

Chemical proximate composition, antinutritional factors content, and antioxidant capacity of anatomical seed fractions of *Moringa oleifera*

Composición química proximal, contenido de factores antinutricionales y capacidad antioxidante de fracciones anatómicas de semillas de *Moringa oleifera*

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Abstract

For rational use of moringa seeds and its anatomical fractions (kernel, shells, and wings), the objective of the present investigation was to analyze their chemical composition, antinutritional factors content, and antioxidant capacity. The seed kernel fraction represents 71.78% of the whole seed weight and possesses high contents of protein (32.19%) and lipids (38.72%), whereas seed shells and wings fractions are mainly composed of dietary fiber and carbohydrates. Phytate was the most abundant antinutritional factor detected in all fractions (604.0 mg PAE/100 g-1674.9 mg PAE/100 g), followed by total phenolics (218.5 mg GAE/100 g-386.9 mg GAE/100 g) and saponins (130.4 mg DE/100 g-197.4 mg DE/100 g). Moringa seeds fractions showed a high antioxidant capacity. The kernel fraction exerts the highest activity (15 251.90 $\mu\text{mol TE}/100\text{g}$), followed by shells (8 499.50 $\mu\text{mol TE}/100\text{g}$) and wings (5 878.90 $\mu\text{mol TE}/100\text{g}$). Moringa seed kernel fraction seems to be a promising source of protein. All anatomical seed fractions of moringa are a reservoir of dietary fiber and antioxidants.

Keywords: *Moringa oleifera*; chemical composition; antinutritional factors; antioxidant capacity.

Resumen

Para una utilización racional de las semillas de moringa y sus fracciones anatómicas (alas, cáscara y almendra), el objetivo de la presente investigación fue analizar su composición química, contenido de factores antinutricionales y capacidad antioxidante. La almendra representa el 71.78% del peso de la semilla completa y tiene un contenido alto de proteína (32.19%) y lípidos (38.72%). La cáscara y alas se componen principalmente de fibra dietaria y carbohidratos. Los fitatos fueron el factor antinutricional más abundante detectado en las fracciones (604.0 mg PAE/100 g-1674.9 mg PAE/100 g), seguido de fenólicos totales (218.5 mg GAE/100 g-386.9 mg GAE/100 g) y saponinas (130.4 mg DE/100 g-197.4 mg DE/100 g). Las fracciones de moringa mostraron una alta capacidad antioxidante. La almendra mostró la mayor actividad (15 251.90 $\mu\text{mol TE}/100\text{g}$), seguida de cáscara (8499.50 $\mu\text{mol TE}/100\text{g}$) y alas (5878.90 $\mu\text{mol TE}/100\text{g}$). La almendra parece ser una fuente prometedora de proteína. Todas las fracciones anatómicas de moringa son un reservorio de fibra dietaria y antioxidantes.

Palabras clave: *Moringa oleifera*; composición química; factores antinutricionales; capacidad antioxidante.

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Introduction

Moringa (*Moringa oleifera* Lam) is one of the thirteen species belonging to the Moringaceae family. It is a fast-growing perennial tree, native to northwestern India, distributed throughout the Middle East and in African and Asian countries and widely cultivated in tropical and subtropical areas due to its adaptability to climatic conditions (Leone *et al.*, 2016). All plant parts of the moringa tree (leaves, flowers, bark, roots, and seeds) are edible and are also used as tea or infusions in traditional medicine to treat several ailments, including malaria, typhoid fever, parasitic diseases, arthritis, swelling, cuts, diseases of the skin, and others (Al-Asmari *et al.*, 2015; Bakre, Aderibigbe & Ademowo, 2013; Ouédraogo *et al.*, 2011; Vasanth *et al.*, 2015; Yassa & Tohamy, 2014). Moringa seeds represent a source of protein and oil. Interest in the oil extracted from moringa seeds has grown significantly over the years, being identified among the most promising emergent seeds for biodiesel production (Martín *et al.*, 2010). A single moringa tree can produce 15 000 to 25 000 seeds per year (Foidl *et al.*, 2001). The seeds are round-shaped, containing a kernel protected by a brownish semi-permeable hull (shell) and have three papery wings (figure 1) (Leone *et al.*, 2016). Besides conventional oilseeds, moringa seeds are dehulled before oil extraction to reduce oil absorption in the cake, avoid undesirable characteristics of the extracted oils such as increased pigments and waxes contents and increased oil extraction yields (Boukandoul, Casal, Cruz, Pinho & Zaidi, 2017). On the other hand, the shells obtained are discarded or burnt due to a lack of economic value (Martín *et al.*, 2010).

For a rational utilization of moringa seeds, it is necessary to investigate the nutritional and antinutritional chemical composition and the nutraceutical properties of each anatomical part. Moringa whole seed and its kernel fraction have been widely studied regarding its nutritional content and antioxidant capacities (Ferreira, Farias, Oliveira & Carvalho, 2008; Singh, Negi & Radha, 2013). However, there is no information available on the shells and wings fractions. In order to contribute to the understanding of their composition and elucidate potential uses as ingredients or nutraceutical applications, in this work, partial characterization of moringa seeds and its anatomical fractions (kernel, shells, and wings) was performed, including proximate chemical composition, antinutritional factors, and antioxidant capacity.

