International Journal of Food Science and Nutrition
www.foodsciencejournal.com
ISSN: 2455-4898
Received: 20-04-2025, Accepted: 21-05-2025, Published: 05-06-2025
Volume 10, Issue 3, 2025, Page No. 35-40

Comparative analysis of physical, functional, and nutritional properties of selected super seeds

Abhishek Gaikwad, PD Shere, SV Ghodke, Rinku Agrawal
MIT School of Food Technology, MIT Art, Design and Technology University, Pune, Maharashtra, India

Abstract

Super seeds like flaxseed, chia seed, watermelon seed, pumpkinseed and sunflower seeds are gaining their interest in food science due to their superior nutritional profile and functional versatility. Physical properties like width, length, thickness, geometric mean diameter (GMD), angle of repose, bulk and true densities, porosity, and 1000-seed are necessary for design of equipment to transport, store, handle and process the seeds. This research compared and tested the physical, functional, and nutritional characteristics of these seeds in order to determine their application in health-oriented food uses. The pumpkin and watermelon seeds were the biggest and the chia and flax the smallest—affecting flow and processing behavior. Pumpkin seeds and watermelon seeds were the biggest and smallest, respectively, and impacted processing and flow behavior. Chia registered the maximum bulk density, and watermelon registered the highest true density. Functionally, pumpkin demonstrated better oil and water adsorption, while chia demonstrated better water solubility and holding capacity as a result of its mucilage composition. Nutritionally, sunflower seeds contained the most fat, pumpkin contained the most protein, and chia contained the most fiber. These results identify each super seed's singular strengths and validate their use in functional foods that seek to enhance dietary quality and health effects.

Keywords: Super seeds, functional properties, proximate properties, physical properties

Introduction

Seeds are being increasingly known for their contribution to human nutrition and the prevention of chronic diseases because of their high content of bioactive compounds. Of these, chia (*Salvia hispanica L*), flax (*Linum Usitatissimmum*), pumpkin (*Cucurbita pepo L.*), watermelon (*Citrullus lanatus Thunb*.), and sunflower (*Helianthus annuus L.*) seeds have been in the limelight for their superior nutritional, physicochemical, and functional attributes.

Among the most promising of these dietary seeds are flaxseed (*Linum usitatissimum*), chia (*Salvia hispanica*), pumpkin (*Cucurbita pepo*), watermelon (*Citrullus lanatus*), and sunflower (*Helianthus annuus*), each with distinct nutritional and physiological effects. Flaxseed, an oilseed crop well known, is most renowned for its rich alpha-linolenic acid (ALA) composition, accounting for more than 45% of its oil and the occurrence of lignans and dietary fiber, found to produce anti-inflammatory and cardioprotective actions. (Soni *et al.*, 2016; Ishag *et al.*, 2019) [2, 1] Chia seeds (*Salvia hispanica L., Lamiaceae*) are nutrient-rich, comprising 15–26% protein, 23–35% dietary fiber, and 30–34% fat, most of which is alpha linolenic acid (omega-3). High in thiamine, niacin, calcium, magnesium, and phosphorus, they contain all the necessary amino acids and are gluten-free perfect for celiac diets. Their lipid profile is useful for conversion to EPA and DHA, providing cardiovascular and anti inflammatory effects (Carrillo *et al.*, 2024; Marcinek & Krejpcio, 2017) [4]. Pumpkin seeds (*Cucurbita spp*.) contain high percentages of protein (28-40%) and oil (up to 53%), dominated by linoleic (47%) and oleic acids (29%). They are rich in amino acids, phytosterols, tocopherols, and minerals such as magnesium and zinc, which are responsible for antioxidant, anti-inflammatory, and anti-parasitic properties (Dotto & Chacha, 2020; Karanja *et al.*, 2013) [5, 6].

