Original Research Article

Morphological and biochemical variability of the fruit and seed kernel of Balanites aegyptiaca from Burkina Faso.

ABSTRACT

Balanites aegyptiaca fruits come in various shapes, which can be beneficial for breeding and industrial production purposes.This study aimed to estimate the morphological and biochemical variability of the fruit and seed kernel of *B.aegyptiaca* based on their shape. Six shapes, namely BLS (big long sharp), BSR (big sharp round), SLR (small long round), BSH (big short hollow), BLR (big long round) and SSR (small short round), were collected. The length, width and thickness of fruits/seeds and the weight of 100 fruits were assessed using a caliper and a scale. Physicochemical properties were determined using official AOAC and AOCS methods. The fatty acids were determined according to the methods of the IUPAC standards. Amino acids were analyzed using the non-derivatization LC-MS/MS method. Mineral and trace element analyses were conducted using inductively coupled plasma emission spectrometry ICP-OES. The results showed significant differences ($P<0.001$) in the length, width, thickness and weight of 100 fruits across the shapes. The BSH shape had the highest crude fat content and energy value, while the BLS shape had the least favorable profile due to high moisture and acid index.Seventeen fatty acids, 18 amino acids, and 23 minerals were identified, with significant variations observed among the shapes. The predominant fatty acid was cis-9,12-linoleic acid, ranging from 295458.09±100 mg/kg (BLS) to 194138.63±39 mg/kg (BLR).The BLS shape was characterized by the presence of cis-9,12,15-linolenic acid and stearic acid. Cysteine was the most abundant amino acid ranging from 615418.83±29 mg/kg (BSR) to 339480.67±81 mg/kg (SSR). Potassium was the most prevalent mineral, followed by phosphorus, calcium, and magnesium. The BLS shape was particularly rich in various minerals. These results highlight the significant morphological and biochemical variability of *B.aegyptiaca* in fruit, seed and kernel variants.

Keywords:Balanites aegyptiaca, Shape, Physiochemistry, Fatty acid, Amino acid, Mineral

1. INTRODUCTION

In Burkina Faso, *Balanites aegyptiaca* (L.) Del. (Zygophyllaceae), also known as desert date palm and commonly known as "*Kiɛglga*" in the local language Mooré, is a plant characteristic of the Sahelian zone found in the Sudanian zone[1].

The chemical composition of the seeds and oil obtained from the seed of this indigenous plant indicates nutritional and therapeutic values. As a multi-purpose local plant,*B. aegyptiaca*is used for food and traditional medicine[2][3]. Increases in the prices of raw materials in Africa and particularly in Burkina Faso combined with the stagnant price of cotton to arouse interest in this oilseed whose cakes are used as raw material in the oil production [4]. As for alternatives, the seeds of *B. aegyptiaca* could play an important role as a raw material in producing oil for food due to its nutritional properties and its high oil contents.

B. aegyptiaca seed oils contain essential nutrients for humans, such as polyunsaturated fatty acids (linolenic and linoleic fatty acids), fat-soluble vitamins (vitamins E, A, D and F) [5].Therefore, fixed oil extracts from seeds play an important role in diet and health[6]. The oil also contains a significant oleic acid content so that it would be recommended as a table oil. Other bioactive substances and phytochemicals have also been found in *B.*

aegyptiaca oil. The phytochemical screening of *B. aegyptiaca* seed oil on variants in Burkina Faso showed a significant content of phenolic and flavonoid compounds, giving the oil substantial free radical scavenging capacities (DPPH and ABTS) [7]. *B. aegyptiaca* seed oils are rich in phytochemicals[8]and essential fatty acids, giving them medicinal properties and can be used as functional foods[9].

Thus, in Burkina Faso, a general study was carried out on *B. aegyptiaca* in the country's south-central region and revealed the biochemical potential of kernels from the seeds of the species[10]. However, in this study, the entire region was not targeted and the possibility of classifying kernels based on the shapes of the seeds from the fruits about their biochemical potential does not appear. Furthermore, from an ecological point of view, the species is distributed naturally[11]and is rarely cultivated by the local population. That said, the species could constitute a source of raw material for oil supply. It is, therefore, important to characterize the morphological and biochemical variability of the oils derived from the shapes of the kernels of this species in Burkina Faso to exploit better and promote it. This characterization of shapes can contribute to better domestication of the species [12] and this promotes industrial exploitation and the perpetuation of the species. This study aims to estimate the morphological and biochemical variability of the fruit and seed kernel of *Balanites aegyptiaca based on their shape*.

