle, and pigs, whose diets require crude protein concentrations between 11 and 23% (INIFAP, 2019).

Nonetheless, the country is dependent on imports, since domestic production meets between 4 and 8% of domestic consumption, being subject to international price fluctuations, which limits the profitability of small livestock producers (SADER, 2023).

A second obstacle to the use of grain is the presence of antinutritional factors, mainly trypsin inhibitors, saponins and phytates, which reduce protein digestibility and mineral bioavailability (De la Luna, 2006). Therefore, it is necessary to apply inactivation processes before use in animal nutrition.

The variation in the response of soybeans to conditioning methods is known to depend on both the nature of the antinutritional factor and the characteristics of the genotype (Singer *et al.*, 2023). Heat treatments favor the reduction of thermolabile compounds, particularly trypsin inhibitors, through protein denaturation; however, intense treatments can affect amino acid availability due to side reactions such as the Maillard reaction (Kong *et al.*, 2022).

On the other hand, processes such as soaking and germination can reduce phytates through solubilization and enzymatic activation, representing alternatives with lower technological demand for production systems with limited resources (Sharma, 2021; Kong *et al.*, 2022; Wang *et al.*, 2022).

Despite the agricultural relevance of soybeans, information is incomplete regarding variation in antinutrient content among varieties adapted to rainfed conditions in temperate zones and dry tropics subject to easy-to-apply and low-cost inactivation methods, and how they can affect the composition of grain used in family livestock production systems.

Therefore, the objective of the research was to evaluate the variation in the contents of crude protein, lipids and antinutritional factors in soybean varieties subjected to inactivation conditioning.

Materials and methods

Varieties

The commercial varieties Tamesí and BM2 were used, along with the experimental varieties Hoja Seca Original (HSO), Hoja Seca Vainas Abundantes (HSVA), Varita and RGNA, which are grown under rainfed conditions in Atlixco, Puebla, Mexico. The climate is subhumid temperate, with an average annual temperature of 16.1-21.8 °C, average rainfall of 906 mm and sandy loam soil.

The crop was established with conventional management practices in a completely randomized experiment with four replications, from which the grain was obtained, keeping each replication separate.

Inactivation treatments

The harvested grain, in its raw form, was dehydrated in a forced-air oven at 40 °C for 72 h until it reached a constant weight, then pulverized in an electric mill. Soaking lasted 5 h at 20 °C, using three times the mass of water relative to the grain weight; later, the grain was sun-dried, spread on metal trays.



Germination consisted of soaking for 48 h in purified water, after which the grain was placed on plastic trays in the shade, maintaining moisture for five days when the radicle emerged. The grain was then removed and placed on metal trays for sun-drying.

Boiling lasted 30 min; the grain was drained through a strainer and placed on trays for sun-drying. Roasting was carried out in an electric oven at 150 °C for 20 min, with the grain spread evenly on metal trays.

All the grains were dehydrated in a forced-air oven at 40 °C for 72 h to be pulverized in an electric mill at 30 000 rpm.

Variables

Crude protein (CP) was determined by Kjeldahl (method 2001.11; AOAC, 2012a); total lipids by Soxhlet (method 920.39; AOAC, 2023); saponins by sequential extraction with ether, 80% ethanol and n-butanol (Hostettmann *et al.*, 1995); trypsin inhibitors by spectrophotometry using BAPNA as a substrate [Welham and Domoney, 2000; AACC 22-40, 2009; AOCS (2017) Ba 12/12a; ISO 14902 (ISO, 2001)], and phytates by the method of Wheeler and Ferrel (1971), quantifying iron by colorimetry (AOAC 2012b, method 986.11).

Experimental design

The design was completely randomized with a 6 x 5 factorial arrangement (variety x grain conditioning method), with four replications. An analysis of variance was performed using the GLM procedure in SAS, and means were compared with Tukey's test ($\alpha = 0.05$).

Results and discussion

The factors variety, method of inactivation, and their interaction generated significant differences in most of the three sources, except for total lipids (Table 1). The variety factor had a greater effect on CP and total lipids (60 and 90% of the total variation explained, respectively); by contrast, the method-of-inactivation factor was decisive for trypsin inhibitors, phytates and saponins, explaining 99, 97 and 99%, respectively. On the other hand, the interaction contributed little, explaining at most 6% in the CP variable.

Table 1. Mean squares and parameters of the analysis of variance for chemical variables of soybean grain as a function of variety and inactivation method.

