



## Assessment of Functional and Nutritional Characteristics in Bolivians Oilseed Varieties

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**Keys:** *Absorption, Flour, Functionals properties, Holding, Nutritional composition, Oilseed*; **Claves:** *Absorción, Composición nutricional, Harina, Propiedad funcional, Retención, Semilla oleaginosa.*

### ABSTRACT

Oilseeds are substantial to national production due to their export value and contribution of unsaturated fats. This study analyzes Bolivian chia, sesame, and flaxseed, considering their variety (white and black) and flour form. Environmental conditions could influence their nutritional profile. Proximate analysis identified compounds that affect their functionality. Chia showed greater absorption, while sesame and flaxseed stood out for their oil retention. The flours exhibit chemical and functional differences due to their affinity with the medium, facilitating proper design of food products.

### RESUMEN

*Evaluación de las características funcionales y nutricionales de variedades de oleaginosas bolivianas.* Las semillas oleaginosas son esenciales en la producción nacional por su valor exportable y aporte de grasas insaturadas beneficiosas para el metabolismo. Este estudio analiza chí, sésamo y linaza bolivianas, considerando su variedad (blanca y negra) y presentación en harina. Las condiciones ambientales podrían influir en su perfil nutricional. El análisis proximal identificó compuestos que afectan su funcionalidad: la chí mostró mayor absorción, mientras que sésamo y linaza destacaron por retención oleosa. Las harinas evidencian diferencias químicas y funcionales por afinidad con el medio, facilitando el adecuado diseño de productos alimentarios.

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## INTRODUCTION

Oilseeds are considered functional foods due to the diverse range of by-products that can be derived from their macromolecules.<sup>1</sup> Additionally, oilseeds encompass a wide variety of species, differing in color, size, and shape. In Bolivia, oilseeds such as chia (*Salvia hispanica* L.), sesame (*Sesamum indicum*), and flaxseed (*Linum usitatissimum*) have recently garnered interest because of their high proportion of extractable lipids.<sup>2 3 4</sup>

Although these three seeds belong to different botanical families, they share similar functional properties due to their bioavailability and versatile applications. Their physical, chemical, and rheological characteristics make them suitable for use both in their original seed form and when processed into flour. These ingredients are commonly incorporated into beverages, edible oils, bakery products, and more.

The nutritional value of these seeds has led to increased research and improved accessibility.<sup>5</sup> Incorporating such functional, plant-based foods into innovative products may help meet evolving consumer demands.<sup>6</sup>

These seeds are beneficial for the metabolism of living beings due to their high content of phytosterols, soluble fiber, and unsaturated lipids, which reduce the absorption of intestinal cholesterol. This makes them suitable for individuals at cardiovascular risk and for preventing degenerative diseases.<sup>7 8 9</sup>

Although they primarily contain lipids, the carbohydrate and protein content of these seeds is also nutritionally important due to its bioavailability. However, their composition may vary depending on environmental factors such as temperature, light, soil type, nutrient availability, plant species, age, and overall soil conditions.<sup>10 11</sup>

In the commercial context, sesame seeds in Bolivia are classified as having agricultural potential in tropical regions, with the possibility of developing new competitive varieties for planting and harvesting that offer higher yields.<sup>12</sup> Similarly, chia seeds produced in Bolivia are marketed internationally, contributing to 15% of global exports alongside other countries.<sup>13</sup> As for flaxseed, Bolivia ranks 42nd out of 113 countries that export this seed worldwide as a source of oil, oilseeds, grains, and fodder.<sup>14</sup>

### Food Functionality

Functional foods offer health benefits due to their compounds such as fiber, protein, prebiotics, probiotics, oligosaccharides, and other essential nutrients that positively impact human health.<sup>15</sup> The analysis of functional properties is valuable to the food industry, where compounds are classified as additives or raw materials based on their affinity and behavior in different media. In aqueous environments, the interaction between water and larger molecules such as proteins can be categorized into two types: absorption and retention.<sup>16</sup>

Absorption capacity refers to the interaction between a solvent and larger molecules, which is limited by permeability. For example, the interaction between water and amino acids or hydrophilic protein molecules can be influenced by the system's pH level.<sup>16</sup> Another way to enhance absorption is by leveraging the physiological behavior of carbohydrate solubility, such as the soluble complex polysaccharides present in these types of oilseeds.<sup>17 18</sup>

Conversely, holding capacity depends on intrinsic factors (such as polymer type, molecular weight, and linearity) and extrinsic factors (including pH, ionic strength, temperature, and the presence of certain cations). The matrix can retain the solvent through interactions with molecules of varying sizes<sup>19</sup> This is exemplified by smaller protein molecules forming hydrolysates, which reduce intermolecular interactions and lead to structures that do not retain water.<sup>16</sup> In contrast, carbohydrates such as fiber can retain water without releasing any liquid.<sup>17</sup> According to Robertson *et al.*<sup>20</sup> water can be associated with fiber, either as trapped water or bound water, so water retention capacity is a function of fiber structure rather than chemical composition.