Watermelon seeds (*Citrullus lanatus*) yield proteins, essential fats, B and E vitamins, and minerals. Of particular interest, they yield phenolics, flavonoids, and carotenoids that exhibit antioxidant, antimicrobial, and hypoglycemic activity, making them a potential underexploited superfood (Tabiri *et al.*, 2016; Nissar *et al.*, 2025) [7, 8]. Sunflower seeds (*Helianthus annuus*) contain 18.7% protein and 37.4% fat, predominantly unsaturated, along with dietary fiber, vitamin E, and selenium. Their bioactive components are known to promote cardiovascular health and immune function owing to their excellent antioxidant activities (Marinova *et al.*, 2008) [9]. The increased demand for these seeds is attributed to the fact that they have the ability to be incorporated into functional food products that can prevent chronic diseases and improve nutritional value. This research aims to assess and compare the nutritional composition, functional properties, and health benefits of the five seeds, thereby validating their increased use in food processing and health-related dietetics.

Methodology

1. Sample Collection

Clean and dry samples of chia seed (*Salvia hispanica*), flaxseed (*Linum usitatissimum*), pumpkin seed (Cucurbita pepo), watermelon seed (*Citrullus lanatus*), and sunflower seed (Helianthus annuus) were obtained from a local market in Pune, Maharashtra, India. The seeds were sorted by hand to remove any foreign materials, damaged seeds, and underdeveloped seeds. All experiments took place in a laboratory setting at a temperature of 25 ± 2 °C with a relative humidity of 55–60%.

2. Physical Properties

The dimensions like thickness (T), length (L) and width (W) of 100 seeds from diffrent variety were measured by using the digital Vernier caliper with the 0.01 mm accuracy. The equivalent diameter (De) and geometric mean diameter (Dg) were calculated using the formulas provided by Mohsenin in 1986 [20].

While, L- Length, W- Width, T- Thickness in mm The surface area (S) was calculated by the method mentioned by (Singh *et al.*, 2013) [13].

The moisture levels of each seed variety were first measured using the oven drying technique at a temperature of 105 ± 1 °C for 24 hours in a hot air oven, following the method established by AOAC (2000) [15].

Weighing a thousand seeds was measured by counting 100 seeds, placing them in electronic compensation and multiplying them by 10 to provide a mass of 1000 cores (Singh *et al*., 2014) [14].

The mass sample of the seeds divided by their entire volume is known as the bulk density. A 1000 ml container was filled with seeds at a height of around 15 cm, the top level was struck, and the contents were weighed (Singh *et al.,* 2012) [13].

True density was determined by a method of shifting water soaked in 50 mL of 5 g seeds into 50 mL of 50 mL of water to 50 mL of 50 mL of water. The seeds were not completely submerged to prevent water adsorption. The volume of displaced water was measured and density was determined by sharing seed weights by the inhibited volume (Coåkuner & Karababa, 2007) [29].

Porosity is the ratio of the bulk grain space that is filled. which isn't filled by the grain (Thompson & Isaacs,1967).

The porosity of the fill was calculated from the true and bulk density values depending on the relationship.

where ρ_t – bulk density, ρ_b – true density

The actual density of seeds was determined using the water shift method. Five grams of seeds were measured and soaked in 50 mL of water in a 100 mL stepped cylinder. The volume of displaced water was measured and the density was calculated by dividing the seed weight by the distribution volume. (Amin, Hossain & Roy, 2004; Olajide, Ade-Obwaye & Otunola, 2000).

A wooden box with a removable front panel measuring 0.3 meters in length, width, and height was utilized to determine the angle of repose and determined as (Ixtaina *et al.,* 2008) [12].

3. Proximate Analysis

The A.O.A.C. (2000) technique was used for determination of materials protein, ash, moisture, fiber, and fat content, where the total carbohydrate content is calculated as the method mentioned by Raghuramulu *et al.*, (1983). For every gram of protein, fat, and carbohydrate, the factors of 4, 9, and 4 were applied to determine the sample's energy value (Shrestha and Noomhorm, 2002).