Variable	Variety	Method of inactivation	Variety x Method	Error	R ²	CV (%)	Mean
CP	108.49 ^{***}	60.59 ^{***}	10.75 ^{***}	0.374	0.97	2.12	108.49 ^{***}
Lipids	3.62 ^{***}	0.09 ns	0.33 ns	0.204	0.58	2.12	3.62 ^{***}
TIU	1.15×10 ^{6***}	5.40×10 ^{9***}	4.26×10 ^{5***}	8.22×10 ⁴	1	2.47	1.15×10 ^{6***}
Phytates	0.738 ^{***}	25.72 ^{***}	0.086 ^{***}	0.00043	1	1.43	0.738 ^{***}
Saponins	0.00061 [*]	0.176 ^{***}	0.00056 ^{**}	0.000214	0.97	3.57	0.00061 [*]

^{ns} = not significant; ^{*} = $p \leq 0.05$; ^{**} = $p \leq 0.01$; ^{***} = $p \leq 0.001$; CP= crude protein.

Crude protein

The varieties differed in CP content $p < 0.0001$ (Table 2). HSO had the highest concentration (32.6%). RGNA ranked second (30.3%); Tamesí, Varita and HSVA were similar, with intermediate values (28% on average), and BM2 had the lowest concentration (25.9%).



Table 2. Mean crude protein values (%) of soybean grain by variety and grain conditioning.

Method	Tamesí	Variety					Mean
		BM2	RGNA	HSO	HSVA	HSVA	
Raw	28.56c	29.23c	32.31a	33.23a	30.37b	28.84c	30.42A
Soaking	28.28c	27.17d	32.97a	33.35a	27.77cd	27.75cd	29.55AB
Boiling	28.07c	27.69cd	32.15a	33.07a	27.54d	27.78cd	29.38B
Germination	28.21c	26.18d	28.29c	31.48b	29.14c	27.3d	28.43C
Roasting	26.52d	19.14e	26.14d	31.71ab	26.37d	27.7cd	26.26D
Mean	27.93D	25.88D	30.37B	32.57A	28.24C	27.87CD	

Means with the same lowercase letter are statistically equal (Tukey, $\alpha = 0.05$); equal uppercase letters for the comparison of the respective factor are not statistically different (Tukey, $\alpha = 0.05$).

The difference between HSO and BM2 was 6.7%, which was a significant variation. These differences were consistent with reports by several authors (Rotundo and Westgate, 2009; Panthee *et al.*, 2016), who attribute the variation to the genetic basis and the relative protein-to-oil ratio in soybeans.

Usually, in soybean seeds, protein concentration can present an inverse relationship with lipid concentration, because both components share metabolic pathways during reserve accumulation in the grain.

Likewise, breeding programs can prioritize increases in protein or oil, depending on the productive objective of the varieties developed, which can also lead to differences among genotypes.

The CP concentration varied with the inactivation method ($p < 0.0001$). Raw grain had the highest value (30.4%). There was a 0.9% decrease with the soaking and boiling methods; germination caused a 2% reduction, and roasting had the lowest value (26.3%), with a 4.1% reduction compared with raw grains.

According to Liu (2019), roasting can slightly reduce CP content, an aspect related to Maillard reactions, which influence CP quantification. The other losses occur due to solubilization (Sharma *et al.*, 2013) and the use of reserves. Although roasting presented the greatest reduction in antinutritional factors, its application implies availability of thermal equipment and energy consumption, factors that may limit its adoption in family livestock production units.

In contrast, methods such as soaking and germination require less infrastructure and may be low-cost alternatives, although they have less capacity to reduce trypsin inhibitors. Therefore, selecting the conditioning method should consider not only inactivation efficiency, but also the availability of resources, the scale of production and the grain's final destination.

Regarding the variety x treatment interaction, the RGNA and BM2 varieties showed the greatest combined effect ($p \leq 0.05$). In both cases, the roasting treatment produced the most pronounced decreases in protein compared with the other methods, an aspect that Liu (2019) related to genetic differences in the protein fraction and the protein-oil ratio.

Total lipids

The varieties were different ($p < 0.0001$) in total lipid concentration (Table 3), but with a reduced range (20-22%). The RGNA variety had the highest concentration (21.4%), whereas HSO and Varita had the lowest values (20%).



Table 3. Mean total lipid values (%) of soybean grain by variety and grain conditioning.

