

Mineral content of sesame seeds (*Sesamum indicum* L.) from the state of Guerrero, Mexico

Antúñez-Ocampo, Oscar M.^{1*}; Puente-Valenzuela, Cristo O.²; Solís-Bonilla, José L.³; Espinosa-Rodríguez, Mariana⁴; Martínez-Valencia, Biaani B.³; Sabino-López, Juan E.⁴

¹ Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Iguala, Iguala de la Independencia, Guerrero. México. C.P. 40000. ² CENID RASPA-INIFAP. Gomez Palacio, Durango. México. C.P. 35079. ³ Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Rosario Izapa. Tuxtla Chico, Chiapas. México. C.P. 30870.

⁴ Facultad de Ciencias Agropecuarias y Ambientales, Universidad Autónoma de Guerrero. Iguala de la independencia, Guerrero. México C.P. 40040.

ABSTRACT

Objective: To determine the chemical composition of the seeds of five sesame (*Sesamum indicum* L.) varieties cultivated in the state of Guerrero, Mexico.

Design/Methodology/Approach: Five sesame seed varieties were evaluated commercially known as Igualteco, Zirándaro, San Joaquín, Calentana (all with cream-colored seeds), and JR-20 (with black seeds) cultivated in Iguala, Guerrero. A completely randomized experimental design with three replications was implemented. Chemical analyses were conducted at the CENID-RASPA of INIFAP, located in Gómez Palacio, Durango. The parameters analyzed included protein content, macronutrients (N, P, K, Ca, Mg), and micronutrients (Cu, Zn, Fe, Mn).

Results: The San Joaquín and JR-20 varieties exhibited the highest levels of nitrogen and protein. Calentana, Igualteco, and San Joaquín stood out in phosphorus and potassium content. Calcium levels were generally consistent across most varieties, except for Calentana, which showed a divergent value. In terms of magnesium, JR-20 and Igualteco demonstrated superior concentrations. Regarding micronutrients, JR-20 seeds were richest in copper and zinc, whereas Zirándaro seeds had the highest levels of iron and manganese. The overall mineral abundance in the seeds followed the descending order: N>P>Ca>K>Mg>Fe>Zn>Cu>Mn.

Limitations/Implications: A significant limitation is the scarce availability of scientific literature or empirical data concerning the chemical composition of sesame seeds.

Findings/Conclusions: The mineral composition of these sesame varieties supports their inclusion in the regular diet of the Mexican population, given their considerable nutritional value and potential health benefits.

Keywords: proximal analysis, composition, minerals, *Sesamum indicum*, varieties.

Citation: Antúñez-Ocampo, O. M., Puente-Valenzuela, C. O., Solís-Bonilla, J. L., Espinosa-Rodríguez, M., Martínez-Valencia, B.B., & Sabino-López, J. E. (2025). Mineral content of sesame seeds (*Sesamum indicum* L.) from the state of Guerrero, Mexico. *Agro Productividad*. <https://doi.org/10.32854/efyzh989>

Academic Editor: Jorge Cadena Iñiguez

Associate Editor: Dra. Lucero del Mar Ruiz Posadas

Guest Editor: Daniel Alejandro Cadena Zamudio

Received: October 23, 2025.

Accepted: December 14, 2025.

Published on-line: February 18, 2026.

Agro Productividad, 19(12). December, 2025. pp: 149-163.

This work is licensed under a Creative Commons Attribution-Non-Commercial 4.0 International license.



INTRODUCTION

Sesame (*Sesamum indicum* L.) originates from the tropical and subtropical regions of the African continent, particularly Ethiopia. It was later introduced to Central Asia, Indonesia, China, and the Americas (Garnica *et al.*, 2020). This species is characterized as an annual herbaceous plant, with green leaves and white or pink flowers. Its upright stem bears capsules containing numerous smooth seeds. The plant's life cycle ranges from 90 to 130 days, depending on the variety and ecological conditions (Chile-Flores *et al.*, 2022), with



an average yield ranging from 900 to 1,200 kg ha⁻¹ (Pérez *et al.*, 2024). One of sesame's notable features is its high drought tolerance, attributed to its extensive root system (Kumar *et al.*, 2013). Additionally, it has minimal nutritional requirements and can thrive in a wide range of soils ideally those with light textures (loam, sandy loam, and clay loam) and a pH between 5.5 and 7.0 (Jara & Díaz, 2005). In Mexico, sesame was introduced during the Spanish conquest by African slaves (Moreiras *et al.*, 2013). As of 2023, *per capita* sesame consumption in Mexico was 700 grams. Its cultivation provided a significant source of employment and income, with the crop grown across 12 states. A total area of 69,438.85 ha yielded 46,260.35 Mg, with the principal producing states being Sinaloa (22,374.44 ha; 10,063.35 Mg), Guerrero (15,831.34 ha; 12,066.08 Mg), and Michoacán (10,644.00 ha; 8,429.10 Mg) (SIAP, 2024). In Guerrero, sesame is predominantly cultivated under rainfed (spring-summer) conditions in shallow, low-fertility soils with limited agronomic management, resulting in seed yields between 0.650 and 0.850 Mg ha⁻¹ (SIAP, 2024). The main factors limiting sesame seed yield and quality include variety, environmental conditions, inadequate agronomic practices (*e.g.*, plant density, fertilization, agricultural technologies), as well as biotic stresses such as pests, diseases, and weeds (Kumar *et al.*, 2013; Kafi *et al.*, 2022). The most commonly cultivated sesame varieties are those with white seeds, followed by brown and black seed types (Villar, 2019). White-seeded varieties are known for their vigorous growth and higher nutrient demands; their seeds are primarily used in baking and confectionery. Brown varieties, which display seed colors ranging from yellow to dark brown, typically have shorter plants with lower yields and are more adaptable to nutrient-poor soils, making them more rustic. These seeds are mainly used for oil and flour production. Previous studies indicate that over half of the seed's weight consists of oil, while the remainder includes protein (18%), fiber (8%), and minerals (2%) (Moreiras *et al.*, 2013). However, nutrient content varies significantly among varieties (Ismalia & Usman, 2012; Montero *et al.*, 2015). Mineral composition per 100 g of seed includes phosphorus (629-720 mg), potassium (468-570 mg), calcium (670-975 mg), iron (10.40-14.55 mg), magnesium (351-370 mg), and zinc (5.30-7.75 mg) (Menchú & Méndez, 2007; Moreiras *et al.*, 2013; USDA, 2016). Sesame seeds are also rich in vitamins (A, B, C, D, E) and possess high nutritional and therapeutic value (Montero *et al.*, 2015). Additionally, they contain lignans primarily sesamin, sesamol, and sesamol which are associated with various health benefits, including cholesterol and blood pressure reduction, as well as antioxidant and anticancer properties (Kansoula & Liakopoulou-Kyriakides, 2010; Hamada *et al.*, 2011). Notably, the consumption of 50 g of sesame per day over five weeks has been shown to improve hormonal levels, antioxidant capacity in body fluids, and blood lipid profiles in postmenopausal women (Romero *et al.*, 1999). Moreover, being gluten-free makes sesame suitable for individuals with celiac disease, and due to its protein content, it is considered a viable ingredient in nutritional supplements (López *et al.*, 2003). In Mexican cuisine, sesame seeds are primarily used in baking and for making traditional sweets such as palanquetas and alegrías, cookies, confections, and iconic dishes like mole, sauces, atole, and pastes (Díaz-Ramírez *et al.*, 2017). However, these culinary uses often overlook the seeds' nutritional properties and health benefits. Although sesame remains a part of the traditional Mexican diet, its consumption has declined due to dietary shifts influenced

by industrialization, which has promoted the intake of processed foods over natural ones. Given this context, the present study aimed to determine the chemical composition of the seeds of five sesame varieties cultivated in the state of Guerrero, under the hypothesis that at least one variety exhibits a distinct mineral and protein profile compared to the others.