2. MATERIAL AND METHODS

2.1 Sampling sites and fruit shape size measurement

Sampling was conducted at six sites in the south-central region of Burkina Faso (Figure 1).

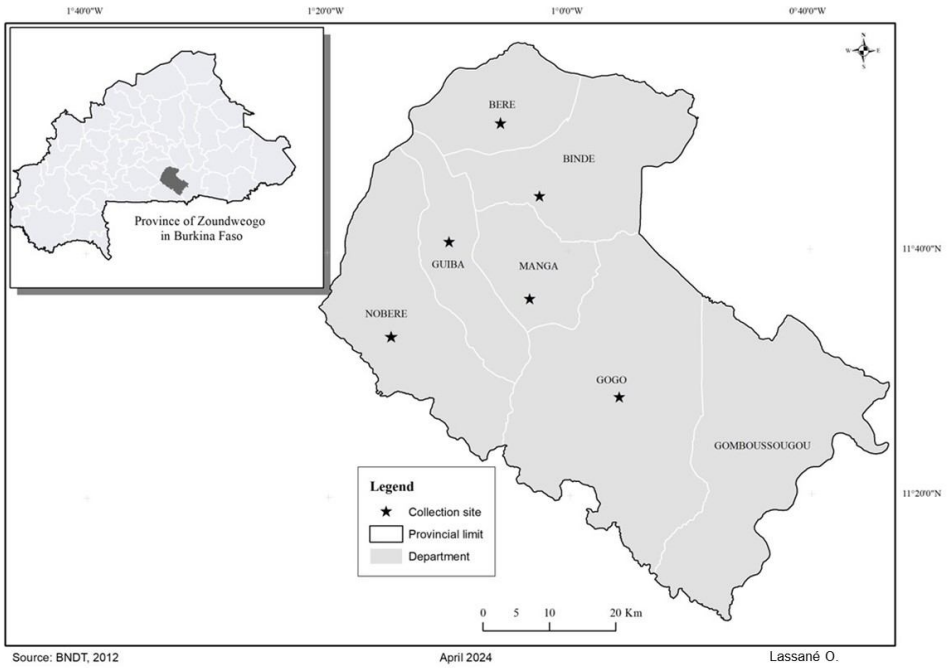

Figure 1. Sampling sites.

These sites had variable annual precipitation averages ranging from 600 mm to 900 mm and were characterized by granitic arenaceous soils and lithosols, often covered by a more or less thick crust. The sampling process involved randomly selecting trees to ensure a representative sample. In November 2022, 50 kg of fruits per shape were collected from the sites (with different weights depending on the site) in south-central Burkina Faso (see Table 1), with each type of fruit coming from different trees.

Table 1. Quantity (kg) of *B.aegyptiaca* fruit shapes collected according to sites.

Collection site	BLR	BLS	BSH	BSR	SLR	SSR
Béré	12.50	10.00	25.00	x	x	12.50

Bindé	12.50	10.00	x	12.50	12.50	12.50
Gogo	12.50	10.00	25.00	12.50	12.50	12.50
Guiba	x	x	x	12.50	12.50	x
Manga	12.50	10.00	x	x	x	12.50
Nobéré	x	10.00	x	12.50	12.50	x
Total per shape	50.00	50.00	50.00	50.00	50.00	50.00

Legend: X: Fruit shapes not found on the site

After harvesting, a total of 300 kg of fruit was collected. Before being transported to the laboratory, the fruits were sorted manually to remove any damaged ones. Upon reaching the laboratory, 2 kg of fruits of each type were chosen and combined to create a composite sample, which was then used for further physical and biochemical analyses. The harvested fruits were classified into six batches based on their shape: BLS (big long sharp), BSR (big long round), SLR (small long round), BSH (big short hollow), BLR (big long round) and SSR (small short round) (Figure 2).