Method	Tamesí	Variety					Mean
		BM2	RGNA	HSO	HSVA	HSVA	
Raw	21.68ab	21.89a	21.75a	20.96b	21.12b	20.51b	21.32A
Soaking	21.55ab	21.39ab	21.73ab	20.79b	21.25ab	21.42ab	21.36A
Boiling	21.18b	21.52ab	22.19a	20.79b	21.03b	20.87b	21.26A
Germination	20.68b	21.35ab	22.42a	20.7b	21.15b	20.91b	21.2A
Roasting	21.37ab	21.64ab	21.8a	21.13b	21.1b	20.81b	21.31A
Mean	21.29BC	21.56AB	21.98A	20.87C	21.13BC	20.9C	

Means with the same lowercase letter are statistically equal (Tukey, $\alpha=0.05$); equal uppercase letters for the comparison of the respective factor are statistically equal (Tukey, $\alpha=0.05$).

According to Hou and Chang (2004); Rotundo and Westgate (2009); Liu (2019), these small differences are due to the lipid content in soybeans presenting moderate genetic variability, but it can be influenced by factors of accumulation efficiency during maturation and the composition of the integument or as Wilson (2004) points out, it can be due to differences in fatty acid biosynthesis pathways.

Inactivation methods did not affect lipid concentration ($p=0.7955$). Hu *et al.* (2002) point out that, in soybeans, lipids are not very susceptible to losses due to moderate heating ($\leq 150^\circ\text{C}$) or short soaking because of their location in the seed.

Trypsin inhibitors

The varieties differed in trypsin inhibitor concentration $p<0.0001$ (Table 4). Varita and Tamesí differed from HSO and HSVA by having 3.8% more on average (402 TIU g^{-1}). Kakade *et al.* (1973); Liener (1994) describe that variation in inhibitor concentration is mainly attributable to genetic factors of the seed.

Table 4. Mean values of trypsin inhibitory units (TIU g^{-1}) of soybean grain by variety and treatment.

Method	Tamesí	Variety					Mean
		BM2	RGNA	HSO	HSVA	HSVA	
Raw	38306a	38216a	38907a	38238a	37736b	38520a	38321A
Soaking	6375c	6447c	5504d	6093c	6480c	6391c	6215B
Boiling	5453d	4635e	4649e	4595e	4348e	5239fd	4820C
Germination	5971c	5506d	6234c	5515d	5438d	6023c	5781B
Roasting	3259f	2384g	3084f	2519f	2584f	3028f	2810D
Mean	10873A	10238BC	10876AB	10192CB	10117C	10240AB	

Means with the same lowercase letter are statistically equal (Tukey, $\alpha=0.05$); equal uppercase letters for the comparison of the respective factor are not statistically different (Tukey, $\alpha=0.05$).

Inactivation methods significantly reduced ($p<0.0001$) the concentration of trypsin inhibitors. Raw grain had the highest value ($38\,321\text{ TIU g}^{-1}$), whereas conditioning treatments reduced the inhibitory activity by 71-121%. Boiling had an effective reduction of $5\,700\text{ TIU g}^{-1}$ (89%), and roasting was more efficient, with a reduction of $2\,509\text{--}3\,431\text{ TIU g}^{-1}$ (91-94% less than raw grain).

The variety x conditioning interaction was not uniform ($p<0.0001$) among varieties, with RGNA showing the greatest variation in the soaking, boiling, and germination methods. Panthee *et al.* (2016); Liu (2019) mention that, among varieties, there are certain genotypes that vary in the relative proportions of Kunitz and Bowman-Birk inhibitors and in their thermal stability, which could be related to this variety.

Phytates

The varieties showed differences in phytate content $p < 0.0001$ (Table 5). RGNA had a higher concentration than Varita, HSO and BM2; the latter had the lowest value (1.17 ppm). This variability is attributable to genetic differences, which aligns with observations by Lott *et al.* (2000); Raboy (2001), who observed that phytate levels in soybean seeds vary among genotypes due to differences in the accumulation of phytic phosphorus during grain filling and to the proportion of cotyledon relative to the total seed.

Table 5. Mean phytate values (ppm) of soybean grain by variety and treatment.