MATERIALS AND METHODS

Germplasm

Five sesame (*Sesamum indicum* L.) varieties were used in this study: Igualteco, Zirándaro, San Joaquín, and Calentana, all characterized by cream-colored seeds, and JR-20, which has black seeds (Figure 1). The agronomic characteristics of four of these varieties are described below (Vásquez & Tavitas, 2017).

Igualteco: This is a branched plant, favored by producers for its extensive fruiting internodes. It reaches a height of 1.70 to 2.00 meters and produces long capsules containing white seeds. Under rainfed conditions, yields range from 920 to 1,000 kg ha⁻¹.

Zirándaro: Also a branched variety, it produces three short capsules per axil, each containing white seeds. Its biological cycle reaches harvest maturity in 97 days. A distinguishing feature of this variety is its complete leaf drop at maturity, which facilitates plant and capsule cutting and drying. Yields typically range from 900 to 1,000 kg ha⁻¹.

San Joaquín. This is an unbranched (single-stemmed) variety with an early growth cycle, producing three to five capsules per axil. The seeds are white, and yields range from 757 to 1,500 kg ha⁻¹. It exhibits excellent agronomic performance under rainfed,



Figure 1. Representative samples of five sesame varieties evaluated.

irrigated, and residual moisture conditions. JR-20 (Black). This is a branched plant with a life cycle of 90 to 100 days and can reach a height of up to 1.60 meters. It produces black seeds, with a minimum yield of 600 kg ha^{-1} and a potential yield of up to $1,000 \text{ kg ha}^{-1}$.

Establishment and crop management

The five sesame (*Sesamum indicum* L.) varieties were cultivated under rainfed conditions (spring-summer cycle) at the experimental fields of the Iguala Experimental Station of INIFAP, located in the municipality of Iguala de la Independencia, in the northern region of Guerrero, Mexico. The site is situated at an altitude of 740 m, at coordinates $18^{\circ} 20' 57''$ N and $99^{\circ} 30' 17''$ W. The soil, sampled at a depth of 0-0.20 m, exhibited a gray color when dry and dark brown when moist. It contained 27.00, 13.80, 547.20, 6,640.00, 3,120.00, and 1.60 kg ha^{-1} of inorganic N, P, K, Ca, Mg, and Na, respectively. The texture was silty clay (1.90% sand, 50.44% clay, and 47.66% silt), with a bulk density of 1.02 g cm^{-3} , electrical conductivity of 0.31 dS m^{-1} , organic matter content of 4.70%, and a pH of 7.7. Sowing was performed manually, placing 8 to 10 seeds per hill with 0.30 m spacing between plants. Thinning was carried out 15 days after seedling emergence (DAE), leaving three plants per hill, resulting in a final plant density of 150,000 plants ha^{-1} . Soil fertilization consisted of a 60N-40P-00K formula, using diammonium phosphate (DAP; 18% N-46% P) and urea (45% N) as sources. Fertilizer was applied manually in two stages: the first at 15 DAE, applying all the phosphorus (86.95 kg DAP) and part of the nitrogen (48.91 kg urea); the second at 40 DAE, incorporating the remaining nitrogen (48.91 kg urea). Fertilizers were applied in bands, 0.10 m from the planting line and 0.15 m deep to avoid direct contact with the plants, then lightly covered with soil. Weed control was conducted manually using hoes and chemically with Paraquat applied at 35 DAE. Soil pests such as wireworms (*Agriotes lineatus* L.) and white grubs (*Phyllophaga* spp.) were controlled by applying 7 kg ha^{-1} of 5% Terbufos at sowing. Foliar pests were managed with 0.75 and 1 L (in 200 L of water) of Cypermethrin and Malathion, respectively. No supplemental irrigation was applied during the crop cycle. Plants were harvested manually once the leaves turned yellow. Bundles were formed for drying, and once fully dry, the seeds were separated by threshing and then cleaned using a 2 mm mesh sieve.

Studied factor and experimental design

The factor under study was the sesame genotype, and the treatments corresponded to the five varieties. A completely randomized design with three replications was used. Each replication consisted of six rows, each 15 m long and spaced 0.80 m apart. The useful plot comprised the two central rows, excluding 1.00 m at each end. For chemical analysis, 100 g samples of representative seed from each variety per replication were used.

Chemical analysis of sesame seeds

Seed analyses were conducted at the Soil Laboratory of CENID-RASPA, INIFAP, in Gómez Palacio, Durango, Mexico. Mineral determinations followed the protocols described in the Laboratory Manual by Plenecassagne *et al.* (1997) and the Handbook of Reference Methods for Plant Analysis by CDC (Kalra, 1998). Samples were dried to

constant weight at 75 °C in a forced-air oven, then ground and homogenized to a fine powder (mesh size <0.5 mm). A 0.2 g subsample was digested with a nitric-perchloric acid mixture at 145 °C for two hours, reduced to near dryness, and diluted to 10 mL with distilled water for analysis by atomic absorption spectrophotometry using a Perkin Elmer[®] Analyst 700 (AACC, 2000). Potassium was quantified from water-diluted samples. Calcium and magnesium were determined from samples diluted with lanthanum in an acidic nitric solution (0.774 g L⁻¹, 1% acidity). Micronutrients (iron, copper, manganese, and zinc) were quantified directly from the digest using a direct aspiration technique. Phosphorus was determined colorimetrically from the digest, using a molybdate -ammonium metavanadate mixed solution, measured at 490 nm with a Jenway[®] 73 UV/VIS spectrophotometer. Total nitrogen was measured via Kjeldahl digestion with a catalytic mixture for complete sample breakdown, followed by colorimetric quantification using the Berthelot method (Plenecassagne *et al.*, 1997). Protein content was calculated by multiplying the nitrogen content by 6.25 (Raya-Pérez *et al.*, 2014). Certified reference material NIST[®] SRM[®] 1573a (tomato leaves) was used as an analytical quality control, with recovery rates exceeding 95% for the analytes assessed. Protein content was expressed as g 100 g⁻¹, while macro- and micronutrient contents were reported as mg 100 g⁻¹.

Statistical analysis

Mineral composition data were organized in Microsoft Excel 2010. An analysis of variance (ANOVA) was performed, and means of significant variables were compared using Tukey's test at a 5% significance level, with the Statistical Analysis System (SAS) software, version 9.0 (SAS Institute, 2002).

RESULTS AND DISCUSSION

The analysis of variance revealed significant differences ($\alpha \leq 0.05$) among sesame varieties in terms of seed protein content, macronutrient, and micronutrient concentrations (Table 1). These results indicate that mineral composition varies across varieties, as evidenced by coefficients of variation (CV) below 10%, suggesting that such differences are due to varietal effects rather than regional environmental factors. In Mexico, research on sesame remains limited, with most studies focusing on agronomic performance, processing, and commercialization. This highlights a gap in scientific literature regarding seed quality and its potential health benefits.