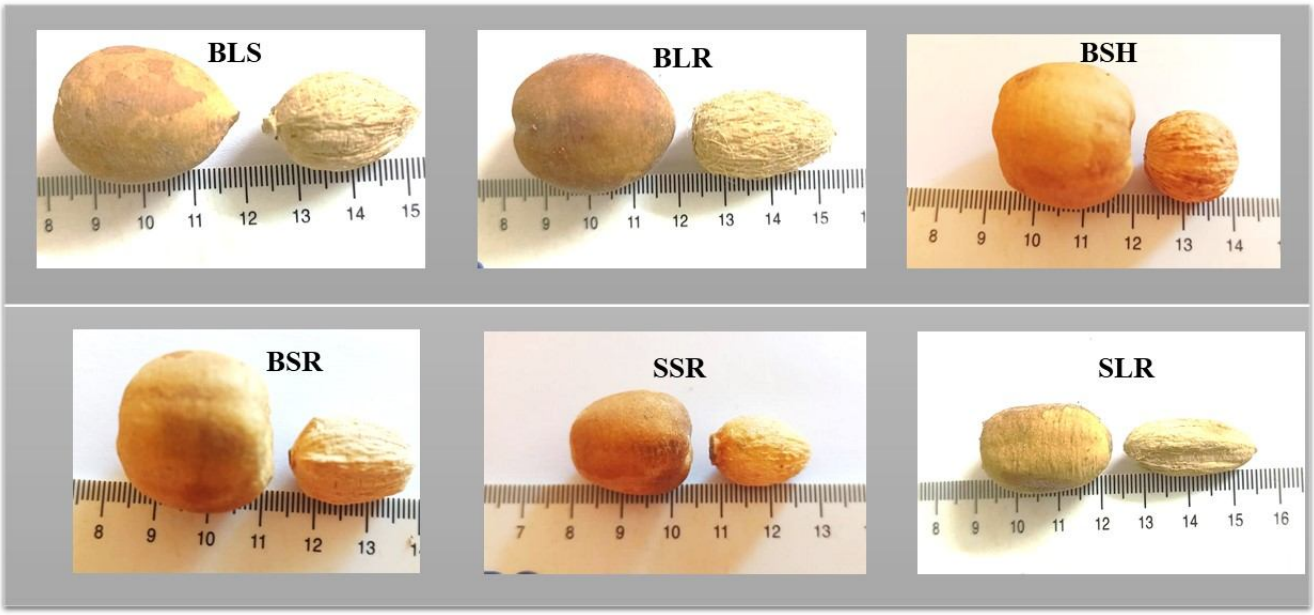

Figure 2. Fruits and seeds of *B.aegyptiaca.*
Legend: BLS: Big Long Sharp; BSR: Big Sharp Round; SLR: Small Long Round; BSH: Big Short Hollow; BLR: Big Long Round; SSR: Small Short Round.

2.2 Sample preparation for biochemical analysis

After that, the fruit samples were thoroughly processed, i.e., washed with distilled water, drained and air-dried under laboratory conditions (22-23°C) for a week. The dried seeds were shelled and ground with a Moulinex grinder (GT550, Zurich, Switzerland), then sieved using a 1 mm mesh sieve and stored at 18 °C until analyses.

2.3 Physicochemical characterization

Moisture content, ash, carbohydrates, pH, acid number, crude protein, crude fat and energetic value were characterized according to the method of Bazongo *et al*. [10]. Analysis was done in triplicate.

The AOAC official method was employed to determine moisture, protein, ash and lipid contents. Moisture was determined gravimetrically after drying the sample overnight at 105°C. The Kjeldahl method was used to determine the total protein content by multiplying the % total nitrogen by 6.25. Ash content was quantified by incinerating the sample overnight at 550°C. Carbohydrate content was estimated by the difference in mean values. The pH was determined according to the method described by Nout *et al*. [13]. A total of five (5 g) grams of the sample was placed in 30 ml of alcohol at 96°C and exposed to a boiling bath for 6 h. After that, a pH meter calibrated with SI Analytics® was used to determine the pH of the sample. Total crude was determined by a Soxhlet extractor with petroleum ether for 6 h and solvent was removed using a

rotary vacuum evaporator. The acid number was determined according to the AOCS official method Ca 3a-63 (AOCS, 1998). The energy values of the samples were determined according to Merrill and Watt[14]. This value was estimated by multiplying the actual nutritional values of proteins, lipids and carbohydrates with the corresponding Atwater factors:
Caloric content (Kcal/100 g) =Protein content x 4 Kcal + Lipid content x 9 Kcal+ Carbohydrate content x 4 Kcal (1).