Method	Variety						Mean
	H500	BM2	RGNA	HSO	HSVA	Varita	
Raw	3.36c	2.94d	3.56b	3.32c	3.68a	2.95d	3.3A
Soaking	1.11g	0.6m	1.2e	0.8j	1.06gh	1.25e	1.02B
Boiling	1.04h	0.72l	1.24e	0.84jk	0.97i	1.17f	1B
Germination	1.05h	0.81k	1.25e	0.85jk	1.25e	0.96i	1.03B
Roasting	1.11g	0.7l	1.16f	0.8k	0.87j	0.8k	0.91C
Mean	1.53AB	1.15C	1.7A	1.32BC	1.57AB	1.43BC	

Means with the same lowercase letter are statistically equal (Tukey, $\alpha = 0.05$); equal uppercase letters for the comparison of the respective factor are statistically equal (Tukey, $\alpha = 0.05$).

Inactivation methods, on the other hand, had a differentiated effect ($p < 0.0001$) on phytate concentration. Raw grain presented the highest value (3.3 ppm); in contrast, soaking, boiling and germination showed similar reductions (1-1.1 ppm). This is related to the partial solubilization of phytates in water during soaking, the activation of endogenous phytases at the beginning of germinative metabolism, and the diffusion of phytic acid into the water.

Roasting recorded the lowest concentration (0.9 ppm), indicating that dry heat contributes both to the partial denaturation of phosphorus complexes and to the thermal degradation of phytic acid. These results coincide with reports by Sandberg *et al.* (1999); Luo *et al.* (2009), who point out that thermal and biological processes effectively reduce phytates through enzymatic hydrolysis, solubilization or heat decomposition.

In the interaction, the most pronounced changes were observed in HSVA in germination; Tamesí showed greater stability and Varita had abrupt reductions.

Saponins

The varieties were different ($p < 0.05$) in saponin content (Table 6), although the range was narrow (0.4-0.42%). This aligns with Shimoyamada *et al.* (1990), who indicated that the total saponin content in soybeans remains relatively stable among yellow-type genotypes, varying mainly with culture conditions and physiological maturity, rather than with genetic factors.



Table 6. Mean saponin values (%) of soybean grain by variety and grain conditioning.

Treatment	Tamesí	Variety					Mean
		BM2	RGNA	HSO	HSVA	Varita	
Raw	0.53a	0.50b	0.53a	0.56a	0.52a	0.52a	0.53a
Soaking	0.44c	0.45c	0.44c	0.44c	0.45c	0.44c	0.44B
Boiling	0.38d	0.38d	0.37d	0.38d	0.38d	0.37d	0.38C
Germination	0.36d	0.39d	0.39d	0.39d	0.37d	0.37d	0.38C
Roasting	0.31e	0.3e	0.31e	0.3e	0.29e	0.3e	0.3D
Mean	0.41AB	0.41AB	0.41AB	0.42A	0.4B	0.4B	

Means with the same lowercase letter are statistically equal (Tukey, $\alpha = 0.05$); equal uppercase letters for the comparison of the respective factor are statistically equal (Tukey, $\alpha = 0.05$).

For their part, the inactivation methods reduced the concentration ($p < 0.0001$) compared with the raw grain. Soaking reduced the value to 0.09%, but roasting had the greatest reducing effect, reaching 0.23 percentage units. The variety x conditioning interaction was highly significant ($p = 0.0011$). Although all varieties followed the same general trend, the intensity of the decline was not uniform.

HSO had the largest drop, and raw grain had the greatest variation. Water conditioning methods had intermediate values. This aligns with the findings of Gu *et al.* (2002), where water causes partial degradation of DDMP saponins by oxidation associated with the initial metabolism of seed germination.

Conclusions

The varieties differ in the concentrations of CP, lipids and inhibitors; however, the ranges of variation are small.

Grain conditioning reduces the concentrations of trypsin inhibitors, phytates and saponins, without affecting lipid concentration, with roasting being more effective in reducing antinutrients but significantly decreasing crude protein.

Nonetheless, the implementation of roasting must be assessed considering protein loss, energy requirements and technological availability. In family production systems, methods such as soaking or germination can represent practical alternatives; nevertheless, they require optimizing their capacity to reduce antinutrients.

The variety x conditioning method interaction is small; however, it confirms that there are specific biochemical and structural characteristics of each genotype whose response depends on the method of conditioning applied.

Therefore, the choice of variety and processing type can be decisive for the use of grain in animal nutrition. Roasting was the most effective at reducing antinutritional factors.