Materials and methods

Plant material

Moringa seeds used in this study were obtained from mature pods of trees harvested in Culiacan, Sinaloa, Mexico (24° 59' 16.15" N; 107° 34' 25.64" W). The seeds were collected, cleaned, and stored at 4 °C until analysis.

Seed physical characteristics

Physical dimensions, namely seed length and width, of 25 seeds randomly selected were determined using a digital micrometer with 0.01 mm accuracy (Milán-Carrillo, Reyes-Moreno, Armienta-Robledo, Cárabes-Trejo & Mora-Escobedo, 2000). For 1000-seed weight determination, 100 seeds were randomly selected and weighted. The weight obtained was then multiplied by ten (Bortey, Sadia & Asibuo, 2016). Hectoliter weight (Kg/hL) was estimated in triplicate using a 1-liter graduated cylinder filled with seeds consistently and uniformly before weighting. The mass obtained was then multiplied by 100.

Seed fractionation and sample preparation

Seeds were manually fractionated into kernel, shells, and wings. Whole seeds and seed fractions were then ground into powder, passed through a 60-mesh screen sieve, packed, and stored at -20 °C until analysis.

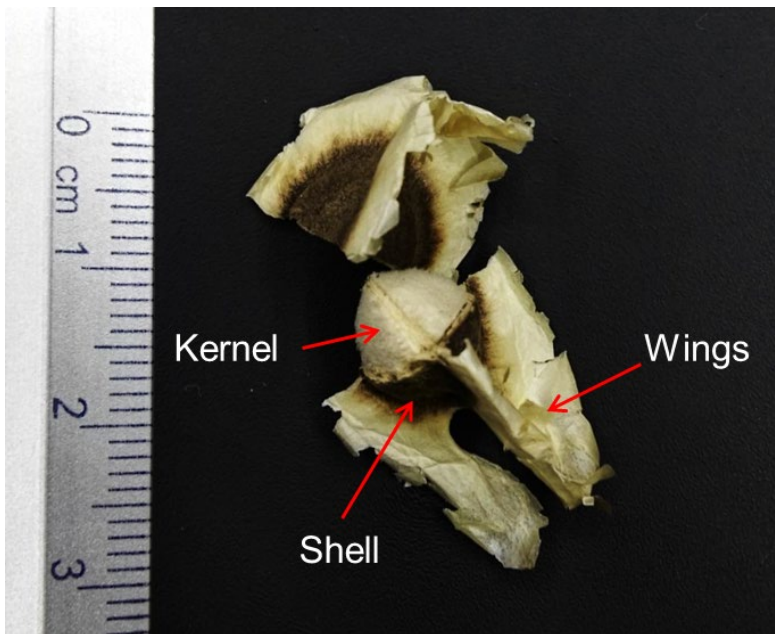


Figure 1. Anatomical fractions of moringa (*Moringa oleifera*) seeds.
Source: Authors' own elaboration.

Proximate composition

Proximate chemical composition analyses were conducted according to the standard methods (Association of Official Analytical Chemists [AOAC], 1999). The samples were dried at 130 °C to determine moisture (method 925.09 B), defatting in a Soxhlet apparatus with petroleum ether for lipid analyses (method 920.39 C), and a micro-Kjeldahl was used for protein quantification (N x 6.25) (method 960.52). Soluble and insoluble dietary fiber (SDF/IDF) were both determined using the total dietary fiber assay kit (Sigma-Aldrich [TDF 100 A]) according to the manufacturer instructions.

Phytate

The phytate content of the samples was determined by the colorimetric procedure described by Vaintraub & Lapteva (1988) with minor modifications. Phytate was extracted using 3.5% HCl (w/v). Suitable aliquots were diluted with distilled water to make 3 mL. They were treated with 1 mL Wade reagent (0.03% FeCl₃·6H₂O + 0.3% sulfosalicylic acid) and determined spectrophotometrically at 500 nm using phytic acid as a standard. The phytate content was expressed as mg Phytic Acid Equivalent (PAE)/100 g (dw) (León-López, Dávila-Ortiz, Jiménez-Martínez & Hernández-Sánchez, 2013).

Saponins

Total saponin content was determined following the method described by Hiai, Oura & Nakajima (1976). The extract was obtained with 80% aqueous methanol. The quantification was done using a standard curve

of diosgenin, and the content of saponins was expressed as mg equivalents of diosgenin (DE)/100 g (dw) (León-López *et al.*, 2013).

Total phenolic content

Free and bound phenolics were extracted using 80% aqueous methanol according to the procedure described by Mora-Rochín *et al.* (2010). Free phenolics were obtained by mixing 0.5 g of sample with a 10 mL extraction solvent for 10 min. The blends were centrifuged (3000 g, 10 min), and the supernatant was recovered and concentrated to 2 mL at 45 °C using a vacuum evaporator and stored at -20 °C. Bound phenolic compounds were released and retrieved from the leftover pellet. The content of free and bound phenolic compounds was determined using the colorimetric method described by Singleton, Orthofer & Lamuela-Raventós (1999). A calibration curve was prepared using gallic acid as standard, and total phenolic content (TPC) was expressed as mg gallic acid equivalents (GAE)/100 g dry weight (dw). TPC was calculated as the sum of free and bound phenolic compounds.