Table 1. Macronutrient, micronutrient, and protein content in sesame seeds cultivated in the state of Guerrero.

Description	N	Pn	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	Macronutrients						Micronutrients			
Significance (α)	**	**	**	**	**	**	**	**	**	**
CM-variety	102213.14	3.98	785090.62	10870.17	75511.37	3053.84	0.49	26.04	323.48	1.53
CV (%)	2	2	7	4	5	4	5	2	8	4
Md	3035.92	18.97	2629.50	942.44	1168.27	226.07	2.28	7.60	13.22	1.58

**=highly significant at $\alpha \leq 0.01$. C.V.=coefficient of variation. CM=mean square. Md=general mean. N=nitrogen. Pc=protein. P=phosphorus. K=potassium. Ca=calcium. Mg=magnesium. Cu=copper. Fe=iron. Zn=zinc. Mn=manganese.

Macronutrients

Nitrogen content ranged from 2,831.50 to 3,327.08 mg 100 g⁻¹, and protein content from 17.70 to 20.79 g 100 g⁻¹. The San Joaquín and JR-20 seed varieties stood out statistically for both parameters, followed by Zirándaro, Igualteco, and finally Calentana, which recorded the lowest values (2,831.50 mg N; 17.70 g protein) (Figure 2a-b). Notably, the protein content found in these sesame varieties is comparable to that reported for quinoa (*Chenopodium quinoa* Willd.) (8 to 22 g 100 g⁻¹), wheat (*Triticum* spp.) (11.48 g), and oats (*Avena sativa* L.) (16.89 g), and surpasses that of rice (*Oryza sativa* L.) (6.61 g), maize (*Zea mays* L.) (9.42 g), and barley (*Hordeum vulgare* L.) (12.48 g) (Moreiras *et al.*, 2013; Garcia-Mazcorro *et al.*, 2016).

Previous studies have documented that the chemical composition of sesame varies depending on the variety, the ecological region where it is cultivated, and post-harvest seed handling. For example, in Veracruz, Mexico, sesame seeds have been reported to contain 22.80% protein (Díaz-Ramírez *et al.*, 2017); whereas in Turkey, values ranged from 18.00% to 23.18%, with the Göl marmara (Menemen) variety standing out (Kemal & Hasan, 2018). In Brazil, 14 sesame genotypes showed protein variability influenced by location (Patos and Barbalha); in Barbalha, protein content ranged from 17.86% to 20.35%, with an average of 18.95%, while in Patos, values ranged from 21.04% to 24.38%, averaging 23.16% (Antoniassi *et al.*, 2013). In Córdoba, Colombia, studies reported that the storage type (warehouse *vs.* natural conditions) and storage duration (30 and 60 days) affected protein content. Prior to packaging, protein content was 18.86%; after 30 days, it increased by 4.5% to 5.93% (19.71%-19.98%), and after 60 days, the increase reached 17.28% to 17.39% (22.12%-22.14%) relative to the initial content (Marrugo *et al.*, 2012). These changes are likely related to seed moisture and storage temperature, which influence industrial quality.

The relevance of sesame's protein content lies in its composition of 15 different amino acids, including a high proportion of methionine (2.91 g 100 g⁻¹), an essential amino acid for the human body (Moreiras *et al.*, 2013). Excess methionine can be converted into

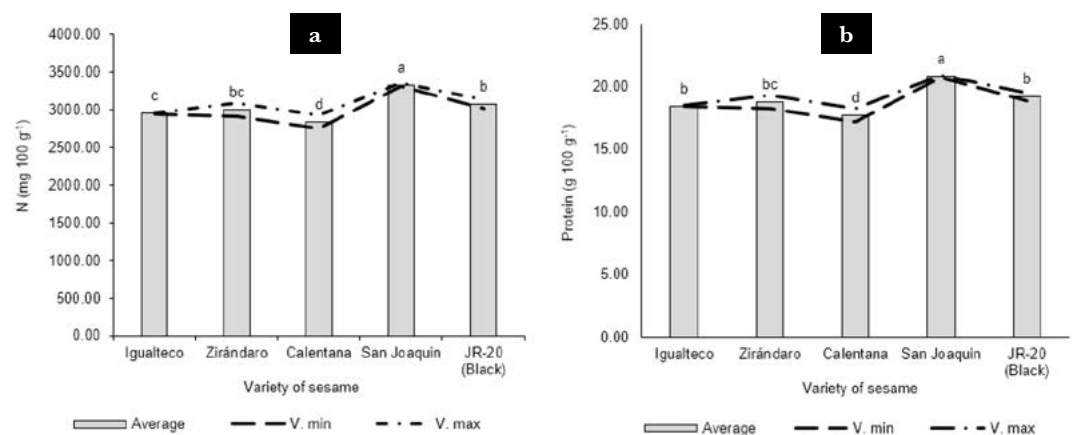


Figure 2. Nitrogen (a) and protein (b) content in seeds of five sesame varieties. Means with different letters within each variety are statistically different ($p \leq 0.05$). LSD(a)=81.23; LSD(b)=0.51.

choline, a nutrient that enhances the body's ability to regulate cholesterol and supports the process by which energy is produced instead of fat. The second most abundant amino acid is tryptophan ($1.93 \text{ g } 100 \text{ g}^{-1}$), a precursor of niacin, which is essential for maintaining a healthy nervous system (Mataix & Carazo, 2002). These properties position sesame as a valuable supplement in food products, as its amino acids are efficiently released during human digestion. Regarding phosphorus (P), the Calentana and Igualteco seed varieties ($3,313.16$ and $2,969.13 \text{ mg } 100 \text{ g}^{-1}$, respectively) exhibited significantly higher concentrations than the other varieties, with differences ranging from 19% to 63%. The San Joaquín and JR-20 varieties showed statistically similar values ($2,360.91$ and $2,483.59 \text{ mg}$), whereas Zirándaro had the lowest P content ($2,020.72 \text{ mg}$) (Figure 3a). A similar trend was observed for potassium (K), with Igualteco, Calentana, and San Joaquín seeds containing the highest levels (975.41 to 998.49 mg), surpassing Zirándaro (874.03 mg) and JR-20 (880.32 mg) by 10% to 13% (Figure 3b).

The consumption of 10 g of sesame seeds from the five varieties (ranging from 202 to 331 mg of P) can provide over 30% of the recommended daily intake (RDI) of phosphorus for the Mexican population (664.00 mg) (NOM, 2008). Furthermore, phosphorus content in these sesame varieties contributes 16% to 26% of the RDI for individuals over 19 years of age ($1,250 \text{ mg}$), as indicated by the U.S. Department of Agriculture (USDA) (IOM, 1997), and far exceeds the P values reported for sesame (57 mg), apple (*Malus domestica* Borkh.) (20 mg), and tomato (*Solanum lycopersicum* L.) (22 mg), all of which provide less than 5% of the RDI (USDA, 2019).