2.4 Determination of fatty acids

Fatty acids were determined according to IUPAC standards methods with a few modifications [15] and following the method used by Bazongo *et al*.[10]. Extraction was done by adding petroleum ether in a few samples for 3 h, then a sodium hydroxide methanol solution (2%) with 8 mL was added to the fat extract.
The procedure involved connecting all of this to the reflux condenser, which was then heated to reflux on the water bath at 80°C until the oil droplets disappeared. Boron trifluoride methanol solution (15%) was added for 7 mL in the upper end of the reflux condenser and the reflux was continued in the water bath (80°C) for 2 min. Subsequently, a few quantities of water were used to flush the reflux condenser. The heating was stopped and the flask was removed from the water bath and cooled to room temperature. Then, about 10 mL to 30 mL of n-heptane was added and stirred for 2 min, followed by the addition of saturated sodium chloride solution. Approximately 5 mL of the top n-heptane extraction solution was absorbed, mixed with 3-5 g of anhydrous sodium sulfate in a 25 mL test tube, shaken for 1 min, left to stand for 5 min, and the upper solution was absorbed into the sample vial for further analysis.
Gas-liquid chromatography (GLC) was performed using the Shimadzu GC-2010 Pro. The column was a SH-Rt-2560 type with a length of 100 m, a film thickness of 0.20 µm and an inner diameter of 0.25 mm. The column temperature was initially set at 100°C, maintained for 8 min and then increased to 240°C at a rate of 3°C/min for 15 min. The injector temperature was 240°C, the injection volume was 1 µL and the flow rate was 1 mL/min. The detector temperature was 245°C. Experimentation was done three time.

2.5 Determination of amino acids

Amino acids were determined using the non-derivatization liquid chromatography-tandem mass spectrometry (LC-MS/MS) method, as described by Dearmond and Bunch[16]and Bazongo *et al*. [10]. Samples were first digested. The digestion solution consisted of hydrochloric acid and water mixed 1 to 1 (1‰ phenol). Then, phenol (1/1000 of the sample weight) was added. A uniform amount of sample (around 1 mg) was taken and mixed with 10 ml of digestion solution. The whole is sealed by injecting nitrogen into the digestion tube to replace the air. The solution was dissolved at 110°C for 24 h, cooled and filtered. After 1 ml of filtrate was dried at 110°C, redissolved with 1 ml of diluted hydrochloric acid (0.1 mol/L). Afterward, the machine is put on after being filtered with a 0.22 µm membrane.
Amino acid analysis was performed using the Shimadzu 8050 LC-MS/MS instrument. The column was Endeavorsil type C18 1.8 µm 100*2.1 mm with a flow rate of 0.2 ml/min. The column temperature was 40℃ with a collection time of 15 minutes (Table 2). The mobile phase was prepared using a blend of acetonitrile with 0.1% formic acid (v/v). The mass conditions of electrospray ionization were as follows: interface temperature was 300℃, desolvation temperature was 526℃ and DL temperature was 250℃. With an atomizing gas flow of 3.00 L/min, airflow heating of 10.00 L/min, heating block temperature of 400℃ then drying air flow of 10 .00 L/min. Experimentation was done three times.

Table 2. Gradient elution.

Time/min	Flow rate mL/min)	Phase A %	B phase %
0.00	0.20	98.00	2.00
5.00	0.20	40.00	60.00
10.10	0.20	98.00	2.00
15.00	0.20	98.00	2.00

2.6 Determination of minerals

Mineral and trace element analyses were performed using inductively coupled plasma emission spectrometry (ICP-OES) as described by Selmi *et al*. [17] with some modifications and following the method used by Bazongo *et al*. [10].The samples were digested with acid beforehand. The 0.5 samples were weighed (accurate to within 0.001 g) in a glass or polytetrafluoroethylene digestion vessel. A mixed nitric acid (10 ml)-perchloric acid (10+1) solution was added and then dissolved on the electric hotplate. When the digestion solution turned brown and black during the process, about 1 mL of acid was mixed in until white smoke was emitted. When the solution became colorless and transparent or slightly yellow, it was cooled and filled with water up to 25 mL. A blank test was carried out simultaneously.
The ICP-OES instrument used was the PerkinElmer (PE) AVIO200 model. Instrumental analysis conditions were set as follows: argon was used; the plasma gas flow rate was 12 L/min, the auxiliary gas flow was 0.2 L/min and the atomizer gas flow rate was 0.6 L/min. The output power was 1300 W, with a pump flow rate of 1.5 mL/min. The carrier gas, more than 99.996% argon, operated at 0.6-0.8 MPa, while the purge gas, more than 99.999% argon or nitrogen, was set at 0.3-0.8

MPa. The air compressor pressure was 0.6-0.8 Pa and a 20°C cooling water circulator was utilized. A total of 63 minerals were screened during the analysis. Analysis was done in triplicate.