Tannins

Tannins were extracted with 80% methanol (Xu & Chang, 2007), assayed colorimetrically according to the modified vanillin method of Price, van Scoyoc & Butler (1978) and expressed as mg catechin equivalents (CE)/100 g (dw).

Trypsin inhibitor activity

The trypsin inhibitor activity was tested according to the enzymatic assay described by Welham & Domoney (2000) using α -N-benzoyl-DL-arginine-p-nitroanilide hydrochloride (BAPNA) as trypsin substrate. Trypsin inhibitor activity expressed as trypsin inhibitor units TIU/mg sample (dw) was calculated from the absorbance read at 410 nm against a reagent blank.

Antioxidant capacity (AoxC)

The antioxidant capacity (AoxC) of aqueous methanol extracts assayed for free and bound phenolic was determined by the oxygen radical absorbance capacity (ORAC) assay using fluorescein as a probe, as described by Ou & Hampsch-Woodill & Prior (2001). Trolox was used as a standard reference, and results were expressed as μ mol Trolox equivalents (TE)/ 100g (dw). Total AoxC was calculated as the sum of AoxC from free and bound 80% methanolic extracts. All measurements were made in triplicate.

Statistical analysis

Results obtained were expressed as mean \pm standard deviations. One-way ANOVA and Duncan's multiple range test for means comparisons were applied to establish significant differences among the anatomical seed fractions of moringa, with a significance level of $p < 0.05$ using the Statgraphics Centurion XVII statistical package.

Results

Seeds physical Properties

The physical properties of moringa seeds are presented in table 1. The average length and width of the whole moringa seed (MWS) were 1.05 cm and 0.86 cm, respectively. MWS show an average weight of 0.22

g, a 1000-seed weight of 212.82 g, and a hectoliter weight of 18.10 Kg/hL. Table 1 also shows the yield of seed anatomical fractions based on 100g of MWS seeds. Seed kernel fraction (SK) represents more than 70% of the whole seed weight, while the shells (SS) and wings (SW) correspond to 23.37% and 3.51%, respectively.

Table 1. Physical characteristics of *Moringa oleifera* seeds.

Parameter	Value
Length * (cm)	1.05 ± 0.07
Width * (cm)	0.86 ± 0.08
Seed weight *(g)	0.22 ± 0.06
1000-seed weight ** (g)	212.82 ± 6.71
Hectolitre weight ** (kg/hL)	18.10 ± 4.12
Wings, % of whole seed weight	3.51 ± 0.09
Shell, % of whole seed weight	23.37 ± 0.05
Kernel, % of whole seed weight	71.78 ± 0.05

*Mean of 25 seeds; ** Mean of triplicate determinations.

Source: Authors' own elaboration.

Proximate composition of whole seeds and seed fractions

Chemical proximate composition of moringa seeds and its fractions are given in table 2. MWS contained significant amounts of crude oil (29.40%), crude protein (25.47%), and dietary fiber (28.12%). Significant differences in composition were observed among the seed anatomical fractions, showing the macronutrient distribution over the seed ($p < 0.05$). SW and SS fractions are mainly composed of carbohydrates (26.38% and 19.73%, respectively) and insoluble fiber (51.06% and 70.94%, respectively). As is well known, the SK fraction is rich in protein (32.19%) and oil (38.72%).

Table 2. Chemical composition of whole seeds and *Moringa oleifera* seed fractions.

Component (g/100g sample)	Whole seeds	Seed fractions		
		Wings	Shell	Kernel
Crude Protein	25.47 ± 0.43	12.67 ± 0.47 ^b	5.20 ± 0.50 ^c	32.19 ± 0.75 ^a
Lipids	29.40 ± 0.14	2.56 ± 0.48 ^b	0.82 ± 0.16 ^c	38.72 ± 0.09 ^a
Ash	2.97 ± 0.10	3.57 ± 0.02 ^a	3.32 ± 0.19 ^a	3.39 ± 0.34 ^a
Carbohydrates	14.04 ± 4.03	26.38 ± 1.68 ^a	19.73 ± 2.41 ^b	12.58 ± 5.03 ^b
Dietary fiber	28.12 ± 3.36	54.82 ± 0.98 ^b	70.94 ± 1.56 ^a	13.31 ± 3.85 ^c
Soluble	2.88 ± 0.06	3.77 ± 0.43 ^a	2.82 ± 0.30 ^b	1.52 ± 0.10 ^c
Insoluble	25.24 ± 4.06	51.06 ± 1.08 ^b	68.12 ± 0.51 ^a	11.79 ± 2.66 ^c

All values are means of triplicate determinations ± standard deviation. Means within rows with different letters are significantly different ($p < 0.05$). All data are expressed on dry weight basis (dw).