4. Functional Properties

4.1. Water and Oil absorption capacity

WAC was determined by the method of Amandikwa *et al*., (2015) with some modifications, While the oil absorption capacity determination was described by Li *et al*., (2020).

4.2. Solubility

The solubility of seed powder was determined with a procedure borrowed from Kaur and Singh (2017) [14].

4.3. Bulk and Tap density

The bulk density was found following the protocol outlined by Ogunbusola *et al*. (2018), whereas tap density was researched following the standard procedure outlined by Wang *et al*. (2019).

5. Statistical analysis

Results are presented as the mean standard deviation (SD) from the triple review. Statistical assessments were performed using SPSS (version 26.0; SPSS Inc., Chicago, Illinois, USA). Significant differences were determined by disposable analysis of variance (ANOVA) and then determined after post hoc tests by Duncan (p <0.05).

Result and Discussion

1. Physical Properties of Seeds

The physical size and geometrical properties of seeds It plays an important role in the design and evaluation of quality functions of processing equipment. Physical properties such as length, width, thickness, geometric medium (GMD), and arithmetic mean diameter (AMD) of five seed types are given in Table 1.

Table 1: Physical Properties of Seeds

Seed	L (mm)	W (mm)	T (mm)	GMD (mm)	AMD (mm)
Flaxseed	5.53 ± 0.060^{b}	2.92 ± 0.40^{b}	0.9 ± 0.20^{a}	2.55 ± 0.20^{b}	3.12 ± 0.35^{b}
Chia Seed	1.86 ± 0.035^{a}	1.21 ± 0.35^{a}	0.86 ± 0.15^{a}	1.25 ± 0.15^{a}	1.32 ± 0.20^{a}
Pumpkin Seed	16.78 ± 0.17^{e}	8.84 ± 0.79^{d}	2.75 ± 0.50^{b}	7.42 ± 0.51^{d}	9.48 ± 0.74^{c}
Watermelon Seed	16.20 ± 0.10^{d}	9.54 ± 0.61^{e}	3.12 ± 0.70^{c}	8.55 ± 0.53^{e}	9.59 ± 0.54^{e}
Sunflower Seed	7.78 ± 0.075^{c}	7.12 ± 0.75^{c}	4.17 ± 0.52^{d}	7.92 ± 0.75^{c}	6.36 ± 0.73^{d}

Values are expressed as the average of standard deviations based on three independent measurements. The mean values (a, b, c, d, e) of the same column with different superscripts refer to significant differences ($p \leq 0.05$), emphasizing statistical differences among the different seed types for each physical property. Where, L- length, W- width, T- thickness, GMD- geometric mean diameter, AMD - Arithmetic Mean Diameter

1.1. Thickness, Length, and Width

From all the seeds investigated, pumpkin seeds showed the largest size having a length of 16.78 ± 0.17 mm, width of 8.84 ± 0.79 mm, and thickness of 2.75 ± 0.50 mm, with watermelon seeds being closely followed by slightly smaller but not so dissimilar values. These larger sizes affect ease of mechanical dehulling and processing efficacy (Sirisomboon *et al.*, 2007) [18]. Conversely, chia seeds were the smallest in all dimensions (length: 1.86 ± 0.035 mm, width: 1.21 ± 0.35 mm, thickness: 0.86 ± 0.15 mm), and due to this, they could be added to fine powder or drink-based products (Coelho & Salas-Mellado, 2014) [19, 25].

Flaxseeds, with moderate size (length: 5.53 ± 0.060 mm, width: 2.92 ± 0.40 mm, thickness: 0.9 ± 0.20 mm), are flat and elongated, which affects flow properties and makes them prone to alignment when packaged (Baryeh, 2001) [21]. Sunflower seeds, though shorter than pumpkin and watermelon, possessed the highest thickness (4.17 ± 0.52 mm), which accounts for their strong structure.