This study aimed to analyze the functional properties of oilseeds produced in Bolivia, based on their variety and composition, for food applications in aqueous and oily media. These properties include absorption and holding capacities, as well as absorption and solubility indices. Nutritional composition was determined through proximate analysis. Additionally, we examined the functional differences of oilseeds in their natural and processed forms, such as flour, to support the design of food products.

## EXPERIMENTAL

### Reagents



The reagents used were: Sulfuric Acid 95-97% (Merck KGaA, Darmstadt, Germany), hydrochloric acid (Sigma-Aldrich, St. Louis, USA), petroleum ether, Sodium hydroxide (Merck KGaA, Darmstadt, Germany) Catalyst potassium sulfate anhydrous  $K_2SO_4$  3,5g+ copper sulfate  $CuSO_4 \cdot 5 H_2O$  p.a. 0,4g (relation 10:1) Thompson & Capper Ltd, Hardwick Road, Astmoor, Runcorn, Cheshire, UK), sodium hydroxide commercial, Boric acid  $H_3BO_3$  4%, distilled water, commercial oil (density=0,932 g/mL).

### Samples

The white sesame seed sample was purchased from local markets in the valley region belonging to the city of Cochabamba. The flaxseed and white and black chia seed samples were provided by the company “GCP” located in the city of Warnes, Santa Cruz, which is responsible for the distribution and export of the seeds. The black sesame seed sample comes from the city of Chuquisaca, but is distributed by the same company as the other seeds.

Table 1. Code used for samples

Code	Sample
BCS	Black Chia Seed
BCF	Black Chia Flour
WCS	White Chia Seed
WCF	White Chia Flour
BSS	Black Sesame Seed
BSF	Black Sesame Flour
WSS	White Sesame Seed
WSF	White Sesame Flour
FS	Flaxseed
FF	Flax Flour

### Proximal analysis

Moisture content was determined using a thermobalance (Radwag, MAC 110/WH, Poland). Water activity was measured with a hygrometer (ROTRONIC HP23-AW-SET-40, Rotronic®). Color was assessed in triplicate using the CIE Lab system and a colorimeter (Konica Minolta Sensing, Inc. CR-400, Japan).

Ash content was quantified according to AOAC method 31.1.05, applicable to cereals, flours, and derived products, using a microprocessor-controlled muffle oven (QUIMIS Q318M21, Diadema-SP, Brazil). Total protein content was measured using AOAC method 960.52 (2019), with modifications to accommodate the equipment specifications: a compact digestion system (RAYPA MBCM-40, R. ESPINAR, S.L., Spain) and a Micro Kjeldahl distillation unit (RAYPA DNP, R. ESPINAR, S.L., Spain). Calculations used the recommended protein conversion factor for nuts and oilseeds (5.4).

Total fat content was obtained via solid-liquid extraction using a Soxhlet apparatus. Carbohydrate content was calculated by difference, and the energy value was estimated using Atwater factors, based on a 100 g sample.

### Functional properties

#### Water holding capacity (WHC)

Water holding capacity was measured according to the method of Capitani *et al.*<sup>21</sup> 1 g of sample and was added 10 mL of distilled water at room temperature. It was stirred using a vortex for 1 min to homogenize the mixture, the centrifuged at 5000 rpm for 30 min at 5°C (Centrifuge Benchtop Centurion Scientific Limited Model K241R BRK-5206), The supernatant was decanted and the hydrated residue was weighed. The values expressed as grams of water retained per gram of sample were calculated according to the equation:

$$WHC \left( \frac{g H_2O}{g sample} \right) = \frac{Hydrated\ residue\ weight - Sample\ weight}{Sample\ weight}$$

#### Oil holding capacity (OHC)

Oil holding capacity was determined according to the standard methods<sup>21 22</sup> slightly modifying for the process. 1 g of sample was added of 10 mL of commercial soybean-sunflower oil. Vortexed it for 1 min every 5 min, then left to

stand for 30 min. It was then centrifuged at 5000 rpm for 30 min at 5°C, the supernatant was decanted, and the residue was weighed, determining the difference in weight gained by retention. The results were expressed in grams of oil retained per gram of sample. The values were calculated according to the equation:

$$WAC \text{ aprox.} = \frac{\text{Hydrated residue weight} - \text{Sample weight}}{\text{Sample weight}}$$

$$\text{Sample weight} = \frac{20}{(WAC \text{ aprox} + 1)} \text{Sample weight} = \frac{20}{(WAC \text{ aprox} + 1)}$$

Then, divide the increase in sample weight by the water needed to make up 20 g (except for sesame samples, which were made up to 15 g), adding 0.75 and 0.25 mL of distilled water above and below the sample, respectively. It was then vortexed for 1 min. Finally, it was centrifuged at 5000 rpm for 15 min to decant the supernatant and weigh the final hydrated residue. WAC was calculated as grams of water absorbed per gram of sample, thus showing that the more water absorption capacity is lost during dehydration, the lower the calculated value will be.

$$WAC \text{ (g H}_2\text{O/g sample)} = \frac{\text{Hydrated final residue weight}}{\text{Sample weight}}$$