Source: Authors' own elaboration.

Antinutritional factors content of whole seeds and seed fractions

The antinutritional components (phytate, saponins, phenolics, tannins, and trypsin inhibitors) in MWS and seed fractions are shown in table 3. Phytate was the most abundant antinutritional factor found in moringa seeds. The phytate content in MWS was 1380.6 mg PAE/100 g, and these compounds were detected in all anatomical fractions assayed; SW (604.0 mg PAE/100 g), SS (1453.0 mg PAE/100 g), and SK (1674.9 mg PAE/100 g). Saponins were also detected in MWS (154.95 mg DE/100 g) and all anatomical fractions assayed;

SW (168.7 mg DE/100 g), SS (197.4 mg DE/100 g) SK (130.4 mg DE/100 g). MWS shows a good TPC (212.8 mg GAE /100 g). The highest-level TPC was detected in SS (386.9 mg GAE /100 g), followed by SK (236.0 mg GAE /100 g) and SW (218.5 mg GAE /100 g). In MWS and its fractions, phenolic in the bound form represents the bulk of the TPC; 92.5% in MWS, 73.5% in SW, 62.5% in SS, and 92.9% in SK. Meanwhile, tannins quantified by the vanillin test were present in an amount of 62.6 mg CE/ 100g in MWS. The highest values were found in SW and SS fractions (189.7 mg CE/ 100g and 196.0 mg CE/ 100g, respectively), and no significant differences were found between them. The lowest content of tannins corresponded to the SK fraction (34.3 mg CE/ 100g). On the other hand, trypsin inhibitor activity detected in MWS was 5.8 TIU/ mg sample. SW fraction presented the lowest trypsin inhibitor activity (1.1 TIU/ mg sample), while SS and SK fractions show the highest activity (5.9 TIU/ mg sample and 5.7 TIU/ mg sample, respectively) without significant difference ($p < 0.05$) between them.

Table 3. Antinutritional factors of whole seeds and *Moringa oleifera* seed fractions.

Component	Whole seeds	Seed fractions		
		Wings	Shell	Kernel
Phytic acid ¹	1380.6 ± 33.8	604.0 ± 38.0 ^c	1453.0 ± 11.2 ^b	1674.9 ± 11.6 ^a
Saponins ²	154.95 ± 6.6	168.7 ± 7.6 ^b	197.4 ± 5.14 ^a	130.4 ± 8.8 ^c
Total phenolics ³	212.8 ± 10.5	218.5 ± 18.1 ^b	386.9 ± 15.2 ^a	236.0 ± 5.8 ^b
Free ³	15.8 ± 1.2	57.9 ± 4.1 ^b	144.9 ± 7.8 ^a	16.7 ± 2.9 ^c
Bound ³	196.9 ± 9.3	160.6 ± 13.9 ^b	242.0 ± 13.9 ^a	219.2 ± 2.9 ^a
Tannins ⁴	62.6 ± 5.40	189.7 ± 10.5 ^a	196 ± 2.7 ^a	34.3 ± 2.0 ^b
Trypsin inhibitors ⁵	5.8 ± 0.0	1.1 ± 0.0 ^b	5.9 ± 0.3 ^a	5.7 ± 0.1 ^a

All values are means of triplicate determinations ± standard deviation. Means within rows with different letters are significantly different ($p < 0.05$). ¹mg Phytic Acid Equivalent (PAE) /100 g (dw); ²mg Diosgenin Equivalent (DE)/100 g (dw); ³mg Gallic Acid Equivalent (GAE)/100 g (dw); ⁴mg Chatequin Equivalent (CE) / 100 g (dw); ⁵Trypsin Inhibitor Units (TIU)/mg sample.
Source: Authors' own elaboration.

Antioxidant capacity

Antioxidant capacity of aqueous methanolic extract from MWS and moringa seed fractions are shown in table 4. The SK fraction's total antioxidant capacity was 2.6 and 1.8 times higher than the SS and SW fractions, respectively. Most of the antioxidant capacity was found in the free aqueous methanolic extracts from all samples tested; SK presents the higher free antioxidant capacity followed by the SS fraction and the SW fraction. The antioxidant capacity of bound aqueous methanolic extracts showed a similar behavior; the highest bound antioxidant capacity was found in SK fraction followed by the SS fraction and the SW fraction.

Table 4. Antioxidant capacity¹ of whole seeds and *Moringa oleifera* seed fractions.

Aqueous Methanolic Extract	Whole seeds	Seed fractions		
		Wings	Shell	Kernel
Free	7818.2 ± 720.8	3562.1 ± 60.2 ^c	5193.4 ± 448.8 ^b	8703.0 ± 343.8 ^a
Bound	2262.3 ± 197.9	2316.7 ± 316.7 ^c	3306.1 ± 297.7 ^b	6548.9 ± 252.5 ^a
Total	10 080.6 ± 918.7	5878.9 ± 376.9 ^c	8499.5 ± 746.5 ^b	15 251.9 ± 596.4 ^a

Data are expressed as means ± standard deviation of triplicate samples. Means with different superscripts in the same row show a significant difference ($p < 0.05$). ¹μmol Trolox equivalents (TE)/100 g (dw).
Source: Authors' own elaboration.