1.2. Arithmetic Mean Diameter and Geometric Mean Diameter

Watermelon seeds exhibited the highest GMD (8.55 ± 0.53 mm), followed by sunflower (7.92 ± 0.75 mm) and pumpkin seeds (7.42 ± 0.51 mm). The least GMD was exhibited by chia (1.25 ± 0.15 mm) and flaxseed (2.55 ± 0.20 mm). GMD is a determining factor for airflow resistance during drying and influences the settling character during fluidization (Mohsenin, 1986) [20].

The arithmetic mean diameter (AMD) also showed a similar trend. Watermelon seeds and pumpkin seeds possessed AMD values of 9.59 ± 0.54 mm and 9.48 ± 0.74 mm, respectively, indicating their applicability in snack or confectionery products where size consistency is preferred.

Flaxseed (3.12 ± 0.35 mm) and chia (1.32 ± 0.20 mm) possessed the lowest AMD values, which are beneficial for powdered forms.

These size parameters are critical for the purpose of understanding mechanical behavior under processing, for example, shelling, grinding, and blending. Large-diameter seeds typically take more energy to reduce size, but small seeds like chia are easy to mill and homogenize (Gupta & Das, 1997) [10].

2. Angle of Repose, Bulk Density, True Density, 1000-Seed Weight and Porosity

The physical characteristics such as angle of repose, bulk density, porosity, 1000-seed weight and true density, are needed for designing and optimizing drying equipment, storage facilities, transportation vessels, and package containers. Values for these parameters for five different seed varieties have been listed in Table 2.

Table 2: Bulk Density, True Density, Porosity, Angle of Repose, and 1000-Seed Weight

seeds	BD (kg/m^3)	TD (kg/m^3)	P (%)	AR (°)	$^{1000\text{-Seed}}$ Weight (g)
Flaxseed	652.15 ± 2.05^{d}	784.08± 1.86^{b}	16.81^{a}	± 0.2025.03^{c}	± 0.215.32^{b}
Chia Seed	667.03 ± 1.85^{e}	1003.1± 1.65^{c}	33.5^{b}	± 0.1927.03^{d}	± 0.151.20^{a}
Pumpkin Seed	321.20 ± 1.62^{a}	784.3± 1.30^{b}	58.9^{e}	± 0.3423.86^{b}	± 0.19261.23^{e}
Watermelon Seed	412.20 ± 1.41^{c}	1543.2± 2.95^{d}	47.45^{d}	± 0.2519.1^{a}	± 0.2714.61^{c}
Sunflower Seed	397.90 ± 1.35^{b}	691.96± 1.87^{a}	42.5^{c}	± 0.2728.01^{e}	± 0.2167.24^{d}

Values are expressed as the average of the standard deviations of three individual measurements. Mean values of the same column with different superscripts (a, b, c, d, e), emphasizing statistical differences among the different seed types for each physical property.BD- bulk density, TD- true density, P-porosity, AR- angle of repose.

2.1. Bulk Density

Chia seeds also possessed the highest bulk density (667.03 ± 1.85 kg/m^3), followed closely by flaxseed (652.15 ± 2.05 kg/m^3). High numbers indicate high packing efficiency and minimum void space, which is most suitable for storage and packaging requirements (Ixtaina *et al.*, 2008) [12]. Similar results were observed by Coelho & Salas-Mellado (2014) [19, 25]. for chia and Gupta & Das (1997) [10] for flax. On the other hand, pumpkin seeds were the ones with the lowest bulk density (321.20 ± 1.62 kg/m^3) because of their flat shape and large size, leading to loose packing**.**

2.2. True Density

Highest true density was found by watermelon seeds (1543.2 ± 2.95 kg/m^3) indicating a denser internal structure, followed by chia seeds (1003.1 ± 1.65 kg/m^3). Lowest true density was found in sunflower seeds (691.96 ± 1.87 kg/m^3), possibly because of more air space inside the seed. High true density in watermelon has been indicated by Razavi *et al*. (2007) [17], as well, and is an indicator of improved internal compactness and oil retention.