#### **Water solubility index (WSI) and Water absorption index (WAI)**

Determined using the modified method.<sup>22</sup> For both indexes, 1 g of sample was dispersed in 15 mL of distilled water using a magnetic stirrer for 30 min at 30° C. It was then centrifuged for 10 min at 5000 rpm. The supernatant was separated and left overnight. At daylight, the residue dissolved in the supernatant was separated and weighed. The centrifuged residue was transferred to crucibles to be dried in an oven (Memmert UN55) for one hour at 110°C and then weight it at room temperature. Calculate the indexes according to the equations:

$$WAI = \frac{\text{Dry residue weight}}{\text{Sample weight}}$$

$$WSI (\%) = \frac{\text{Weight of residue dissolved in supernatant}}{\text{Sample weight}} \times 100$$

#### **Statistical analysis**

All tests were performed in triplicate and standard deviation was calculated. To normalize the data were applied square root and logarithm transformation at the energy value.<sup>23 24</sup> Normality tests (Leneve and Shapiro-Wilk) confirmed that the variables met homogeneity of variances. A two-way ANOVA was used to identify significant differences among seed varieties, followed by Tukey's test at 5%. However, some variables (ash, energy, WHC, OHC, WAI) did not exhibit homoscedasticity post-transformations, leading to the application of the nonparametric Kruskal-Wallis test to determine whether the groups came from the same distribution using Dunn's test as a post hoc analysis. Additionally, a Bonferroni adjustment was utilized for pairwise comparisons. Principal component analysis (PCA) with Varimax rotation with Kaiser normalization analyzed all variables, producing an 11-component sedimentation graph that showed a biplot of 82.82% variability, with two main components 1 (45.08%) and 2 (37.74%) of the variance. Data processing was performed using SPSS Statistics 22.0, USA.

## **RESULTS AND DISCUSSION**

The oilseeds are a type of dry food in which moisture and water activity are related to their composition and structural characteristics.<sup>25</sup> Water activity shows values above 0.5 with a probability of microbial formation for all samples. This may be related to the moisture values obtained between 4.8-9.0%, especially BCF and WCF had higher values than seeds (Table 2). Given that the recommended moisture content should be less than 8% to ensure that water activity remains below the critical limit of 0.6, achieving stability in physical and chemical properties, as well as higher quality and safety during storage.<sup>26 27</sup>

Comparison of the composition between chia varieties shows similar values for moisture, protein, and carbohydrates. However, the white variety has higher values than the black variety. Bibliographic values of chia seeds from the Chaco region indicated 19-23% protein and 32% fat.<sup>11 28</sup> However, it has been reported the composition of the seeds 4.4% ash, 30.0% lipids, 9.5% carbohydrates and 21% protein for the black variety of chia. For the White variety, it



reports 4.3% ash, 30.9% lipids, 6.7% carbohydrates and 19% proteins. Compared to the values obtained for black and white chia seeds in this study obtained similar values between 6.1-6.9% for moisture content, 4.7-4.9% ash, 32.6-32.7% lipids, 61.9-64.0% de carbohydrates and a higher value for proteins 23.3-25.5% respectively (Table 2). The comparison between flour and chia seeds shows values grouped by significant difference according to statistical analysis, showing higher energy values in the flours of the varieties due to their higher nutritional composition.

Sesame varieties have similar values for moisture, ash, and protein. However, there is a significant difference between flour and seeds in terms of carbohydrate values and lipid percentages, which is related to the caloric intake obtained 536.9-557.8 kCal/100 g for the flour of both varieties, respectively. The composition ranges of sesame are 46.4-62.7% lipids, 18-40% protein and 14.7-167 carbohydrates.<sup>3</sup> In comparison with this study, approximate values were obtained 20.9-42.4% protein and 13.2-69.4% carbohydrates.

The comparison of flax flour and flaxseed shows significantly different values for 5.8-7.4% moisture, 26.4-33.8% for protein, 3.6-43.5% for lipids, 61.4-12.4% for carbohydrates. These coincide with [4]<sup>4</sup> 5.3-8.9% moisture, 17.-21.3% protein, 36.8-45.8% lipids and 28.9 % carbohydrate. Flaxseed and flaxseed meal have similar ash content percentages. Also, flaxseed and chia had similar caloric value is associated with high percentages of lipids<sup>15</sup>.

Flours have a higher nutritional value due to these macromolecules. Particle size is important when processing seeds using a grinding procedure, as it causes changes surface composition to increase the surface area in relation to the volume.<sup>29</sup> The processing method probably increases their availability, and this can be observed in the statistical analysis groupings.

According to the nonparametric Kruskal-Wallis test applied to the Energy variable, there are significant differences between the samples  $\chi^2([9],N=[30])=[29]$ ,  $p=[<0,001]$  showing a difference between the averages of the seeds compared to the flours of the oilseed varieties. The energy content is higher in the flour of all oilseed samples (Table 2). The energy values are ranked as follows according to seed type: Flaxseed< White sesame < Black chia < Black sesame < White chia. The ranking according to the processed form as oilseed flour is: Flaxseed< White sesame < Black sesame < Black sesame < White chia < Black chia.