Regarding potassium (K), the content in sesame seeds (87 to 99 mg per 10 g) accounts for approximately 3% of the RDI for individuals under 18 (860 mg) and over 18 years ($3,400 \text{ mg}$) (NASEM, 2019), also according to the USDA. These values surpass those of peanuts (*Arachis hypogaea* L.) (90 mg), flaxseed (*Linum usitatissimum* L.) (84 mg), and cooked white rice (54 mg), which contribute only 1-2% of the RDI. However, sesame varieties showed lower K content compared to lentils (*Lens culinaris* Medik) (731 mg), pumpkin (*Cucurbita* spp.) (644 mg), raisins (*Prunus domestica* L.) (618 mg), red beans (*Phaseolus vulgaris* L.) (607 mg),

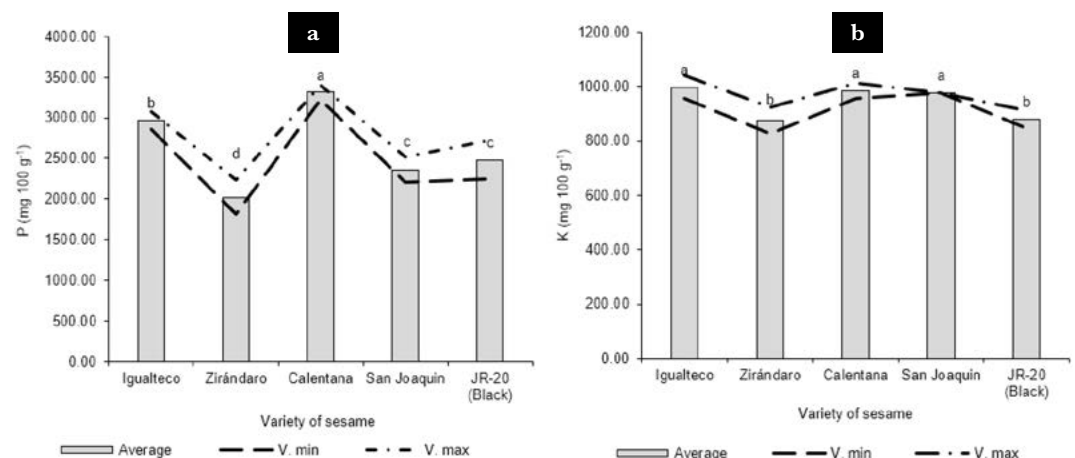


Figure 3. Phosphorus (a) and potassium (b) content ($\text{mg } 100 \text{ g}^{-1}$) in seeds of five sesame varieties. Means with different letters within each variety are statistically different ($p \leq 0.05$). $\text{LSD}(a) = 229.02$; $\text{LSD}(b) = 46.62$.

soybeans (*Glycine max* (L.) Merrill) (443 mg), banana (*Musa paradisiaca* L.) (422 mg), tomato (292 mg), apple (195 mg), and cooked brown rice (154 mg), which collectively provide between 6% and 16% of the RDI. The U.S. Food and Drug Administration recommends a daily intake of 28 g of sesame (equivalent to three tablespoons) to absorb most of the seed's nutrients (USDA, 2019).

The nutritional relevance of these minerals lies in the fact that phosphorus is primarily stored in bones and teeth (85%) and is distributed throughout the blood and soft tissues (15%) (Heaney, 2012). It also plays a vital role in cellular energy production (ATP), gene transcription regulation (DNA and RNA), enzyme activation, extracellular fluid pH maintenance, and intracellular energy storage (Heaney, 2012). Potassium, on the other hand, is essential for overall body function, particularly kidney and heart health, muscle contraction, and nerve transmission (IOM, 2005). Consequently, daily intake of 275 to 1,250 mg of phosphorus and 860 to 3,400 mg of potassium is recommended (NASEM, 2019). Deficiency in either mineral can lead to symptoms such as appetite loss, anemia, muscle weakness, poor coordination, bone pain, soft or deformed bones, increased infection risk, skin burning or itching sensations, confusion, elevated blood pressure, kidney stone formation, urinary calcium loss, and salt sensitivity (IOM, 2005).

Regarding calcium (Ca), the JR-20 variety had the highest content (1,334 mg), although it was statistically similar to Zirándaro and San Joaquín (1,175-1,270 mg), but all three differed from Igualteco (1,188 mg). These four varieties significantly outperformed Calentana, which had the lowest Ca content (894.94 mg) (Figure 4a). In contrast, magnesium (Mg) content varied more notably among varieties. JR-20 and Igualteco seeds were statistically superior, with values 19% to 35% higher than those of the remaining varieties (Figure 4b).

Sesame seeds from the five varieties, with calcium contents ranging from 89 to 133 mg per 10 g, contribute between 9% and 14% of the Recommended Daily Intake (RDI) of calcium (900 mg), as established by NOM-247-SSA1-2008 for the Mexican population (NOM, 2008), and between 8% and 11% of the RDI indicated by the USDA, depending on

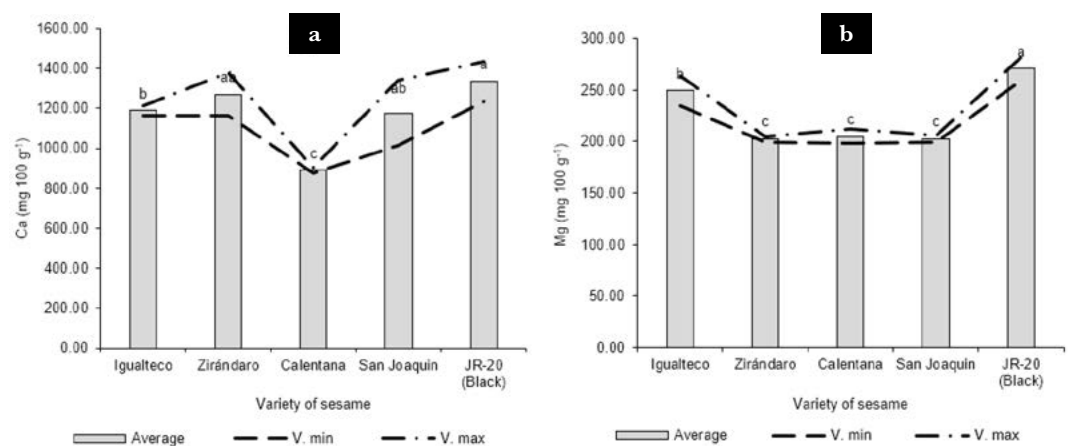


Figure 4. Calcium (a) and magnesium (b) content (mg 100 g⁻¹) in seeds of five sesame varieties. Means with different letters within each variety are statistically different ($p \leq 0.05$). LSD(a)=77.72; LSD(b)=12.37.

age and sex (children: <700 mg; 4-71 years: 1,000-1,200 mg day⁻¹) (IOM, 2011; USDA, 2019). These contributions make sesame a notable plant-based source of calcium; however, the presence of antinutritional compounds should be considered as a limiting factor for mineral bioavailability.