2.3. Porosity

Pumpkin seeds were most porous (58.9 ± 0.34%), and flaxseed was the least porous (16.81 ± 0.20%). Increased porosity suggests more bulk air space, influencing aeration in drying and increasing the likelihood of oxidative degradation upon storage. Porosity trend follows that reported by Baryeh (2001) [22] for legumes and cereal grains. A moderate porosity in chia (33.5%) and sunflower (42.5%) suggests a balance between packing and air circulation.

2.4. Angle of Repose

Sunflower seeds had the highest repose angle (28.01 ± 0.21°) with higher internal friction and poor flowability. Watermelon seeds with the smallest repose angle (19.1 ± 0.27°) had better flowability, which is more appropriate for processing. Chia (27.03°), flax (25.03°), and pumpkin (23.86°) had middle values. The data obtained here accorded with Sirisomboon *et al* [18]. (2007), who found that seed geometry and the repose angle had a straight correlation.

2.5. 1000-Seed Weight

The 1000-seed weight was greatest in pumpkin seeds (261.23 ± 0.71 g), due to their being much larger in size and greater weight. Sunflower (67.24 g) and watermelon seeds (14.61 g) were next. The lowest 1000-seed weight of 1.20 ± 0.01 g was found in chia seeds, which was due to its small structure. These findings agree with those of Ixtaina *et al.* (2008) for chia and Gupta & Das (1997) for sunflower [12, 10].

3. Proximate analysis of seeds

Table 3: Proximate analysis of seeds

Parameter	Moisture (%)	Protein (%)	Total ash (%)	Fat (%)	Crude Fiber (%)	Carbohydrate (%)
Flax seed	6.59 ± 0.20^{b}	20.55 ± 0.182^{b}	3.37 ± 0.11^{ab}	37.20 ± 0.15^{d}	20.03 ± 0.12^{c}	12.26 ± 0.36^{a}
Chia seed	6.413 ± 0.94^{b}	20.55 ± 0.186^{b}	4.75 ± 0.10^{c}	21.69 ± 0.15^{a}	34.89 ± 0.44^{e}	11.71 ± 0.62^{a}
Pumpkin seed	6.593 ± 0.24^{b}	24.47 ± 0.13^{d}	3.62 ± 0.20^{b}	23.54 ± 0.09^{b}	12.61 ± 0.14^{a}	29.17 ± 0.61^{d}
Watermelon seed	7.86 ± 0.95^{c}	19.76 ± 0.19^{a}	2.98 ± 0.36^{a}	26.80 ± 0.12^{c}	15.28 ± 0.35^{b}	27.32 ± 1.12^{c}
Sunflower seed	3.27 ± 0.16^{a}	22.54 ± 0.63^{c}	4.57 ± 0.11^{c}	53.80 ± 0.06^{e}	26.43 ± 0.11^{d}	10.39 ± 0.44^{a}

Values are presented as the average of the standard deviations of three independent measurements. Superscripts (a, b, c, d, e) in the same column, significant differences are mean ($p \leq 0.05$) among the final proximate compositions of the seed-based shake mix. These values demonstrate the variations in nutritional quality regarding moisture, protein, fat, ash, crude fiber, and carbohydrates, and highlight the effect of super seed formulations on the overall quality.