Table 2. Proximal Analysis in varieties of oilseeds

Sample	Parameter						
	Water activity	Moisture (%)	Ash (%)	Protein (%)	Lipid material (%)	Carbohydrate (%)	Energy (kCal/100g)*
BCS	0.57±0.01	6.1±0.1 <sup>d,c</sup>	4.7±0.01 <sup>c</sup>	25.5±2.3 <sup>d,e</sup>	1.7±0.1 <sup>c</sup>	61.9 <sup>a</sup>	365.6 <sup>a</sup>
BCF	0.66±0.01	9.0±0.3 <sup>a</sup>	6.4±0.01 <sup>a</sup>	41.8±1.9 <sup>a</sup>	32.6±0.8 <sup>c</sup>	10.2 <sup>c</sup>	501.6 <sup>b</sup>
e	0.70±0.02	6.9±0.04 <sup>c,d</sup>	4.9±0.1 <sup>b,c</sup>	23.3±1.8 <sup>d,e</sup>	1.0±0.1 <sup>f</sup>	64.0 <sup>a</sup>	357.7 <sup>a</sup>
e	0.68±0.01	7.9±0.02 <sup>b</sup>	4.8±0.02 <sup>b,c</sup>	36.4±1.7 <sup>a,b</sup>	32.7±0.8 <sup>c</sup>	18.2 <sup>b</sup>	512.6 <sup>b</sup>
BSS	0.54±0.02	4.50±0.1 <sup>b</sup>	5.1±0.1 <sup>b</sup>	27.7±2.0 <sup>c,d</sup>	0.1±0.05 <sup>e</sup>	62.6 <sup>a</sup>	362.3 <sup>a</sup>
ee	0.56±0.01	4.8±0.6 <sup>g,h</sup>	4.6±0.3 <sup>c</sup>	42.4±1.9 <sup>a</sup>	34.9±1.0 <sup>c</sup>	13.2 <sup>b,c</sup>	536.9 <sup>b</sup>
WSS	0.56±0.01	4.8±0.3 <sup>g,h</sup>	4.2±0.1 <sup>d</sup>	20.9±1.7 <sup>c</sup>	0.7±0.3 <sup>f</sup>	69.4 <sup>a</sup>	367.5 <sup>a</sup>
WSF	0.69±0.01	5.3±0.2 <sup>f,g</sup>	4.9±0.1 <sup>b,c</sup>	36.5±1.8 <sup>a,b</sup>	39.7±1.1 <sup>b</sup>	13.7 <sup>b,c</sup>	557.8 <sup>b</sup>
FS	0.71±0.01	5.8±0.1 <sup>e,f</sup>	2.8±0.1 <sup>c</sup>	26.4±1.6 <sup>d,e</sup>	3.6±0.1 <sup>d</sup>	61.4 <sup>a</sup>	383.9 <sup>a</sup>
FF	0.68±0.01	7.4±0.3 <sup>b,c</sup>	3.0±0.04 <sup>c</sup>	33.8±3.7 <sup>b,c</sup>	43.5±1.0 <sup>a</sup>	12.4 <sup>b,c</sup>	576.0 <sup>b</sup>

BCS: Black chia seed; BCF: Black chia flour; WCS: White chia seed; WCF: White chia flour; BSS: Black sesame seed; BSF: Black sesame flour; WSS: White sesame seed; WSF: White sesame flour; FS: Flaxseed; FF: Flaxseed flour

Different superscript in row indicates significant difference ( $p < 0.05$ ), by ANOVA analysis and Tukey test.

\* Analysis no parametric by Kruskal-Wallis test and Dunn test and Bonferroni adjustment

The composition of the seeds provides basic information for their use in industry. However, stability during storage is important, as is the process for increasing their shelf life. Initial analysis of moisture and water activity according to the form of processing (seed and flour) showed that they are suitable for use or storage under stable environmental conditions.

The color values according to the CIE Lab scale are shown in Table 3. The values obtained differ between seeds and flour, possibly because the colors within the seeds are lighter. Color analysis could contribute to the development of products to generate greater visual appeal for their acceptance as processed foods.

Table 3. Color Analysis in oilseeds

Sample	Parameter		
	L	a	b
BCS	25.63±0.075	1.17±0.04	5.06±0.32
BCF	19.61±0.04	1.60±0.04	6.89±0.03
WCS	33.94±0.93	1.61±0.04	6.31±0.14
WCF	25.06±0.021	3.22±0.01	8.68±0.02
BSS	14.38±0.55	-0.17±0.04	1.08±0.07
BSF	14.35±0.046	-0.38±0.01	1.39±0.01
WSS	43.96±0.61	2.38±0.04	11.66±0.19
WSF	34.92±0.43	1.62±0.06	9.09±0.16
FS	24.37±0.025	5.63±0.38	7.85±0.46
FF	23.90±0.13	2.86±0.03	7.78±0.01