Discussion

Moringa seeds are used to obtain oil and proteins. During these processes, the seeds are dehulled, and the obtained fraction is discarded and subtilized. On the other hand, the population in developing countries consumes the whole seeds without any recommendation or prescription by health promoters. In the current study, moringa seeds cultivated in Sinaloa, México, show different dimensions (length and width) compared to other authors who found values from 2 cm to 2.5 cm for height and 0.4 cm–0.7 cm for width (Leone *et al.*, 2016; Nouhi, Kwaambwa, Gutfreund & Rennie, 2019). Average weight and 1000-seed weight were similar to previous results reported by Olson & Fahey (2011), while hectoliter weight (18.10 kg/hL) is published for the first time, as far as it is known. This parameter describes a low-density seed.

Moringa SK fraction represents more than 50% of the seed's total weight, being similar to other non-conventional oilseeds such as *Jatropha curcas* and *Azadirachta indica* (Neem) (Martín *et al.*, 2010). Besides, moringa SK presents high crude oil content very similar to neem seeds (39.7%). In this study, SS and SW fractions yield and composition are reported separately for the first time. Moringa SS fraction is composed mainly of dietary fiber with low protein content, indicating a poor nutritional value, whereas SW fraction, also rich in dietary fiber, showed considerable protein content.

Conventional antinutritional factors such as trypsin inhibitors, saponins, and tannins have been little studied in moringa seeds. However, in the seeds used in this research, tannins, phytates, and saponins were detected at considerable levels. Phytic acid and its salts, collectively referred to as phytate, are potent inhibitors of iron and zinc absorption (Gibson, Raboy & King, 2018). In legumes and most oilseeds, phytate is uniformly distributed within the protein bodies of the endosperm or kernel (Gibson *et al.*, 2018; Gupta, Gangoliya & Singh, 2015). Despite being present in all anatomical fractions, the highest proportion of phytate in moringa was found in the SK fraction (1674.9 mg PAE/100 g). This value, apparently high, still falls within the range reported for other oilseeds as soybeans, sesame seeds, sunflower kernels, linseeds, and rape seeds (1000-5400 mg/100 g) (Gupta *et al.*, 2015). Although most reports underline the phytate action as an antinutritional agent, in recent studies, dietary phytate has been associated with specific therapeutic effects, including anti-diabetic, anti-cancer, and anti-inflammatory properties, among others (Abdulwaliyu *et al.*, 2019).

The saponin content in moringa whole seed (MWS) found in this study differs from a previous study by Ijarotimi, Adeoti & Ariyo (2013), which reported a substantially lower saponin amount (9.83 mg/100 g). However, the saponin content found in MWS (154.95 mg DE/100 g), or in any of the anatomical seed fractions, is lower when compared with those values reported for quinoa seeds (1260 mg/100 g) (Lim, Park & Yoon, 2020) and other edible legumes such as soybean (800 mg/100g) (Mohan, Tresina & Daffodil, 2016).

On the other hand, tannin content in MWS found in this study (62.6 mg CE/100 g) was higher than that reported by Igwilo, Okonkwo, Ugochukwu, Ezekwesili & Nwenyi (2017), who described a 40 mg/100 g value. The SK fraction showed a lower tannin content than those reported in commercially important edible nut seeds (100 CE/100 g–800 CE/100 g) (Venkatachalam & Sathe, 2006). Tannin content found in moringa SS and SW fractions were almost 6-fold higher than in the SK fraction. Similar behavior was observed on tannin distribution in Mexican pecan nut. Flores-Cordova *et al.* (2017) found a tannin content of 7-fold to 8-fold higher in pecan shell than it was found in the edible part.

Trypsin inhibitor activity detected in MWS (5.8 TIU/ mg) was similar to the one reported for different varieties of lentils (4.98 TIU/ mg–6.29 TIU/ mg), and it was lower compared to chickpeas (14.22 TIU/mg–15.96 TIU/mg) and common beans (15.18 TIU/mg–20.83 TIU/mg) (Shi, Mu, Arntfield & Nickerson, 2017). Generally, trypsin inhibitor activity tends to be higher in the cotyledon fractions than in whole seeds. In

this study, no significant difference was observed among the trypsin activity found in MWS and moringa SK fraction.

Despite the appreciably high protein contents in MWS and moringa SK fraction, the presence of antinutritional components could be a restriction to their incorporation into food matrixes. Moringa SK fraction, which is particularly rich in protein and fat, once defatted, results in a protein-rich meal. Based on its amino acid composition, it is expected that this meal support growth when tested as feed-in animal models. However, Igwiló *et al.* (2013) determined the effect of defatted Moringa seed powder on growth rate and some biochemical parameters in albino rats for 21 days. They observed a reduction in growth accompanied by body weight loss. The results obtained by Igwiló *et al.* (2013) suggested that moringa seed proteins have a low digestibility due to the presence of antinutritional factors. On the other hand, the whole Moringa seeds are consumed by the population as traditional medicine; however, it is crucial to know the chemical composition of each anatomical part in order to recommend people how to use this type of seeds either as a source of protein or as a source of phytochemicals.