The calcium content in sesame compares favorably with that of soybeans (131 mg) and spinach (*Spinacia oleracea* L.) (123 mg), both contributing 9%-10% of the RDI. Furthermore, sesame surpasses the mineral content of chia seeds (*Salvia hispanica* L.) (76 mg), pinto beans (54 mg), corn tortillas (46 mg), and apples (10 mg), all of which contribute less than 6% of the daily requirement (USDA, 2019; USDA, 2021). Regarding magnesium (Mg), the sesame varieties, with contents ranging from 20 to 27 mg per 10 g, contribute more than 4% of the RDI (250 to 420 mg) (NOM, 2008; USDA, 2019). These values are higher than those found in apples (9 mg), white rice (10 mg), and avocado (*Persea americana* Mill.) (22 mg), which meet less than 5% of the daily requirement. However, they are lower than those reported in bananas (32 mg), red beans (35 mg), brown rice (42 mg), black beans (60 mg), spinach (78 mg), toasted almonds (*Prunus dulcis* Mill.) (80 mg), chia seeds (111 mg), and toasted pumpkin seeds (156 mg), which provide between 8% and 37% of the RDI for children aged 1-13 years (80-240 mg) and for adults and pregnant women (310-420 mg) (USFDA, 2016; USDA, 2019). Sesame's importance in human health lies in its role as a plant-based calcium source, especially for individuals with lactose intolerance (due to lactase deficiency), who can obtain highly absorbable calcium from sesame seeds (975 mg 100 g⁻¹), in comparison to other seeds like chia (631 mg), flaxseed (256 mg), and quinoa (40 mg) (Barrera *et al.*, 2012). Sesame is also recommended during menopause to prevent osteoporosis and during pregnancy, when calcium demand increases. These nutritional attributes make sesame ideal for vegetarian diets (Ursell, 2001). In the human body, calcium is essential for forming the structural matrix of bones and teeth, supporting movement by maintaining firm, flexible, and resilient tissues (IOM, 2011; USDA, 2019). It also contributes to blood vessel contraction and dilation, muscle function, blood clotting, nerve transmission, and hormone secretion (Heaney, 2010; IOM, 2011; USDA, 2019). Magnesium, meanwhile, is critical for energy production, oxidative phosphorylation, and glycolysis. It supports bone structure and is necessary for DNA, RNA, and glutathione synthesis (IOM, 1997). Moreover, it is involved in the active transport of calcium and potassium ions across cell membranes key to nerve impulse conduction, muscle contraction, and maintaining normal heart rhythm (Rude, 2012).

Micronutrients

The JR-20 variety stood out for its copper (Cu) and zinc (Zn) content, with seed concentrations of 29.99 mg and 12.87 mg, respectively. For copper, the difference among varieties ranged from 35% to 52%. The seeds of Iqualteco, Zirándaro, and San Joaquín showed statistically similar Cu values (2.08 to 2.21 mg), while Calentana had the lowest content (19.64 mg) (Figure 5a). As for zinc, values ranged from 6.06 to 12.87 mg (a 101%-112% difference), with Zirándaro, Calentana, and San Joaquín statistically grouped (6.33 to 6.38 mg), while Iqualteco recorded the lowest Zn concentration (6.06 mg) (Figure 5b).

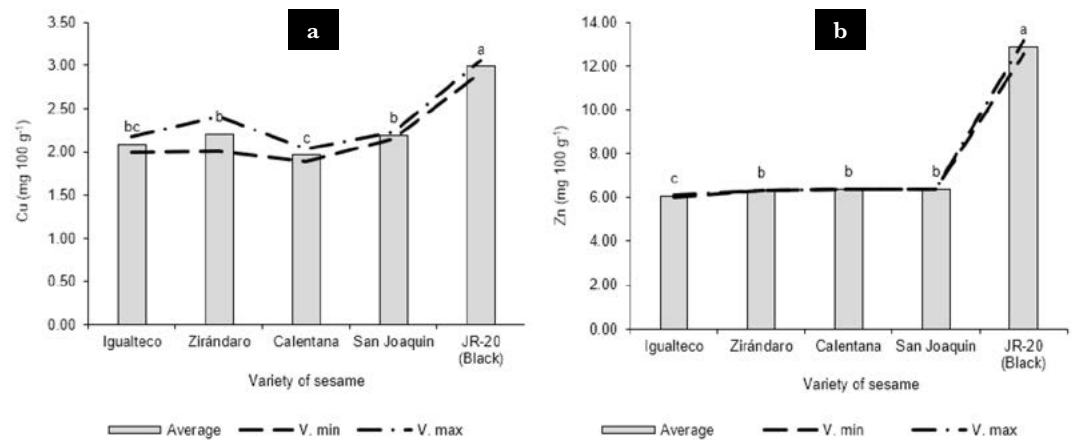


Figure 5. Copper (a) and zinc (b) content (mg 100 g⁻¹) in seeds of five sesame varieties. Means with different letters within each variety are statistically different ($p \leq 0.05$). LSD(a)=0.15; LSD(b)=0.18.

The copper content observed (0.20-0.30 mg per 10 g) in sesame seeds represents more than 30% of the Recommended Daily Intake (RDI) for the Mexican population (0.650 mg) (NOM, 2008), and exceeds by over 30% the value reported by the USDA (2019) for sesame seeds (0.147 mg per 10 g), which contributes only 6% of the RDI (0.80-1.40 mg). Moreover, these values are higher than those found in tomato (0.053 mg) and apple (0.017 mg), both of which contribute less than 6% of the RDI. However, all sesame seed varieties showed lower Cu content than sunflower seeds (*Helianthus annuus* L., roasted: 0.615 mg), chickpeas (*Cicer arietinum* L.) (0.289 mg), avocado (219 mg), and spinach (157 mg), which contribute 17%-68% of the RDI. For zinc, sesame seeds contributed between 5% and 11% of the RDI (0.60-1.28 mg per 10 g), based on the recommended intake of 10-11 mg (IOM, 2001; NOM, 2008; USDA, 2019). These contributions exceed those of peanuts (roasted: 0.8 mg), brown rice (0.7 mg), red beans (0.6 mg), white rice (0.3 mg), tomato (0.1 mg), and blueberries (*Vaccinium corymbosum* L.) (0.1 mg), which provide only 1%-7% of the RDI. Nevertheless, sesame seeds had lower Zn content than pumpkin seeds (2.2 mg) and lentils (1.3 mg), which contribute 12%-20% of the adult dietary requirement (USDA, 2019). Sesame seeds stand out as an important plant-based source of Cu and Zn, both absorbed primarily in the upper small intestine (Collins, 2014; Prohaska *et al.*, 2012). Copper is essential for brain development, immune and nervous system function, and gene activation. It is also required for energy production, connective tissue formation, and blood vessel development, and is a structural component of bones and muscles (Collins, 2014; IOM, 2001). Zinc, on the other hand, plays a role in carbohydrate, fat, and protein metabolism (USDA, 2019); it also supports healthy growth and development during pregnancy, infancy, childhood, and adolescence, and is involved in taste perception (King *et al.*, 2014; Nagraj *et al.*, 2017; Ryu & Aydemir, 2020). Copper absorption is strongly influenced by its dietary concentration: its bioavailability is about 75% when intake reaches 0.400 mg day⁻¹, but drops to 12% when the intake is only 0.0075 mg day⁻¹ (King *et al.*, 2014). It has also been documented that up to 50% of individuals diagnosed with celiac disease are at high risk of zinc deficiency (Wierdsma *et al.*, 2013; Rondanelli *et al.*, 2019). In this context, zinc-fortified breakfast cereals represent

an important dietary source of this mineral in the U.S. diet (King *et al.*, 2014), contributing 12.1% and 18.4% of daily Zn intake in American children and adolescents, respectively (Berner *et al.*, 2014). A distinct trend was observed for iron (Fe) and manganese (Mn), with Zirándaro seeds statistically outperforming all other varieties in both minerals (Fe: 25.12 mg; Mn: 2.57 mg) (Figure 6a-b). For iron, although Zirándaro showed the highest content, it was statistically similar to San Joaquín (24.05 mg). Both exceeded the iron content of the other varieties by over 200%, which ranged between 5.22 and 6.29 mg. These four varieties were statistically similar, with Igualteco showing the lowest Fe value. For manganese, the seeds of Zirándaro exceeded JR-20 by 11% and Igualteco by 115%. The largest differences were observed when compared to Calentana and San Joaquín, whose seeds had the lowest Mn content (1.00-1.04 mg), and were statistically similar to each other (Figure 6).