Bibliography

- 1 AACC. 2009. International Approved Methods of Analysis. 11th. Edition. Method 22-40.01: Measurement of trypsin inhibitor activity of soy products-spectrophotometric method. AACC International. St. Paul, MN, USA.
- 2 AOAC. 2012a. International. Official Method 2001.11: protein (crude) in animal feed, forage (plant tissue), grain and oilseeds: block digestion method using copper catalyst and steam distillation into boric acid. In: official methods of analysis of AOAC international. AOAC International. Gaithersburg, MD, USA.

- 3 AOAC. 2012b. International. AOAC Official Method 986.11: Phytate in foods. In: Official Methods of Analysis of AOAC International. AOAC International. Gaithersburg, MD, USA.
- 4 AOAC. 2023. International. AOAC Official Method 920.39: fat (crude) or ether extract in animal feed. In: Official Methods of Analysis of AOAC international. 22th. Edition. Oxford University Press. Oxford, UK.
- 5 AOCS. 2017. American Oil Chemists' Society. Official methods and recommended practices of the 7th. Edition. Method Ba 12-75: trypsin inhibitor activity. AOCS Press. Urbana, IL, USA.
- 6 De la Luna, J. A. 2006. Valor nutritivo de la proteína de soya. México. Investigación y Ciencia- Universidad Autónoma de Aguascalientes (UAA). 14(36):29-34. <https://www.redalyc.org/articulo.oa?id=67403606>.
- 7 Gu, L.; Tao, G. and Gu, W. 2002. Changes of saponins during soybean germination. Food Chemistry. 78(4):497-501. [https://doi.org/10.1016/S0308-8146\(02\)00214-7](https://doi.org/10.1016/S0308-8146(02)00214-7).
- 8 Hostettmann, K. and Marston, A. 1995. Saponins. Cambridge University Press. Cambridge, UK. <https://doi.org/10.1017/CBO9780511565113>.
- 9 Hou, H. J. and Chang, K. C. 2004. Storage conditions affect soybean color, chemical composition and tofu quality. Journal of Food Science. 69(4):C293-C300. <https://doi.org/10.1111/j.1365-2621.2004.tb06337.x>.
- 10 Hu, J.; Webster, D. E.; Brauer, D. and Thompson, L. U. 2002. Quantification of group B soyasaponins by high-performance liquid chromatography. Journal of Agricultural and Food Chemistry. 50(9):2587-2594. <https://doi.org/10.1021/jf011181r>.
- 11 INIFAP. 2019. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Tablas de requerimientos nutricionales de especies pecuarias. INIFAP. Ciudad de México, México.
- 12 ISO. 2001. International Organization for Standardization. ISO 14902:2001. Animal feeding stuffs-determination of trypsin inhibitor activity of soya products. ISO. Ginebra, Suiza. <http://higiene.unex.es/Bibliogr/ISO-BS-USDA/ISO-BS/BS%20EN%20ISO/BS%20EN%20ISO%2014902-2001.pdf>.
- 13 Kakade, M. L.; Rackis, J. J.; McGhee, J. E. and Puski, G. 1973. Determination of trypsin inhibitor activity of soy products: a collaborative analysis of an improved procedure. Cereal Chemistry. 51(3):376-382.
- 14 Kong, X.; Li, Y. and Liu, X. 2022. A review of thermosensitive antinutritional factors in plant-based foods. Journal of Food Biochemistry. 46(9):e14199. <https://doi.org/10.1111/jfbc.14199>.
- 15 Liener, I. E. 1994. Implications of antinutritional components in soybean foods. Critical Reviews in Food Science and Nutrition. 34(1):31-67. <https://doi.org/10.1080/10408399409527649>.
- 16 Liu, K. 2019. Soybeans: chemistry, technology, and utilization. 2nd. Edition. Wiley-Blackwell. Hoboken, NJ, USA. <https://doi.org/10.1002/9781119383956>.
- 17 Lott, J. N. A.; Ockenden, I.; Raboy, V. and Batten, G. D. 2000. Phytic acid and phosphorus in crop seeds and fruits: a global estimate. Seed Science Research. 10(1):11-33. <https://doi.org/10.1017/S0960258500000039>.
- 18 Luo, Y.; Xie, W. and Cui, Q. 2009. Effects of phytase, germination, and cooking on the total phosphorus and phytic acid contents of brown rice. Journal of Agricultural and Food Chemistry. 57(20):9600-9606. <https://doi.org/10.1021/jf901628q>.
- 19 Panthee, D. R.; Pantalone, V. R.; Saxton, A. M.; West, D. R. and Sams, C. E. 2016. Quantitative trait loci controlling soybean seed protein and oil content. Agronomy Journal. 108(3):1134-1142. <https://doi.org/10.2134/agronj2015.0386>.