Likewise, the results clearly show MWS and its fractions contained substantial amounts of TPC. Some studies have demonstrated a linear relationship between TPC and AoxC. However, in this work, AoxC evaluated by the ORAC assay was not correlated with TPC in moringa samples ($r^2 = 0.1387$). Moringa SS, particularly rich in phenolics, including tannins, did not show the higher values of AoxC. This behavior could be attributed to other compounds that also exert antioxidant capacities in the extracts assayed for AoxC, such as saponins.

Antioxidant capacity of aqueous methanolic extracts from MWS and moringa seed fractions showed a considerable antioxidant capacity. The antioxidant capacity values found in all moringa samples were higher than those present in 100 g of almonds (4282 $\mu\text{mol TE}$) (US Department of Agriculture, Agricultural Research Service, 2010). The SK fraction exerts the highest activity among the samples assayed (15 252 $\mu\text{mol TE} / 100 \text{ g, dw}$), this value is similar to those found in nuts like walnuts (13 057 $\mu\text{mol TE} / 100 \text{ g, dw}$) or pecans (17 524 $\mu\text{mol TE} / 100 \text{ g, dw}$) (US Department of Agriculture, Agricultural Research Service, 2010).

Assuming that $\mu\text{moles Trolox}$ are equivalent to $\mu\text{moles tocopherol}$, and 0.67 mg $\alpha\text{-tocopherol}$ represent 1 IU vitamin E (Apak *et al.*, 2013), in 100 g dry weight of whole moringa seeds an antioxidant activity equivalent to 6479 IU vitamin E is found. The SK fraction exerts the highest antioxidant capacity, providing 9802 IU vitamin E/100g sample, followed by SS and SW fractions that exert an antioxidant capacity equivalent to 5463 vitamin E/100g and 3778 vitamin E/100g, respectively.

Conclusions

Moringa seed kernel fraction seems to be a promising source of protein. However, due to its considerable antinutritional factors content, more in-depth research is needed regarding its suitability and utilization as food or food ingredients in the human diet. All anatomical seed fractions of moringa are a reservoir of dietary fiber and antioxidants. Seed shells and wings fractions, generally removed before moringa processing for oil production, represent a good alternative for the extraction of natural antioxidant phenolic compounds, including tannins, which could be used for different purposes an ingredient in both pharmaceutical and food industries.

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Conflicts of interest

The authors declare no conflict of interest.

References

- Abdulwaliyu, I., Arekemase, S. O., Adudu, J. A., Batari, M. L., Egbule, M. N., & Okoduwa, S. I. R. (2019). Investigation of the medicinal significance of phytic acid as an indispensable anti-nutrient in diseases. *Clinical Nutrition Experimental*, 28, 42-61. doi: <https://doi.org/10.1016/j.yclnex.2019.10.002>
- Al-Asmari, A. K., Albalawi S. M., Athar M. T., Khan A. Q., Al-Shahrani H., & Islam, M. (2015). *Moringa oleifera* as an anti-cancer agent against breast and colorectal cancer cell lines. *PLoS ONE*, 10(8), 1-14. doi: <https://doi.org/10.1371/journal.pone.0135814>
- Association of Official Analytical Chemists (AOAC). (1999). *Official methods of analysis of AOAC international* (16th ed.). Gaithersburg, MD, USA: AOAC.
- Apak, R., Gorinstein, S., Böhm, V., Schaich, K. M., Özyürek, M., & Güçlü, K. (2013). Methods of measurement and evaluation of natural antioxidant capacity/activity (IUPAC Technical Report). *Pure and Applied Chemistry*, 85(5), 957-998. <https://doi.org/10.1351/PAC-REP-12-07-15>
- Bakre, A. G., Aderibigbe, A. O., & Ademowo O. G. (2013). Studies on the neuropharmacological profile of ethanol extract of *Moringa oleifera* leaves in mice. *Journal of Ethnopharmacology*, 149(3), 783-789. doi: <https://doi.org/10.1016/j.jep.2013.08.006>
- Boukandoul, S., Casal, S., Cruz, R., Pinho, C., & Zaidi, F. (2017). Algerian *Moringa oleifera* whole seeds and kernels oils: Characterization, oxidative stability, and antioxidant capacity. *European Journal of Lipid Science and Technology*, 119(10). doi: <https://doi.org/10.1002/ejlt.201600410>
- Bortey, H. M., Sadia, A. O., & Asibuo, J. Y. (2016). Influence of seed storage techniques on germinability and storability of cowpea (*Vigna unguiculata* (L) Walp). *Journal of Agricultural Science*, 8(10), 241-248. doi: <http://dx.doi.org/10.5539/jas.v8n10p241>
- Flores-Cordova, M., Muñoz-Márquez, E., Muñoz-Márquez, E., Ojeda-Barríos, D. L., Soto-Parra, J. M., & Preciado-Rangel, P. (2017). Phytochemical composition and antioxidant capacity in Mexican pecan nut. *Emirates Journal of Food and Agriculture*, 29(5), 346-350. doi: <https://doi.org/10.9755/ejfa.EJFA-2016-08-1075>
- Foidl, N., Makkar, H. P. S., & Becker, K. (2001). The potential of *Moringa oleifera* for agricultural and industrial uses. *The miracle tree: The multiple attributes of Moringa*, 45-76. https://miracletrees.org/moringa-doc/the_potential_of_moringa_oleifera_for_agricultural_and_industrial_uses.pdf
- Gibson, R. S., Raboy, V., & King, J. C. (2018). Implications of phytate in plant-based foods for iron and zinc bioavailability, setting dietary requirements and formulating programs and policies. *Nutrition reviews*, 76(11), 793-804. doi: <https://doi.org/10.1093/nutrit/nuy028>
- Gupta, R. K., Gangoliya, S. S., & Singh, N. K. (2015). Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. *Journal of food science and technology*, 52(2), 676-684. doi: <https://doi.org/10.1007/s13197-013-0978-y>
- Hiai, S., Oura, H., & Nakajima, T. (1976). Color reaction of some sapogenins and saponins with vanillin sulfuric acid. *Planta Medica*, 29(2), 116-122. doi: <https://doi.org/10.1055/s-0028-1097639>
- Igwilo, I. O., Ogoke, T. J., Ogbu, D. O., Igwilo, S. N., Obi, E., & Abdulsalami, M. S. (2013). Effect of soaked *Moringa oleifera* seeds on growth rates and the levels of some biochemical parameters in albino rats. *Pakistan Journal of Biological Sciences*, 16(1), 48-50. doi: <https://doi.org/10.3923/pjbs.2013.48.50>