2.7 Statistical analysis

The Minitab 19.1 software was used to carry out an analysis of variance (ANOVA) to find out if significant differences exist between the varieties for the characteristics studied. The separation of means was done using the Tukey test at the 5% threshold. The SIMCA 18 software was used for a PCA biplot analysis to identify the particularities that exist in the relationships between individuals and variables.

3. RESULTS AND DISCUSSION

3.1 Fruit shape size

The fruit shapes BLS, BSR,SLR, BSH, BLR and SSR size are summarized in Table 3.

Table 3. Fruit shape parameters.

Shape	Length (cm)	Width (cm)	Thickness (cm)	Weight of 100 fruits (g)
BLS	2.9 ± 0.25^{a}	1.47 ± 0.33^{a}	1.88 ± 0.23^{b}	640.00 ±5.00^{b}
BLR	2.76 ±0.23^{a}	1.47 ± 0.27^{a}	2.05 ± 0.50^{ab}	760.00±2.00^{a}
SLR	2.34± 0.54^{ab}	0.93 ± 0.07^{b}	1.33 ± 0.09^{c}	620.00 ±10.00^{c}
BSR	2.12 ± 0.70^{b}	0.58± 0.04^{c}	2.11 ± 0.11^{ab}	620.00 ±0.00^{b}
BSH	2.12± 0.19^{b}	1.08 ± 0.22^{b}	1.56 ± 0.06^{ab}	640.00 ± 8.00^{b}
SSR	2.01± 0.3^{b}	1.54 ± 0.31^{a}	2.22 ± 0.27^{a}	380.00 ±6.00^{c}

Means not sharing any letters are significantly different.

There was a significant difference (P<0.001) between fruit shapes regarding the length, width, thickness and weight of 100 fruits. BLS and BLRfruit shapes were elongated measuring2.9±0.25 cm and 2.76±0.23 cm in length, respectively. The width was ranged between 1.54±0.31 cm (SSR)and 0.58±0.04 cm (BSR). The maximum thickness of the fruit was observed in the shape SSR (2.22±0.27 cm), while the minimum thickness of the fruit was found in the Shape SLR (1.33±0.09 cm). The weight of 100 fruits of the six shapes fluctuated between 760±2 g (BLR) and 380±6 g (SSR).
The study revealed statistically significant variations (p<0.001) in seed parameters (Table 4). Seed shapes BLR (2.70±0.15 cm) and BLS (2.66±0.08 cm) had the greatest seed lengths, while SSR (1.08±0.13 cm) and BLS (0.72±0.05 cm) had the greatest widths. In addition, seed shape SSR (1.74±0.05 cm) and BLS (1.68±0.04 cm) had the thickest seeds. The fruit length (2.4-3.6 cm)and width (1.00-1.27 cm) were close to the value found in Hamada et al.[18], which characterized fruits from Egypt and Saudi Arabia. The seed's length was close to those from Niger found by Amadou [19] with a value of 1.5-3 cm and the diameters were less wide than the dimensions found byAbdoun [20] around 1 to 1.53 cm in their study about morphological and chemical constituents from Sudan. The difference found through these studies can be explained by the geographical location and the type of climate.

Table 4. Seed shape parameters.

Shape	Length (cm)	Width (cm)	Thickness (cm)
BLS	2.66±0.08^{a}	0.72± 0.05^{a}	1.68±0.04^{a}
BLR	2.70±0.15^{a}	0.66±0.11^{b}	1.3±0.10^{b}
SLR	2.26±0.54^{b}	0.2±0.00^{c}	0.66±0.10^{c}
BSR	1.96±0.08^{c}	0.14 ±0.02^{c}	1.2±0.07^{b}
BSH	1.93±0.10^{bc}	0.66±0.05^{b}	1.32±0.10^{c}

SSR	1.88±0.11[c]	1.08±0.13[a]	1.74±0.05[a]

Means not sharing any letters are significantly different.