Consumption of sesame seeds from the five varieties provides more than 3% (0.52 to 2.51 mg per 10 g) of the RDI for iron (8-18 mg) in adults (NOM, 2008; USDA, 2019), which is comparable to the contribution of red beans (2 mg), chickpeas (2 mg), tomato (2 mg), and peas (*Pisum sativum* L.) (1 mg), all of which provide 6%-11% of the recommended intake. However, the values reported for these varieties are lower than those from white beans (8 mg), lentils, and spinach (3 mg; 17%), which satisfy between 17% and 44% of the daily requirement. In the case of manganese, Zirándaro (0.26 mg per 10 g) and JR-20 (0.21 mg) (Figure 6b) showed values comparable to those reported by the USDA (2019) for sesame seeds (0.20 mg per 10 g), whereas Igualteco, Calentana, and San Joaquín recorded contents approximately 50% lower. The nutritional contribution of sesame for manganese ranged from 4% to 9% (0.10-0.26 mg per 10 g) of the RDI (1.5-2.3 mg) (IOM, 2001; USDA, 2019), exceeding that of apple (0.1 mg) but remaining lower than other manganese-rich foods such as blueberries (0.3 mg), pumpkin (0.3 mg), red beans (0.3 mg), white rice (0.3 mg), lentils (0.5 mg), peanuts (0.5 mg), oats (0.7 mg), soybeans (0.7 mg), pineapple (*Ananas comosus* L.) (0.8 mg), spinach (0.8 mg), chickpeas (0.9 mg), and brown rice (1.1 mg). Notably, the human body absorbs only 1% to 5% of dietary manganese (Nielsen, 2012; Chen *et al.*, 2018), and absorption efficiency increases with lower dietary intake and decreases with higher intake levels (Buchman, 2014).

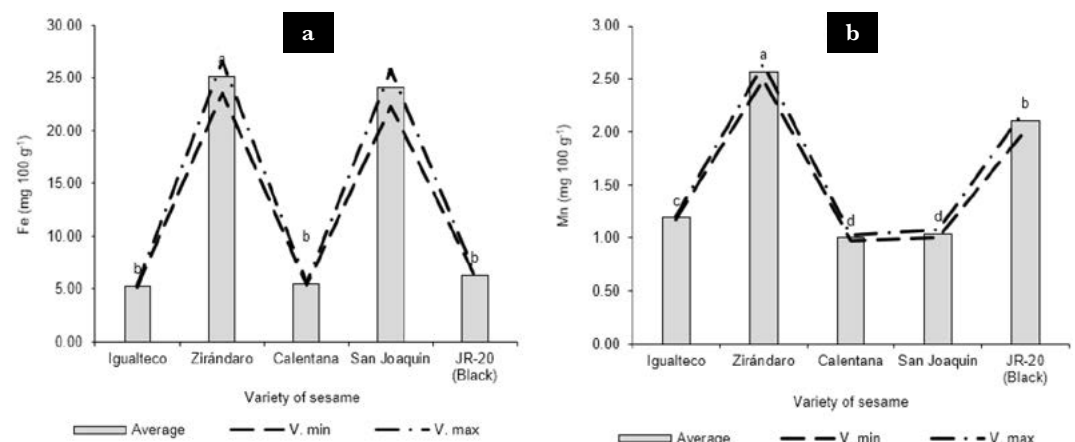


Figure 6. Iron (a) and manganese (b) content (mg 100 g⁻¹) in seeds of five sesame varieties. Means with different letters within each variety are statistically different ($p \leq 0.05$). LSD(a)=1.41; LSD(b)=2.24.

The mineral composition of sesame seeds particularly Fe and Mn offers significant health benefits. Iron is a key component of hemoglobin and myoglobin, proteins that transport oxygen (Wessling-Resnick, 2014), and supports muscle metabolism and connective tissue health (Aggett *et al.*, 2012). It is also required for physical growth, neurological development, cellular function, and hormone synthesis (Murray-Kolbe & Beard, 2010; Aggett *et al.*, 2012). Dietary sources of non-heme iron include nuts, legumes, vegetables, and fortified grains (IOM, 2001; Murray-Kolbe & Beard, 2010; Aggett *et al.*, 2012). Heme iron, found in meat and seafood, has greater bioavailability than non-heme iron (Hurrell & Egli, 2010; Murray-Kolbe & Beard, 2010), with absorption rates of 14%-18% in mixed diets containing substantial amounts of meat, seafood, and vitamin C (which enhances non-heme iron absorption), and only 5%-12% in vegetarian diets (Aggett *et al.*, 2012). Manganese plays a role in the metabolism of amino acids, cholesterol, glucose, and carbohydrates; the elimination of reactive oxygen species; bone formation; reproduction; and immune function (Chen *et al.*, 2018; Li & Yang, 2018). It also contributes to blood clotting and hemostasis in conjunction with vitamin K (Aschner & Aschner, 2005). Because only 1%-5% of dietary Mn is absorbed, a daily intake of 1.5 to 2.3 mg is recommended (USDA, 2019). Its absorption improves with lower intake and decreases with higher intake (Buchman, 2014). Manganese deficiency may disrupt lipid and carbohydrate metabolism and lead to abnormal glucose tolerance (Li & Yang, 2018). Animal studies have shown that Mn supplementation can improve glucose tolerance, reduce oxidative stress, and alleviate endothelial dysfunction in diabetes (Li & Yang, 2018), although clinical trials in humans are lacking to confirm its role in diabetes prevention.

CONCLUSIONS

The five sesame varieties studied are protein-rich foods (>19%), with San Joaquín and JR-20 (black seeds) standing out. Additionally, the seed mineral composition particularly phosphorus, potassium, calcium, and magnesium support their inclusion in the regular diet of the population, as these nutrients contribute to overall nutrition and health. Sesame also serves as a valuable source of calcium and essential micronutrients. The abundance of macro- and micronutrients in the seeds followed the order: N>P>Ca>K>Mg>Fe>Zn>Cu>Mn.

The mineral content values identified in this study may serve as potential quality indicators for the differentiation and commercialization of sesame seed varieties.

ACKNOWLEDGMENTS

We would like to thank INIFAP-Iguala Experimental Station and the INIFAP project “*Ex situ* characterization and productivity, and socioeconomic aspects of native bean producers in Guerrero, Mexico.” We also extend our gratitude to the social service students from the August 2023 cohort of the Colegio Superior Agropecuario del Estado de Guerrero (CSAEGro) and the Universidad Autónoma de Guerrero (UAGro).

REFERENCES

AACC. (2000). Approved Methods of American Association of Cereal Chemists. 10th Ed. The Association, St. Paul, Minnesota, USA. *Methods*. 56-11.02, 76-21.02.