The proximate analysis of seeds rich in protein revealed notable differences in their moisture, protein, fat, fiber, ash, and carbohydrate levels, which affect their nutritional value in food products. The moisture content increased from 3% to 8%, with the lowest found in sunflower seeds and the highest in watermelon seeds, influencing their shelf life and vulnerability to spoilage (Shrivastava and Verma, 2014; Betty *et al.,* 2016). There was a considerable increase in protein content, which varied from 19% to 24%, with pumpkin seeds exhibiting the highest levels, followed by sunflower, flax, and chia seeds, supporting their role as protein-rich components (Mattila *et al.*, 2018; Kibui *et al.*, 2018). Fat content ranged between 21% and 54%, with sunflower seeds demonstrating the highest fat content, categorizing them as a high-energy ingredient, while chia seeds had the least (Vaid and Kaur, 2022; Wilman *et al.,* 2018). Crude fiber content differed significantly, ranging from 12% to 35%, with chia and sunflower seeds contributing the most, thereby increasing dietary fiber intake (Kwiri *et al.,* 2014) Carbohydrate content showed marked variations as well, spanning from 10% to 29%, with pumpkin and watermelon seeds having the highest levels, whereas flax and chia seeds contained lower amounts, affecting their total energy contribution (Khan and Saini, 2016; Everlyne *et al.,* 2020).

4. Functional Properties of Seed Powders

Functional characteristics such as water absorption and oil absorption, solubility, and hydration capacity are of critical for determination the behavior of seed powders in various food items. Such properties influence texture, moisture holding capacity, mouthfeel, and product stability.

Table 4: Functional Properties of Seed Powders

Seed	WA_bC (g/g)	WA_dC (g/g)	OAC (g/g)	WSI (%)	WHC (g/g)
Flaxseed	2.64 ± 0.03^{c}	0.17 ± 0.01^{c}	1.72 ± 0.02^{a}	5.84 ± 0.05^{c}	1.4 ± 0.02^{b}
Chia Seed	2.88 ± 0.03^{d}	0.32 ± 0.013^{d}	1.85 ± 0.02^{b}	9.24 ± 0.04^{e}	12.05 ± 0.07^{e}
Pumpkin Seed	3.4 ± 0.05^{e}	0.1 ± 0.012^{a}	3.75 ± 0.03^{e}	6.11 ± 0.06^{d}	4.69 ± 0.04^{d}
Watermelon Seed	1.89 ± 0.02^{b}	0.12 ± 0.01^{b}	1.92 ± 0.02^{c}	4.11 ± 0.03^{a}	3.12 ± 0.02^{c}
Sunflower Seed	1.6 ± 0.02^{a}	0.09 ± 0.02^{a}	2.51 ± 0.03^{d}	4.88 ± 0.03^{b}	2.49 ± 0.03^{b}

Values are presented as the average of standard deviations from three independent measurements. Mean values of the same column with different superscripts (a, b, c, d, e). WA_bC- Water Absorption Capacity, WA_dC- Water Absorption Index, OAC Oil Absorption Capacity, WSI- Water Solubility Index, WHC- Water Holding Capacity.

4.1. Water Absorption Capacity (WA_bC)

Pumpkin seed powder had the greatest water absorption capacity (3.4 ± 0.05 g/g), followed by chia (2.88 ± 0.03 g/g) and flaxseed (2.64 ± 0.03 g/g). Greater WAbC indicates greater water binding capability of the protein and fiber matrix, which is desirable in bakery and meat products for enhancing juiciness and texture. Chia's hydrophilic mucilage has an extensive water binding capacity, as also reported by Ixtaina *et al*. (2011) [12]. Watermelon (1.89 g/g) and sunflower (1.6 g/g) had relatively lower values, which would be expected by their lower soluble fiber and mucilage content. Azhari *et al*. (2014) also obtained similar results for watermelon seeds, and Subaşı *et al*. (2022) also obtained similar results for sunflower meal.

4.2. Water Absorption Index (WA_dC)

Chia seed powder had the highest WAdC (0.32 ± 0.013 g/g) because they contain mucilage, which gelates when rehydrated. This characteristic adds to satiety and is preferred in healthy-oriented products. The same patterns were observed for chia-rich flours by Coelho and Salas-Mellado (2014) [19, 25]. Contrarily, the lowest WAdC was measured for sunflower (0.09 ± 0.02 g/g) and pumpkin seed powders (0.10 ± 0.012 g/g), and these contained relatively few solubilized water components, similar were shown by.