- Igwilo, I. O., Okonkwo, J. C., Ugochukwu, G. C., Ezekwesili, C. N., & Nwenyi, V. (2017). Comparative studies on the nutrient composition and antinutritional factors in different parts of *Moringa oleifera* plant found in Awka, Nigeria. *The Bioscientist Journal*, 5(1), 1-12. https://bioscientistjournal.com/index.php/The_Bioscientist/article/view/8
- Ijarotimi, O. S., Adeoti, O. A., & Ariyo, O. (2013). Comparative study on nutrient composition, phytochemical, and functional characteristics of raw, germinated, and fermented *Moringa oleifera* seed flour. *Food science & nutrition*, 1(6), 452-463. doi: <https://doi.org/10.1002/fsn3.70>
- Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2016). *Moringa oleifera* seeds and oil: Characteristics and uses for human health. *International Journal of Molecular Sciences*, 17(12), 2141. doi: <https://doi.org/10.3390/ijms17122141>
- León-López, L., Dávila-Ortiz, G., Jiménez-Martínez, C., & Hernández-Sánchez, H. (2013). Sequentially integrated optimization of the conditions to obtain a high-protein and low-antinutritional factors protein isolate from edible *Jatropha curcas* seed cake. *International Scholarly Research Notices*, 2013, 1-7. doi: <https://doi.org/10.5402/2013/197201>
- Lim, J. G., Park, H.-M., & Yoon, K. S. (2020). Analysis of saponin composition and comparison of the antioxidant activity of various parts of the quinoa plant (*Chenopodium quinoa* Willd.). *Food Science & Nutrition*, 8(1), 694-702. doi: <https://doi.org/10.1002/fsn3.1358>
- Martín, C., Moure, A., Martín, G., Carrillo, E., Domínguez, H., & Parajo, J. C. (2010). Fractional characterization of jatropha, neem, moringa, trisperma, castor, and candlenut seeds as potential feedstocks for biodiesel production in Cuba. *Biomass and Bioenergy*, 34(4), 533-538. doi: <https://doi.org/10.1016/j.biombioe.2009.12.019>
- Milán-Carrillo, J., Reyes-Moreno, C., Armienta-Robledo, E., Cárabez-Trejo, A., & Mora-Escobedo, R. (2000). Physicochemical and nutritional characteristics of extruded flours from fresh and hardened chickpea (*Cicer arietinum* L.). *Food Science and Technology*, 33(2), 117-223. doi: <https://doi.org/10.1006/fstl.1999.0620>
- Mohan, V. R., Tresina, P. S., & Daffodil, E. D. (2016). Antinutritional factors in legume seeds: Characteristics and determination. In B. Caballero, P. M. Finglas, & F. Toldrá (Eds.), *Encyclopedia of Food and Health* (pp. 211-220). Oxford: Academic Press. doi: <https://doi.org/10.1016/B978-0-12-384947-2.00036-2>
- Mora-Rochín, S., Gutiérrez-Urbe, J. A., Serna-Saldívar, S. O., Sánchez-Peña, P., Reyes-Moreno, C., & Milán-Carrillo, J. (2010). Phenolic content and antioxidant activity of tortillas produced from pigmented corns processed by conventional nixtamalization of extrusion cooking. *Journal of Cereal Science*, 52(3), 502-508. doi: <https://doi.org/10.1016/j.jcs.2010.08.010>
- Nouhi, S., Kwaambwa, H. M., Gutfreund, P., & Rennie A. R. (2019). Comparative study of flocculation and adsorption behavior of water treatment proteins from *Moringa peregrina* and *Moringa oleifera* seeds. *Scientific Reports*, 9, 17945. doi: <https://doi.org/10.1038/s41598-019-54069-2>
- Olson, M. E., & Fahey, J. W. (2011). *Moringa oleifera*: Un árbol multi usos para las zonas tropicales secas. *Revista Mexicana de Biodiversidad*, 82(4), 1071-1082. doi: <https://doi.org/10.22201/ib.20078706e.2011.4.678>
- Ou, B., Hampsch-Woodill, M., & Prior, R. L. (2001). Development and validation of an improved oxygen radical absorbance capacity assay using fluorescein as the fluorescent probe. *Journal of Agricultural and Food Chemistry*, 49(10), 4619-4626. doi: <https://doi.org/10.1021/jf010586o>
- Ouédraogo, M., Lamien-Sanou, A., Ramdé, N., Ouédraogo, A. S., Ouédraogo, M., Zongo, S. P., Gombri, O., Duez, P., & Guissou, P. I. (2011). Protective effect of *Moringa oleifera* leaves against gentamicin-induced nephrotoxicity in rabbits. *Experimental and Toxicologic Pathology*, 65(3), 335-339. doi: <https://doi.org/10.1016/j.etp.2011.11.006>
- Pinheiro, P. M., Farias, D. F., Oliveira, J. T., & Urano, A. F. (2008). *Moringa oleifera*: Bioactive compounds and nutritional potential. *Revista de Nutrição*, 21(4), 431-437. doi: <http://dx.doi.org/10.1590/S1415-52732008000400007>
- Price, M. L., Van Scoyoc, S., & Butler, L. G. (1978). A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. *Journal of Agricultural and Food Chemistry*, 26(5), 1214-1218. doi: <https://doi.org/10.1021/jf60219a031>
- Shi, L., Mu, K., Arntfield, S. D., & Nickerson, M. T. (2017). Changes in levels of enzyme inhibitors during soaking and cooking for pulses available in Canada. *Journal of Food Science and Technology*, 54(4), 1014-1022. doi: <https://doi.org/10.1007/s13197-017-2519-6>