- Aggett P. J. (2012). Iron. In: Erdman J. W., Macdonald I. A. & Zeisel S. H (Eds). Present Knowledge in Nutrition. 10th edition. Washington, DC: Wiley-Blackwell, 506-20.
- Antoniassi R., Arriel N. H. C., Goncalves E. B., Freitas S. C. de, Zanotto D. L. & Bizzo H. R. (2013). Influência das condições de cultivo na composição da semente e do óleo de gergelim. *Revista Ceres, Viçosa*, 60(3), 301-310. doi: 10.1590/S0034-737X2013000300001
- Aschner J. L. & Aschner M. (2005). Nutritional aspects of manganese homeostasis. *Mol Aspects Med*, 26, 353-62.
- Barrera P. M. del P., Lancheros P. L. & Vargas Z. M. (2012). Consumo de calcio: evolución y situación actual. *Revista Facultad de Medicina*, 60(1), 50-61.
- Berner L. A, Keast D. R, Bailey R. L. and Dwyer J. T. (2014). Fortified foods are major contributors to nutrient intakes in diets of US children and adolescents. *J Acad Nutr Diet*, 114, 1009-22e8.
- Buchman A. R. (2014). Manganese. In: Ross A. C., Caballero B., Cousins R. J., Tucker K. L., Ziegler T. R. (Eds). Modern Nutrition in Health and Disease. 11th ed. Baltimore, MD: Lippincott Williams & Wilkins, 238-44.
- Chen P, Bornhorst J. & Aschner M. (2018). Manganese metabolism in humans. *Front Biosci (Landmark Ed)*, 23, 1655-79.
- Chile-Flores N. R., Rodríguez-Urrutia E. A., Molina-Escalante M. O., Rodríguez-Gracias O. A. & Carranza-Estrada F. A. (2022). Evaluación de cinco dosis de un fertilizante químico y una dosis de fertilizante orgánico en el desarrollo y rendimiento del cultivo de ajonjolí (*Sesamum indicum* L.) en San Luis Talpa, La Paz, El Salvador. *Revista Agrociencia*, 22, 6-17.
- Collins J. F. (2014). Copper. In: Ross A. C., Caballero B., Cousins R. J., Tucker K. L., Ziegler T. R. (Eds). Modern Nutrition in Health and Disease. 11th ed. Baltimore, MD: Lippincott Williams & Wilkins, 206-16.
- Díaz-Ramírez M., Hernández-Unzón H. Y., Salgado-Cruz Ma. de la P., Cruz-Monterrosa R. G., Jiménez-Guzmán J., Miranda-de la Lama G. C. & Rayas-Amor A. A. (2017). Efecto del almacenamiento en la actividad antioxidante de *Sesamum indicum* L., tratado térmicamente en horno convencional y microondas. *Revista Agroproductividad*, 10(10), 15-21.
- García-Mazcorro J. F., Mills D. & Noratto G. (2016). Molecular exploration of fecal microbiome in quinoa-supplemented obese mice. *FEMS Microbiology Ecology*, 92(7), fiw089.
- Garnica J., Rodríguez O., Jaramillo C., Villamil J. & Valencia J. (2020). Caracterización morfológica de 160 accesiones de ajonjolí (*Sesamum indicum* L.) del banco de germoplasma de Colombia. *Ciencia Y Agricultura*, 17(3): 63-77.
- Hamada N., Tanaka A., Fujita Y., Itoh T., Ono Y., Kitagawa Y., Tomimori N., Kiso Y., Akao Y., Nzawa Y. & Ito M. (2011) Involvement of heme-oxygenase-1 induction via Nrf2/ARE activation in protection against H₂O₂-induced PC12 cell death by a metabolite of sesamin contained in sesame seeds. *Bioorg Med Chem Lett*, 19, 1959-1965.
- Heaney R. P. (2010). Calcium. In: Coates PM, Betz JM, Blackman MR, et al., eds. Encyclopedia of Dietary Supplements. 2nd ed. London and New York: Informa Healthcare, 101-6.
- Heaney R. P. (2012). Phosphorus. In: Erdman J. W., Macdonald I. A., Zeisel S. H (Eds). Present Knowledge in Nutrition. 10th edition. Washington, DC: Wiley-Blackwell, 447-58.
- Hurrell R. & Egli I. (2010). Iron bioavailability and dietary reference values. *The American Journal of Clinical Nutrition*, 91, 1461S-7S. <https://doi.org/10.3945/ajcn.2010.28674F>
- Institute of Medicine (IOM). (1997). Food and Nutrition Board. Dietary Reference Intakes: Calcium, Phosphorus, Magnesium, Vitamin D and Fluoride. Washington, DC: National Academy Press.
- Institute of Medicine (IOM). (2001). Food and Nutrition Board. Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC: National Academies Press.
- Institute of Medicine (IOM). (2005). Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC.
- Institute of Medicine (IOM). (2011). Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: The National Academies Press.
- Ismalia A. & Usman A. (2012). Genetic Variability for Yield and Yield Components in Sesame (*Sesamum indicum* L.). *International Journal of Science and Research (IJSR)*, 3(9), 63-66.
- Jara S. M. E. & Díaz A. R. R. (2005). Efecto de fósforo y nitrógeno en el rendimiento de sésamo (*Sesamum indicum* L.), sobre un Alfisol en el distrito de Horqueta. *Investigacion Agraria*, 7(2), 42-44.
- Kafi M., Nabati J., Rezazadeh E. B., Oskoueian A. & Soureshjani H. K. (2022). Single and poly capsule sesame (*Sesamum indicum* L.) productivity in response to plant growth-promoting rhizobacteria and foliar application of silicon, potassium, and calcium. *Acta Physiologiae Plantarum*, 44(10), 103. <https://doi.org/10.1007/s11738-022-03437-z>