4.3. Oil Absorption Capacity (OAC)

Pumpkin seed powder possessed the highest oil absorption capacity (3.75 ± 0.03 g/g), then sunflower (2.51 ± 0.03 g/g), and watermelon (1.92 ± 0.02 g/g). High OAC results from hydrophobic protein surfaces, and it plays a significant role in flavor preservation in food systems. The intermediate values of flaxseed (1.72 g/g), chia (1.85 g/g) were observed. The results agree with Aremu *et al*. (2007) and Ixtaina *et al*. (2011), whose research showed high protein and lipid content led to high oil retention capacity [12].

4.4. Water Solubility Index (WSI)

Chia seed powder again took the lead in this attribute with a WSI of 9.24 ± 0.04%, followed by pumpkin (6.11%) and flaxseed (5.84%), showing higher solubilized solids, likely due to the presence of soluble dietary fiber and mucilage. WSI stands for water-soluble component dispersion and is appropriate for application in beverage and instant product production. The findings are consistent with research published by Olivos-Lugo *et al*. (2010) [24]. Lower WSI was observed in watermelon (4.11%) and sunflower (4.88%), which reflected lower soluble content.

4.5. Water Holding Capacity (WHC)

The WHC was significantly higher in chia seeds (12.05 ± 0.07 g/g), due to their mucilaginous polysaccharide layer that can gel in the presence of water—an activity highly useful in thickening and emulsifying agents. This is consistent with Segura-Campos *et al*. (2014). Watermelon (3.12 g/g) and pumpkin (4.69 g/g) were the next, while flax (1.4 g/g) and sunflower (2.49 g/g) were lower in WHC, likely due to lesser soluble fiber or lack of gelling properties.

Conclusion

This study highlights the specific nutritional, functional, and physical characteristics of chia, flax, pumpkin, watermelon, and sunflower seeds as they are revalidated as super seeds. Great differences in size, density, and porosity among seeds affect their handling and processing accommodation. Chia and pumpkin exhibited high hydration capacity and absorption capacity, sunflower exhibited high fat content, pumpkin exhibited high protein content, and chia exhibited high dietary fiber content. These original properties make each seed suitable for use in some foods, which vary from protein-rich snacks to fiber-enriched drinks. Overall, the use of such seeds in functional foods offers positive opportunities for nutritional quality enhancement and responsiveness to health-conscious consumer demands.