BCS: Black chia seed; BCF: Black chia flour; WCS: White chia seed; WCF: White chia flour; BSS: Black sesame seed; BSF: Black sesame flour; WSS: White sesame seed; WSF: White sesame flour; FS: Flaxseed; FF: Flaxseed flour

### Functional properties

Chia and flaxseed are considered functional ingredients that contain polyunsaturated fatty acids such as alpha-linoleic acid, omega-3, and omega-6; essential amino acids such as arginine, leucine, and phenylalanine; and carbohydrates such as lignans and polysaccharides with potential applications.<sup>30-31</sup> These seeds are covered by a polymeric composition called mucilage, which is excellent for providing functional properties such as the ability to absorb or retain aqueous or oily solvents.<sup>21</sup> These oilseeds with mucilage have been used to prepare hot vegetable drinks, taking advantage of their high temperature to extract this mucilage. At the same time, their direct consumption is recommended as a source of unsaturated fats<sup>32-33-34</sup> as a fat substitute for making vegan ice cream<sup>35</sup> or as potential added in yogurt.<sup>36</sup> However, sesame seeds are used to obtain oils due to their unsaturated fat content in gastronomy<sup>37</sup> and as a source of protein in mixtures for food hydrocolloids.<sup>38</sup>

Chia seeds can be used as an emulsifier and stabilizer due to their carbohydrate content, specifically fiber and protein. In addition to enriching baked goods such as cookies, cereal bars, and breads, they can also be used to thicken soups and stews.<sup>15</sup> The analysis of functional properties according to their water and lipid retention capacity guides possible applications such as the addition of fibers in meat products to increase cooking performance or reduce retention to increase moisture content in fried products.<sup>39</sup> Likewise, incorporating these seeds with functional nutritional sources could have an effect on decreasing or increasing brightness and color within the red/green color axes in the formulation of meat products, taking advantage of the different capabilities they also provide.<sup>40</sup>

The functional properties showed a different behavior in the seeds. At first glance, it is possible to distinguish whether a seed absorbs or holding a drop of oil or water (Figure 1). It can be seen that the seeds on the left are white and black chia seeds with the mucilage formed in an aqueous media. Black chia seed are larger than white chia seed. This could be associated with the values obtained in WHC and WAC, which are the same results. In contrast, flaxseed do not form mucilage, but have a greater affinity for oil than chia seeds. However, black and white sesame show a similarity in the size of surface film around the seed with oil medium. This is related with values in OHC.

The results of the absorption and holding capacities and indices according to non-parametric statistical analysis indicated differences among the samples for all variables between the seed and flour samples of the oilseed varieties  $\chi^2(9, N=30)=28.5$ ,  $p=0.001$  for WHC;  $\chi^2(9, N=30)=26.9$ ,  $p=0.001$  for OHC;  $\chi^2(9, N=30)=28.2$ ,  $p=0.001$  for WAC;  $\chi^2(9, N=30)=26.2$ ,  $p=0.001$  for WSI;  $\chi^2(9, N=30)=27.3$ ,  $p=0.001$  for WAI. The means of the variables differ, but they

were grouped according to significant differences (Table 4), indicating that the median values of the samples behave differently between seeds and flours for OHC. In contrast, the chia samples showed a similar pattern for WAC, WHC, and WAI. For WSI, the means of samples presented a dispersed pattern but they were subsequently grouped into three different behaviors. Post-hoc comparisons performed using Dunn's method ( $p$ ) with Bonferroni correction ( $pb$ ) for multiple pairwise test indicated differences in several cases: BSS-BCS ( $p<0.05;pb=0.009$ ) and WSS-BCS ( $p<0.05;pb=0.05$ ) for WHC; FF-WCF ( $p<0.05;pb=0.02$ ) and WSF-WCF ( $p<0.05;pb=0.04$ ) for WAI.