- Kalra Y. P. (1998). Handbook of Reference Methods for Plant Analysis. CRC Press, Boca Raton. Florida. 300 p.
- Kansoula Z. & Liakopoulou-Kyriakides M. (2010). Effect of endogenous antioxidants of sesame seeds and sesame oil to the thermal stability of edible vegetable oils. *LWT - Food Science and Technology*, 43(9), 1379-1386. <https://doi.org/10.1016/j.lwt.2010.04.016>
- Kemal Ü. M. & Hasan Y. (2018). Proximate composition of Turkish sesame seeds and characterization of their oils. *Grasas y aceites*, 59(1), 23-26.
- King J. C. & Cousins R. J. Zinc. In: Ross AC, Caballero B, Cousins RJ, Tucker KL, Ziegler TR, eds. (2014). Modern Nutrition in Health and Disease. 11th ed. Baltimore, MD: Lippincott Williams & Wilkins, 189-205.
- Kumar N., Tikka S. B. S., Dagla M. C., Ram, B. & Meena H. P. (2013). Genotypic Adaptability for Seed Yield and Physiological Traits in Sesame (*Sesamum indicum* L.). *The Bioscan*, 8(4), 1503-1509.
- Li L. & Yang X. (2018). The Essential Element Manganese, Oxidative Stress, and Metabolic Diseases: Links and Interactions. *Oxid Med Cell Longev*, 7580707. <https://doi.org/10.1155/2018/7580707>
- López G., Flores I., Gálvez A., Quirasco M. & Farrés A. (2003). Development of a liquid nutritional supplement using a *Sesamum indicum* L. protein isolate. *LWT - Food Science and Technology*, 36(1): 67-74. [https://doi.org/10.1016/S0023-6438\(02\)00173-1](https://doi.org/10.1016/S0023-6438(02)00173-1)
- Marrugo L. Y. A., Fuentes B. L., Montero C. P. M. & Acevedo C. D. (2012). Evaluación bromatológica de semillas de ajonjolí (*Sesamum indicum*) empacadas en bolsas silobag. *Vitae*, 19(1): S156-S158.
- Matix J. & Carazo E. (2002). Nutrición para Educadores. 2ª edición. Editorial Días de Santos. España. 752 p.
- Menchú M. T. & Méndez H. (2007). Tabla de Composición de Alimentos de Centroamérica. Guatemala. 2ª edición. INCAP/OPS. 128 p.
- Montero P., Acevedo D., Arnedo A. & Miranda N. (2015). Efecto de la Incorporación de Plasma Sanguíneo y Pasta de Ajonjolí en la Fabricación de un Embutido tipo Salchicha. *Información Tecnológica*, 26(6), 55-56.
- Moreiras O., Carbajal A., Cabrera L., y Cuadrado C. (2013). Tablas de composición de alimentos. Guía de prácticas. Ediciones Pirámide. 16ª edición. https://www.academia.edu/78953267/LA_ALIMENTACION_ESPAÑA
- Murray-Kolbe L. E. & Beard J. (2010). Iron. In: Coates PM, Betz JM, Blackman MR, et al., eds. Encyclopedia of Dietary Supplements. 2nd ed. London and New York: Informa Healthcare, 432-8.
- Nagraj K. S., George R. P., Shetty N., Levenson D., Ferraiolo D. M., & Shrestha A. (2017). Interventions for managing taste disturbances. *Cochrane Database of Systematic reviews*, 12(12), CD010470. <https://doi.org/10.1002/14651858.CD010470.pub3>
- National Academies of Sciences, Engineering, and Medicine. (NASEM). (2019). Dietary Reference Intakes for Sodium and Potassium. Washington, DC. The National Academies Press.
- Nielsen F. H. (2012). Manganese, Molybdenum, Boron, Chromium, and Other Trace Elements. In: Erdman Jr. J. W., Macdonald I. A. & Zeisel S. H. (Eds). Present Knowledge in Nutrition. 10th edition. Wiley-Blackwell, 586-607.
- Norma Oficial Mexicana (NOM). (2008). NOM-247-SSA1-2008 Productos y servicios. Cereales y sus productos. Cereales, harinas de cereales, sémolas o semolinas. Alimentos a base de: cereales, semillas comestibles, de harinas, sémolas o semolinas o sus mezclas. Productos de panificación. Disposiciones y especificaciones sanitarias y nutrimentales. Métodos de prueba. Disponible en: https://dof.gob.mx/nota_detalle.php?codigo=5100356&fecha=27/07/2009#gsc.tab=0. Consultado: 29/12/2023.
- Pérez D. Y., Calero Hurtado A., Peña Calzada K., Gutiérrez Díaz J. L. y Rodríguez González V. (2024). Densidades de plantas y aplicación foliar de aminoácidos incrementan el rendimiento del ajonjolí. *Temas Agrarios*, 29(1), 100-112. <https://doi.org/10.21897/w2sd1542>
- Plenecassagne A., Romero-Fierro E. & Lopez-Borrego C. (1997). Manual de Laboratorio, Análisis de suelos, aguas, plantas, Gomez Palacio. CENID RASPA. Durango. México.
- Prohaska J. R. (2012). Copper. In: Erdman J. W., Macdonald I. A. & Zeisel S. H. (Eds). Present Knowledge in Nutrition. 10th edition. Washington, DC. Wiley-Blackwell, 540-53.
- Raya-Pérez J. C., Gutiérrez-Benicio G. M., Ramírez P. J. G., Covarrubias-Prieto J. & Aguirre-Mancilla C. L. (2014) Caracterización de proteínas y contenido mineral de dos variedades nativas de frijol de México. *Agronomía Mesoamericana*, 25, 01-11.
- Romero I. M. C., Hernández F. M., Hernández L. M. A. & Gámez B. A. I. (1999). Alimentación de las mujeres embarazadas en los hogares maternos. *Revista Cubana de Alimentación y Nutrición*, 13(1), 55-62.
- Rondanelli M., Faliva M. A., Gasparri C., Peroni G., Naso M., Picciotto G., Riva A., Nichetti M., Infantino V., Alalwan T. A., Perna S. (2019). Micronutrients Dietary Supplementation Advices for Celiac Patients

- on Long-Term Gluten-Free Diet with Good Compliance: A Review. *Medicina (Kaunas)*, 55(7), 337. <https://doi.org/10.3390/medicina55070337>
- Rude R. K. (2012). Magnesium. In: Ross A. C., Caballero B., Cousins R. J., Tucker K. L. & Ziegler T. R. (Eds). *Modern Nutrition in Health and Disease*. 11th ed. Baltimore, Mass: Lippincott Williams & Wilkins, 159-75.
- Ryu M. S., Aydemir T. B. (2020). Zinc. In: Marriott B. P., Birt D. F., Stallings V. A. & Yates A. A. (Eds). *Present Knowledge in Nutrition*. 11th edition. Cambridge, Massachusetts. Wiley-Blackwell, 393-408.
- SAS Institute. (2002) SAS/STAT User's Guide. Version 9.1. Volumes 1-7. SAS Institute. Cary, NC, USA.
- Servicio de Información Agroalimentaria y Pesquera (SIAP). (2024). Avance de Siembras y Cosechas. Resumen nacional por cultivo. En: http://infosiap.siap.gob.mx:8080/agrícola_siap_gobmx/AvanceNacionalSinPrograma.do (Consultado: 17/12/2024).
- U.S. Department of Agriculture (USDA). (2019). Agricultural Research Service. FoodData Central external link disclaimer.
- U.S. Department of Agriculture. (USDA) (2021). Food Data Central. Calcio.
- U.S. Food and Drug Administration (USFDA). (2016). Food Labeling: Revision of the Nutrition and Supplement Facts Labels. external link disclaimer
- Ursell A. (2001). Guía completa de los alimentos saludables. Editorial El Ateneo. España. 256 p.
- Vásquez O. R. & Tavitas F. L. (2017). Ajonjolí. In: Agenda Técnica Agrícola de Guerrero. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Ciudad de México, México. 120 p.
- Villar V. L. (2019). Cultivo de Sésamo. Disponible en: <https://es.scribd.com/document/421616262/CultivoDel-Sesamo#download>
- Wessling-Resnick M. (2014). Iron. In: Ross A. C., Caballero B., Cousins R. J., Tucker K. L. & Ziegler R. G. (Eds). *Modern Nutrition in Health and Disease*. 11th ed. Baltimore, MD. Lippincott Williams & Wilkins, 176-88.
- Wierdsma N. J., van Bokhorst-de van der Schueren M. A., Berkenpas M., Mulder C. J. & van Bodegraven A. A. (2013). Vitamin and mineral deficiencies are highly prevalent in newly diagnosed celiac disease patients. *Nutrients*, 5, 3975-92.