Reference

1. Ishag OAO, Khalid AA, Abdi A, Erwa IY, Omer AB, Nour AH. Proximate composition, physicochemical properties and antioxidant activity of flaxseed. Ann Res Review Biol,2019:1(1):1–10.
2. Soni RP, Katoch M, Kumar A, Verma P. Flaxseed—Composition and its health benefits. Res Environ Life Sci,2016:9(1):310–316.
3. Cáceres A, Cruz SM, De León C, Méndez R. Yield and Chemical Characteristics of *Salvia hispanica* L. (Chia) Oil from Native Seeds from Four Provenances of Guatemala. Combinatorial Chemistry & High Throughput Screening,2024:27(4):555–561.
4. Marcinek K, Krejpcio Z. Chia seeds (*Salvia hispanica*): health promoting properties and therapeutic applications-a review. Roczniki Państwowego Zakładu Higieny,2017:68(2):1–10.
5. Dotto JM, Chacha JS. The potential of pumpkin seeds as a functional food ingredient: A review. Scientific African,2020:10:00575.
6. Karanja J, Mugendi BJ, Khamis F, Muchugi A. Nutritional composition of the pumpkin (*Cucurbita* spp.) seed cultivated from selected regions in Kenya. 2013.
7. Tabiri B, Agbenorhevi JK, Wireko-Manu FD, Ompouma EI. Watermelon seeds as food: Nutrient composition, phytochemicals and antioxidant activity. 2016.
8. Nissar J, Sidiqi US, Dar AH, Akbar U. Nutritional composition and bioactive potential of watermelon seeds: a pathway to sustainable food and health innovation. Sustainable Food Technology,2025:1(1):1–10.
9. Marinova E, Toneva A, Yanishlieva NJ. Synergistic antioxidant effect of α-tocopherol and myricetin on the autoxidation of triacylglycerols of sunflower oil. Food Chemistry,2008:106(2):628–633.
10. Gupta RK, Das SK. Physical properties of sunflower seeds. Journal of Agricultural Engineering Research,1997:66(1):1–8.
11. Coşkuner Y, Karababa E. Some physical properties of flaxseed (*Linum usitatissimum* L.). Journal of Food Engineering,2007:78(3):1067–1073.
12. Ixtaina VY, Nolasco SM, Tomás MC. Physical properties of chia (*Salvia hispanica* L.) seeds. Industrial Crops and Products,2008:28(3):286–293.
13. Singh KK, Mridula D, Barnwal P, Rehal J. Physical and chemical properties of flaxseed. International Agrophysics,2012:26(4):1–10.
14. Singh AK, Sharma V, Yadav KC. Effect of moisture content on physical properties of flaxseed. Research & Reviews: Journal of Food Science and Technology,2014:3(2):19–27.
15. AOAC. Official Methods of Analysis (17th ed.). Association of Official Analytical Chemists,2000.
16. Jain RK, Bal S. Properties of pearl millet. Journal of Agricultural Engineering Research,1997:66(2):85–91.
17. Razavi SM, Rafe A, Moghaddam TM, Amini AM. Physical properties of pistachio nut and its kernel as a function of moisture content and variety. Part II. Gravimetrical properties. Journal of Food Engineering,2007:81(1):218–225.
18. Sirisomboon P, Kitchaiya P, Pholpho T, Mahuttanyavanitch W. Physical and mechanical properties of *Jatropha curcas* L. fruits, nuts and kernels. Biosystems Engineering,2007:97(2):201–207.
19. Coelho MS, Salas-Mellado MDLM. Chemical characterization of chia (*Salvia hispanica L.*) for use in food products. Journal of Food and Nutrition Research,2014:2(5):263–269.
20. Mohsenin NN. Physical Properties of Plant and Animal Materials (2nd ed.). Gordon and Breach Science Publishers,1986.
21. Baryeh EA. Physical properties of bambara groundnuts. Journal of Food Engineering,2001:47(4):321–326.
22. Gültekin Subaşı B, Vahapoğlu B, Capanoglu E, Mohammadifar MA. A review on protein extracts from sunflower cake: Techno-functional properties and promising modification methods. Critical Reviews in Food Science and Nutrition,2022:62(24):6682–6697.
23. Aremo MO, Olaofe O. Functional properties of some Nigerian varieties of legume seed flours and flour concentration effect on foaming and gelation properties, 2007.
24. Olivos-Lugo BL, Valdivia-López MÁ, Tecante A. Thermal and physicochemical properties and nutritional value of the protein fraction of Mexican chia seed (*Salvia hispanica* L.). Food Science and Technology International,2010:16(1):89–96.
25. Fernandes SS, Bernardino JCC, Owen PQ, Prentice C, Salas Mellado MDLM, Segura Campos MR. Effect of the use of ethanol and chia mucilage on the obtainment and techno functional properties of chia oil nanoemulsions. Journal of Food Processing and Preservation,2021:45(2):15181.

26. Obtainment and techno functional properties of chia oil nanoemulsions. *Journal of Food Processing and Preservation*, *45*(2), 15181.
27. Patel G, Naik RK, Patel KK. Studies on some physical and engineering properties of linseed. Biological Forum–An International Journal,2021:13(1):303–308.
28. H A, Ghatge PU, Sawate AR. Studies on physico-chemical and mineral evaluation of flaxseed. The Pharma Innovation Journal,2020:9(3):476–478.
29. Coşkuner Y, Karababa E. Some physical properties of flaxseed (*Linum usitatissimum* L.). Journal of Food Engineering,2007:78(3):1067–1073.