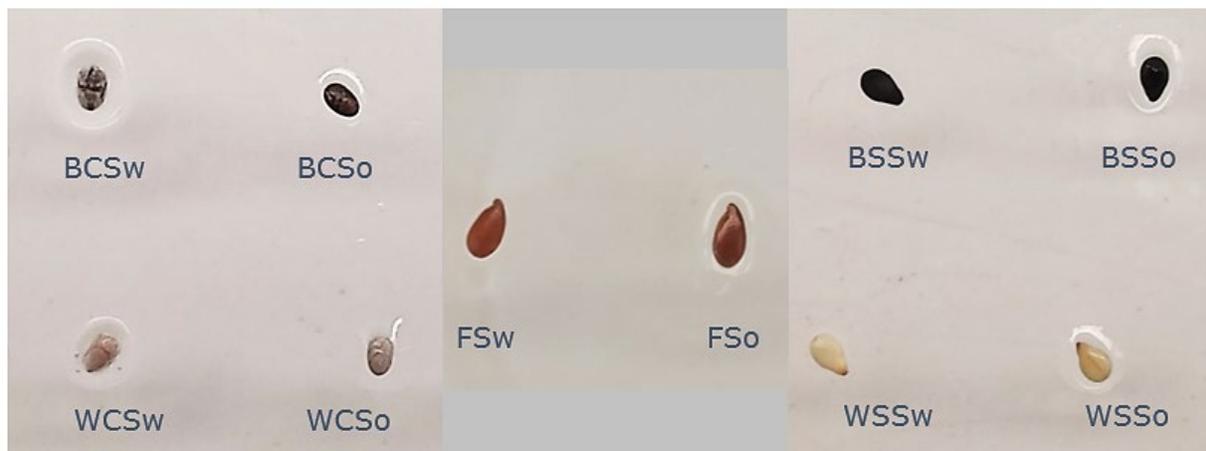


Figure 1. Seed sample in different media. (photo by D.M.) BCSw: Black chia seed in water; BCSo: Black chia seed in oil; WCSw: White chia seed in water; WCSo: White chia seed in oil; FSw: Flaxseed in water; FSo: Flaxseed in oil; BSSw: Black sesame seed in water; BSSo: Black sesame in oil; WSSw: White sesame seed in water; WSSo: White sesame in oil

Table 4. Functional properties in varieties of oilseeds

Sample	Parameter				
	WHC g H <sub>2</sub> O/ g sample	OHC g oil/g sample	WAC g H <sub>2</sub> O/ g sample	WSI	WAI %
BCS	7.47 <sup>a,c</sup> (6.88-7.83)	0.52 <sup>a</sup> (0.51-0.53)	3.80 <sup>a</sup> (3.54-4.13)	1.45 <sup>a</sup> (1.00-2.24)	5.80 <sup>a</sup> (5.19-6.22)
BCF	6.40 <sup>a</sup> (5.79-7.18)	1.31 <sup>b</sup> (1.26-1.35)	4.76 <sup>a</sup> (3.79-4.23)	2.79 <sup>a</sup> (2.14-3.83)	5.47 <sup>a</sup> (4.76-6.36)
WCS	6.08 <sup>a</sup> (5.78-6.26)	0.75 <sup>a</sup> (0.52-1.14)	3.17 <sup>a</sup> (3.07-3.22)	1.08 <sup>a</sup> (0.34-2.15)	6.08 <sup>a</sup> (5.76-6.32)
WCF	5.29 <sup>a</sup> (5.18-5.40)	1.35 <sup>b</sup> (1.35-1.36)	3.98 <sup>a</sup> (4.36-5.47)	2.92 <sup>a</sup> (2.39-3.55)	6.67 <sup>a,c</sup> (6.46-7.08)
BSS	0.68 <sup>b,c</sup> (0.61-0.76)	0.85 <sup>a</sup> (0.78-0.92)	0.19 <sup>b</sup> (0.17-0.21)	2.48 <sup>a</sup> (1.64-3.02)	0.92 <sup>b</sup> (0.91-0.93)
BSF	1.38 <sup>b</sup> (1.28-1.46)	1.63 <sup>b</sup> (1.49-1.73)	0.52 <sup>b</sup> (0.23-0.30)	7.85 <sup>c</sup> (7.35-8.57)	0.79 <sup>b</sup> (0.74-0.82)
WSS	0.89 <sup>b,c</sup> (0.84-0.93)	0.77 <sup>a</sup> (0.69-0.83)	0.19 <sup>b</sup> (0.18-0.21)	12.30 <sup>b</sup> (11.91-13.07)	1.07 <sup>b</sup> (0.93-1.18)
WSF	1.25 <sup>b</sup> (1.24-1.26)	1.51 <sup>b</sup> (1.45-1.54)	0.27 <sup>b</sup> (0.39-0.64)	7.66 <sup>c</sup> (6.63-8.48)	0.76 <sup>b,c</sup> (0.75-0.77)
FS	1.71 <sup>b</sup> (1.70-1.71)	0.56 <sup>a</sup> (0.56-0.57)	0.30 <sup>b</sup> (0.28-0.32)	2.15 <sup>a</sup> (0.39-1.67)	0.90 <sup>b</sup> (0.83-0.94)
FF	2.14 <sup>b</sup> (2.11-2.15)	1.33 <sup>b</sup> (1.27-1.41)	0.51 <sup>b</sup> (0.48-0.55)	12.74 <sup>b</sup> (11.93-13.78)	0.74 <sup>b,c</sup> (0.70-0.80)

WHC: Water Holding Capacity; OHC: Oil Holding Capacity; WAC: Water Activity Capacity; WSI: Water solubility index; WAI: Water Absorption Index

BCS: Black chia seed; BCF: Black chia flour; WCS: White chia seed; WCF: White chia flour; BSS: Black sesame seed; BSF: Black sesame flour; WSS: White sesame seed; WSF: White sesame flour; FS: Flaxseed; FF: Flaxseed flour

Different superscript in row indicates significant difference ( $p < 0.05$ ) Asymptotic meanings, by analysis no parametric, Kruskal-Wallis test and Dunn test and Bonferroni adjustment. And the range of values in parenthesis of functional properties.