- 20 Raboy, V. 2001. Seeds for a better future: 'low phytate' grains help to overcome malnutrition and reduce pollution. *Trends in Plant Science*. 6(10):458-462. [https://doi.org/10.1016/S1360-1385\(01\)02054-5](https://doi.org/10.1016/S1360-1385(01)02054-5).
- 21 Rotundo, J. L. and Westgate, M. E. 2009. Meta-analysis of environmental effects on soybean seed protein and oil concentration. *Field Crops Research*. 110(2):147-156. <https://doi.org/10.1016/j.fcr.2008.07.012>.
- 22 SADER. 2023. Secretaría de Agricultura y Desarrollo Rural. Panorama agroalimentario 2023. Soya. Ciudad de México, México. <https://nube.agricultura.gob.mx/panorama-dgsiap/>.
- 23 Sandberg, A. S.; Larsen, T. and Sandström, B. 1999. High dietary phytate intake is associated with low mineral absorption in humans. *The Journal of Nutrition*. 129(10):1910-1914. <https://doi.org/10.1093/jn/129.10.1910>.
- 24 Sharma, A. 2021. A review on traditional technology and safety challenges with regard to antinutrients in legume foods. *Journal of Food Science and Technology*. 58(8):2863-2883. <https://doi.org/10.1007/s13197-020-04883-8>.
- 25 Sharma, S.; Goyal, R. and Barwal, S. 2013. Domestic processing effects on physiochemical, nutritional and anti-nutritional attributes in soybeans (*Glycine Max* L. Merrill). *International Food Research Journal*. 20(6):3203-3209.
- 26 Shimoyamada, M.; Ikedo, S.; Ootsubo, R. and Watanabe, K. 1990. Effects of soybean saponins on chymotryptic hydrolysis of proteins. *Journal of Agricultural and Food Chemistry*. 38(3):717-722. <https://doi.org/10.1021/jf00093a015>.
- 27 Singer, W. M.; Lee, Y. C.; Shea, Z.; Vieira, C. C.; Lee, D.; Li, X.; Cunicelli M.; Kadam, S. S.; Khan, M. A. W.; Shannon, G.; Mian, M. A. R.; Nguyen, H, T. and Zhang, B. 2023. Soybean genetics, genomics, and breeding for improving nutritional value and reducing antinutritional traits in food and feed. *The Plant Genome*. 16(4):e20415. <https://doi.org/10.1002/tpg2.20415>.
- 28 Wang, N.; Hatcher, D. W. and Gawalko, E. J. 2022. Legume seed protein digestibility as influenced by traditional and emerging physical processing technologies. *Foods*. 11(15):2202.
- 29 Welham, T. and Domoney, C. 2000. Temporal and spatial activity of a promoter from a pea enzyme inhibitor gene and its exploitation for seed quality improvement. *Plant Science*. 159(2):289-299. [https://doi.org/10.1016/S0168-9452\(00\)00358-7](https://doi.org/10.1016/S0168-9452(00)00358-7).
- 30 Wheeler, E. L. and Ferrel, R. E. 1971. A method for phytic acid determination in wheat and wheat fractions. *Cereal Chemistry*. 48(3):312-320.
- 31 Wilson, R. F. 2004. Seed composition. In: Soybeans: Improvement, production and uses. Boerma, H. R. and Specht, J. E. (Eds.). 3th edition. American Society of Agronomy. Crop Science Society of America and Soil Science Society of America. Madison, WI, USA. 621-677 pp. <https://doi.org/10.2134/agronmonogr16.3ed.c13>.



Soybean grain conditioning and its effect on anti nutrients, protein and lipids

Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
ISSN (electronic): 2007-9230
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (México)

Article/Issue Information
Date received: 01 May 2026
Date accepted: 01 August 2026
Publication date: 01 September 2026
Volume: 17
Issue: 6
Electronic Location Identifier: e4195
DOI: 10.29312/remexca.v17i6.4195

Categories

Subject: Article

Keywords:

Keywords:

family livestock farming

phytates

trypsin inhibitors

Counts

Figures: 0

Tables: 6

Equations: 0

References: 31