- Singh, R. S. G., Negi, P. S., & Radha, C. (2013). Phenolic composition, antioxidant and antimicrobial activities of free and bound phenolic extracts of *Moringa oleifera* seed flour. *Journal of Functional Foods*, 5(4), 1883-1891. doi: <https://doi.org/10.1016/j.jff.2013.09.009>
- Singleton, V. L., Orthofer R., & Lamuela-Raventós, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Methods in Enzymology*, 299, 152-178. doi: [https://doi.org/10.1016/S0076-6879\(99\)99017-1](https://doi.org/10.1016/S0076-6879(99)99017-1)
- US Department of Agriculture, Agricultural Research Service (2010). USDA Database for the oxygen radical absorbance capacity (ORAC) of selected foods, Release 2. Nutrient Data Laboratory Homepage: <http://www.drmarcofranzreb.com/wp-content/uploads/2013/04/ORAC-de-alimentos-2.pdf>
- Vaintraub, I. A., & Lapteva, N. A. (1988). Colorimetric determination of phytate in unpurified extracts of seeds and the products of their processing. *Analytical Biochemistry*, 175(1), 227-230. doi: [https://doi.org/10.1016/0003-2697\(88\)90382-X](https://doi.org/10.1016/0003-2697(88)90382-X)
- Vasanth, K., Minakshi, G. C., Ilango, K., Kumar, R. M., Agrawal, A., & Dubey, G. P. (2015). *Moringa oleifera* attenuates the release of pro-inflammatory cytokines in the lipopolysaccharide-stimulated human monocytic cell line. *Industrial Crops and Products*, 77(23), 44-50. doi: <https://doi.org/10.1016/j.indcrop.2015.08.013>
- Venkatachalam, M., & Sathe, S. K. (2006). Chemical composition of selected edible nut seeds. *Journal of Agricultural and Food Chemistry*, 54(13), 4705-4714. <https://doi.org/10.1021/jf0606959>
- Welham, T., & Domoney, C. (2000). Temporal and spatial activity of a promoter from a pea enzyme inhibitor gene and its exploitation for seed quality improvement. *Plant Science*, 159(2), 289-299. doi: [https://doi.org/10.1016/S0168-9452\(00\)00358-7](https://doi.org/10.1016/S0168-9452(00)00358-7)
- Xu, B. J., & Chang, S. K. C. (2007). A comparative study on phenolic profiles and antioxidant activities of legumes as affected by extraction solvents. *Journal of Food Science*, 72(2), 159-66. doi: <https://doi.org/10.1111/j.1750-3841.2006.00260.x>
- Yassa, H. D., & Tohamy, A. F. (2014). Extract of *Moringa oleifera* leaves ameliorates streptozotocin-induced Diabetes mellitus in adult rats. *Acta Histochemica*, 116(5), 844-854. doi: <https://doi.org/10.1016/j.acthis.2014.02.002>