### **Water holding capacity (WHC)**

The values obtained show greater capacity for flour and chia seeds of both varieties. Among them, the black variety has greater water holding capacity 6.40-4.47 g of water per gram of sample for flour and seeds, respectively. Flaxseed flour 2,14 g/g has a higher value than the seed 1.71 g/g. The holding capacity could be related to the type of carbohydrate known as mucilage, present in flax and chia, which coats the seeds or is also found in the flour of the seeds. This fiber is capable of forming polysaccharide interactions in aqueous media, generating retention seen as a three-dimensional network.<sup>41 42</sup> The BSS and WSS have a lower capacity compared to all other seeds, even though its carbohydrate content is similar to the others. However, the significant difference in the statistical analysis shows a similarity between the values of BSF, WSF, FF and FS. Measuring this by centrifugation could estimate the amount of water that can be bound and trapped by the fiber, while free water depends on chemical composition.<sup>20</sup>

### **Oil holding capacity (OHC)**

Through the analysis of oil retention capacity, the values are grouped into two groups between seeds and flours, which coincides with the statistical analysis. For seeds, there is a range of 0.78-0.92 g oil/ g sample for black sesame and between the lower values of 0.51-0.53 g oil/g sample for black chia. Higher values were obtained for BSF, with a range of 1.49-1.73 g oil/gram of sample and lower values for BCF with a range of 1.26-1.35 g oil/g sample. The values could be related to the interaction between their nonpolar nutritional components, such as lipids, as the flours showed higher percentages in this study. The composition and processing of dry foods is directly related to their functional properties in the study by [48]<sup>48</sup> shows a comparison of dry grain flours, with higher water holding capacity values for chickpea flour < rice flour < wheat flour, for oil holding capacity is wheat flour < Chickpea flour < rice flour as they have a higher amount of carbohydrates such as gluten, with values according to oil holding capacity and hydrophobicity, their moisture content is in the same order. Similarly Nyam *et al.*<sup>5</sup> reported 2.1g holding water/g of Roselle seed which is related to the majority composition of protein and fat. In contrast, it has a higher oil holding capacity (14.1 g/g) due to the absorption or binding of hydrophobic or partially apolar compounds that have fewer free hydroxyl groups. Thus, fiber-type carbohydrates are responsible for oil interactions. They could be used as emulsifiers in products with high lipid content.

### **Water absorption capacity**

According to the measured values, higher values were obtained in the BCS, BCF, WCS and WCF (3.07-5.47 g water/g sample) this may be due to the presence of a greater amount of carbohydrates, which are characterized as hydrophilic constituents contained in the mucilage characteristic of these seeds. In contrast, lower values are observed for BSS, BSF, WSS and WSF (0.17-0.21 g water/g sample), corresponding to the absence of this type of carbohydrate or a lower availability of polar amino acids. Oilseeds containing mucilage, which provides functional properties such as gelling agent, emulsifier, and shear-thinning fluid, in addition to contributing to physiological nutrition during consumption as an absorbent ingredient.<sup>32 43</sup>

### **Water solubility index and Water absorption index**

The solubility index shows higher values for WSF with a range of 6.63-8.48 and BSF 7.35-8.57 which also correspond to a statistically significant group that includes FF, with a range of 11.93-13.78. The chia samples show low values, probably as a result of reduced interaction with the aqueous medium to partially dissolve the hydrophilic compounds. As for the flax samples can be observed the value of FF is 0.39-1.67, which significantly coincides with BCS, BSF, WCF and WCF. In addition, they have the same possible decomposition behavior in the aqueous medium. The absorption index showed a behavior opposite to that of the previous index. The sesame and flaxseed samples had lower values in all forms compared to chia. The chia samples had similar values depending on their form like a seed or flour. This could be related to the absorption capacity also analyzed.

The absorption and holding properties of macromolecules in food, such as amino acids, starches, fibers, and fatty acids, may depend on intrinsic factors and the polarity of these compounds. The data reported by Capitani *et al.*, 2012 [21] show approximate values for the water holding capacity of the chia samples analyzed, taking into account that solvent-degreased flours have a higher water-holding capacity (WHC=10.64; OHC=2.03) than pressed flours (WHC=10,58; OHC=1,26). Comparison with these values could indicate the importance of other compounds such as carbohydrates and proteins capable of providing higher values or different functions for chia varieties seeds. Amino acids vary in their ability to interact with water and lipids and in their chemical constitution, exhibiting hydrophilic or hydrophobic behavior. This not only influences the different analyses of capacities or indices but also the flavor and palatability of food products.<sup>45 46 47</sup>