3.2 Physicochemical profile

The physicochemical profile of the kernel of *B. aegyptiaca* showed no significant difference (P>0.05) among the shapes concerning ash and pH (Table 5). Parameters like moisture, acid number, crude protein, crude fat, carbohydrates and energetic value indicated significant differences (P<0.001) between the shapes. Moisture content was highest in the BLS shape (3.90±0.21%).

The highest moisture content was found in the BLS shape with a content up to 3.90±0.21%. The shape with the high acid number was from BLS (5.16 mg KOH/g) and the low acid number was SSR (2.27±0.03mg KOH/g). Crude protein was higher in the SLR shape (29.97±0.02%) than in the other shape. Crude fat ranged between 48.9±0.1% (BSH) and 38.02±0.0% (SLR). The highest value of carbohydrates was recorded in the SLR shape (28.39±0.52%) and low in the shape from BSH (20.68±0.03). The shape energetic value varied between 630.7±0.03% (BSH) and 574.4±0.00 (SLR).

The results indicate that while ash and pH are not significant factors, parameters such as moisture, acid number, crude protein, crude fat, and energetic value are important in assessing the quality and potential applications of *B. aegyptiaca* kernel oil. The BSH shape appears to have the most desirable characteristics, with high crude fat and energetic value, while the BLS shape has the least favorable profile due to its high moisture and acid number. The acid number was high, ranging from approximately 0.5 to 0.7 as reported by Amadou et al. [21]. This can be linked to the type of extraction used during the process. The moisture content was high regarding other studies, which found values between 0.1 and 0.4% [22][21].In fact, drying conditions can affect moisture content in *B. aegyptiaca* seeds [23].

Table 5. Physicochemical profile of *B. aegyptiaca* kernels according to seed and fruit shape.

Morpho types	Moisture (%)	Ash (%)	pH	Acid number (mg KOH/g)	Crude protein (%)	Crude fat (%)	Carbohydrates (%)	Energetic value (%)
BLS	3.90±0.21[a]	3.90±0.40[a]	5.84±0.14[a]	5.16±0.00[a]	28.95±0.00[b]	42.29± 0.00[b]	24.86±0.00[c]	595.8±0.01[c]
BSR	2.95±0.00[a]	3.7±0.30[a]	5.85±0.25[a]	5.02±0.02[a]	28.72±0.72[b]	41.5±1.50[b]	26.08±0.00[b]	592.7±0.00[e]
SLR	3.33±0.20[ab]	3.93±0.00[a]	5.78±0.08[a]	5.00±0.00[a]	29.97±0.02[a]	38.02±0.01[c]	28.39±0.52[a]	574.4±0.00[f]
BSH	3.14±0.01[ab]	3.62±0.33[a]	5.86±0.04[a]	3.00±0.20[c]	26.98±0.03[cd]	48.9±0.10[a]	20.68±0.03[d]	630.7±0.03[a]
SSR	3.08±0.02[bc]	3.94±0.00[a]	5.93±0.06[a]	2.27±0.03[d]	27.66±0.15[c]	42.24±0.05[b]	26.1±0.08[b]	595.5±0.01[d]
BLR	2.63±0.01[c]	3.7±0.00[a]	5.92±0.00[a]	3.56±0.02[b]	26.74±0.04[d]	48.71±0.03[a]	20.86±0.00[d]	628.8±0.01[b]

Means not sharing any letters are significantly different.

3.3 Fatty acid profile of *B. aegyptiaca* kernel oil

Sixteen fatty acids were identified in *B. aegyptiaca* kernel oil regarding shapes, except one shape (BLS) with 17 fatty acids (Table 6). The fatty acids characterized in the six shapes showed a significant (P<0.001) difference between the shapes. There was 9 Saturated fatty acid: behenic acid (C22:0); myristic acid (C14:0), lauric acid (C12:0), pentadecanoic acid (C15:0), palmitic acid (C16:0), heptadecanoic acid (C17:1), stearic acid (C18:0), arachidic acid, decanoic acid. Two monounsaturated fatty acids identified were palmitoleic acid and cis-9-oleic acid (C18:1n-9). There were also, 6 polyunsaturated acids: Cis-9,12-linoleic acid (C18:2(n-6)), cis-11-arachidonic acid (C20:4 (n-6)), cis-9,12,15-linolenic acid(C18:3 (n-3)), eicosanodienoic acid (C20:2), arachidonic acid (20: 4) and docosadienoic acid (C22:2).

The main fatty acids were the Cis-9,12-linoleic acid, which ranged between 295458.09±100 mg/kg (BLS) and 194138.63±39 mg/kg (BLR). There was cis-9-oleic acid (ranged between 195422.92±10 mg/kg for the BLR shape) and 40828.74±21 mg/kg for the BSH shape. This work proved the richness of *B. aegyptiaca* kernel oil in fatty acids. This is

confirmed by the work of Ibrahim *et al.*[24],which indicated the richness of kernel oil of *B. aegyptiaca*. Our results are in line with the work of Morgan *et al*. [25], which showed that the main unsaturated fatty acid was linoleic acid. The high content of unsaturated fatty acids, particularly linoleic acid, makes *B.aegyptiaca* seed oil nutritionally valuable. For research into oil rich in omega 6 (essential fatty acid) relative to Cis-9,12-linoleic acid, the BLS shape followed by the BSR shape are recommended given their high content compared to other shapes. For needs in cis-11-arachidonic acid, also an omega 6, the BLR shape is was recommended. In terms of oil richness in omega 3 relative to cis-9,12,15-linolenic acid, BLR shape almonds can be recommended.

Table 6. Fatty acid profile and oil content (mg/kg) of *B. aegyptiaca* kernels according to seed and fruit shape.

Fatty acids	BLS	BSR	SLR	BSH	SSR	BLR
Arachidic acid (C20:0)	1540.81±40.80^{b}	1486.25±60.00^{b}	1621.51±12.00^{ab}	1332.82±32.80^{c}	1707.49±7.5.00^{a}	1084.31±82.30^{d}
Arachidonic acid (20: 4)	28.69±0.00^{b}	23.66±3.00^{b}	48.16±8.00^{a}	22.66±0.00^{b}	ND	26.34±0.00^{b}
Behenic acid (C22:0)	281.99±3.99^{b}	277±7.00^{b}	309.12±0.00^{ab}	222.24±0.00^{c}	334.91±34.90^{a}	276.27±0.00^{b}
Cis-9,12,15-linolenic acid (C18:3 (n-3))	366.63±66.30^{c}	426.19±26.20^{bc}	449.81±0.00^{ab}	352.8±0.00^{c}	454.37±0.00^{ab}	512.34±0.00^{a}
Cis-9,12-linoleic acid (C18:2(n-6))	295458.09±100.00^{a}	246112.80 ±80.00^{b}	195862.9±63.00^{d}	231251.7±51.00^{c}	205253.97± 54.00^{c}	194138.63±39.00^{d}
Cis-9-oleic acid (C18:1n-9)	109426.89±117.00^{c}	116412.55±13^{b}	96114.12±10.00^{d}	40828.74±21.00^{f}	76293.31±93.00^{e}	195422.92±10.00^{a}
Cis-11-arachidonic acid (C20:4(n-6))	442.22±42.20^{c}	510.71±10.20^{b}	503.21±5.80^{b}	424.35±24.30^{c}	506.21±6.21^{b}	605.96±5.96^{a}
Decanoic acid (C10:0)	44.67±0.00^{ab}	43±3.00^{ab}	42.49±2.00^{b}	30.57±0.57^{c}	41.62±0.00^{b}	46.84±0.00^{a}
Docosadienoic acid (C22:2)	91.03±0.00^{c}	133.5 ± 33.00^{b}	93.31±0.31^{c}	194.8±0.00^{a}	127.52±7.00^{bc}	104.02±4.00^{bc}
Eicosanodienoic acid (C20:2)	73.39±3.00	ND	ND	ND	ND	ND
Heptadecanoic acid (C17:1)	454.57±4.57^{b}	469.36±9.36^{b}	491.98±0.02^{ab}	478.75±0.04^{b}	555.64±52.00^{a}	476.58±6.00^{b}
Lauric acid (C12:0)	25.62±0.00^{b}	30. 87±0.70^{b}	29.18±0.00^{a}	24.02±0.40^{b}	26.05±0.00^{b}	32.01±0.00^{a}
Myristic acid (C14:0)	299.00±7.55^{b}	296.7±6.66^{b}	292.7±0.80^{b}	323.5±0.00^{a}	274.3±3.20^{c}	265.10±5.11^{c}
Pentadecanoic acid (C15:0)	31.67±1.67^{a}	31.00 ± 1.00^{ab}	29.18±0.18^{b}	29.22±0.22^{b}	31.45 ± 0.45^{ab}	30.43±0.47^{ab}
Palmitic acid (16:0)	62812.6±47.10^{b}	58771.5±1.70^{d}	54143.04±3.00^{e}	61497.19±100.00^{c}	49335.23±35.20^{e}	65836.02±6.00^{a}
Palmitoleic acid (Cis-16:1n-7)	582.87±0.95^{d}	599.62±0.01^{d}	649.78±9.78^{c}	718.82±8.82^{b}	512.98±12.98^{e}	993.8±3.80^{a}
Stearic acid (18:0)	48285.08±32.12^{a}	41688.99±18.00^{b}	41490.43±27.40^{c}	40841.59±0.10.00^{d}	40941.77±8.20^{d}	39528.5±8.00^{e}