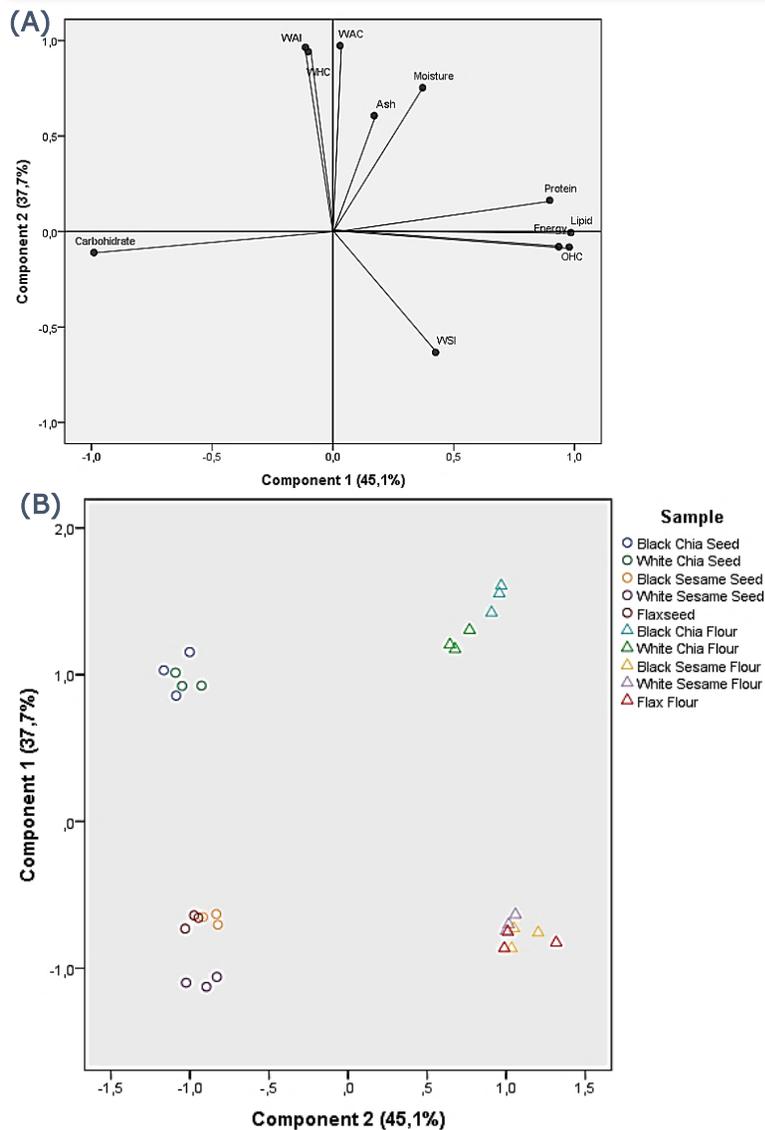


Figure 2. Principal component analysis (PCA) of the chemical composition and functional properties in oilseeds and oilseed flours. (A) Biplot of the vectors of the variables in principal components PC1 and PC2 in rotated space (B) Arrangement of all samples in the space defined by the principal components, showing the grouping patterns according to oilseed variety and processed form as oilseed flour.

### Principal component analysis (PCA)

PCA showed a total variability of 82.8% with the first component (PC1) accounting for 37.7% and the second component (PC2) accounting for 45,1% an additional. In figure 2A, the CP1 axis was negatively associated with WSI, and the proximity of the WAI, WHC, and WAC variables on its positive axis can be observed, suggesting that this axis mainly represents functional properties related to interaction in aqueous media. On the other hand, PC2 was defined by the positive association of the variables protein, energy, lipids, and OHC, while only carbohydrates are found on the negative axis. The oil retention capacity and energy could be related to lipids due to the affinity between media (polarity). Additionally, a tendency toward separation in PC2 is observed among oilseed varieties based on macronutrient content and particularly in relation to their energy value.

In figure 3B shows the projection of the grouping patterns of the samples on the first two components. The upper right quadrant shows the varieties of chia flour characterized by their higher moisture and ash content. The lower right quadrant grouped black sesame, white sesame, and flaxseed flours differentiated by their interaction with high



WSI and OHC values. The lower left quadrant was defined by black sesame, white sesame, and flaxseed samples showing proximity to the carbohydrate axis. Finally, the upper left quadrant contained seeds from chia varieties showing affinity with the WHC, WAI, and carbohydrate variables. The grouping patterns reinforce the difference between oilseed varieties in terms of both chemical composition and functional properties. In general, flours were distributed to the right of the biplot, associated with higher protein, lipid, OHC, and WSI contents, while whole seeds were distributed to the left, associated with higher carbohydrate content, which shows the effect of processing on composition and functionality.

## CONCLUSIONS

The analysis of functional properties helps to design different products by taking advantage of the composition of foods such as seeds in their natural form or flour for the proportion of different textures. The functionality of flours and seeds can be attributed to the physical or chemical properties of new products. As a raw material, seeds could be functionally processed substances such as instant beverages or soups, dough bases in baking, balanced animal feed, among others. The different behaviors of seed compounds and the type of processing analyzed proved to be characteristics that must be considered when evaluating the functionality of a food. It should be noted that they can generate greater affinity with solvents or media (hydrophobic or hydrophilic). It should also be taken into account that the composition of the seeds is directly related to their functional properties, giving them characteristics of absorption, retention, and solubility. Additionally, the rheological properties could be analyzed to define the functionality of the macromolecules of these seeds according to their structural variety and beneficial interaction with the metabolism in living beings.

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