Means not sharing any letters are significantly different. ND: Not Detected.

3.4 Amino acids profile

B. aegyptiaca kernel shapes showed 18 amino acids, including the 9 essential and 9 non-essential amino acids (Table 7). The higher amino acid was cystine with a value comprised between 615418.83±29 mg/kg (BSR) and 339480.67±81 mg/kg (SSR) followed by glutamine (44308.28±101.3 (BLS) for the high value and 29285.45±108.5 (SSR) corresponding to the low value).

The most important amino essentials were phenylalanine (with a value between 13324.03±43 mg/kg (BSR) and 10332.24±31 mg/kg (SSR)) followed by leucine (with a value of 13262.05±88.70 mg/kg (BSR) and 10315.81±12.33 mg/kg (SSR)).

The case of chia seeds and Sea-buckthorn oil seed which also revealed the presence of 18 amino acids, similar to *B. aegyptiaca*studied, as noted in the works by Zielińska and Nowak [26] and Ashura *et al*. [27]. The kernel oil from the seed contained the 9 essentials that the human body cannot synthesize and must be obtained from the diet. These include phenylalanine, leucine, isoleucine, lysine, methionine, threonine, tryptophan, valine, and histidine. Essential amino acids are essential for building proteins, transmitting cellular signals, controlling gene activity, and regulating crucial metabolic processes that improve general well-being, facilitate growth, support development and promote reproductive health[28]; [29]. This indicates that the seed of *B. aegyptiaca* would have therapeutic values to be explored for the well-being of the population. The kernel contains non-essential amino acids while some non-essential amino acids, such as arginine, glutamine, glutamate, glycine, and proline, play crucial roles in humans beyond their protein-building functions [30]. Notably, arginine serves as a precursor for the production of nitric oxide, polyamines, and proline, which are essential for supporting placental and fetal growth during pregnancy[30]. According to Holeček[31]amino acid supplements can effectively prevent nutritional deficiencies and provide various benefits, including relieving fatigue, facilitating ammonia detoxification, stimulating protein synthesis, and promoting muscle growth. This reinforces our idea that seed oil is nutritional. The work of Wu [28] showed that amino acid imbalances or deficiencies can have significant consequences on health. For example, arginine deficiency can negatively impact sperm quality and embryo/fetal survival, even if nitrogen balance is maintained. Kernels contain arginine and can help fill deficiencies in this amino acid, especially those in BLS Shapes with a higher content.

Table 7. Amino acid profile and content (mg/kg) of *B. aegyptiaca* kernels according to fruit and seed shape.

Shape	BLS	BSR	SLR	BSH	SSR	BLR
Alanine	7309.73±29.70^{b}	7587.06±87.10^{a}	7182.02±82.00^{b}	6900.71±0.00^{c}	6558.78±0.00^{d}	7564.21±0.00^{a}
Arginine	43561.12±100.10^{a}	43244.31±44.30^{b}	37644.76±54.80^{c}	34328.54±58.50^{e}	29239.69±51.70^{f}	36582.25±102.30^{d}
Aspartic acid	17739.46±51.50^{b}	20519.2±21.20^{a}	16387.02±87.00^{d}	16714.61±3 6.20^{c}	15439.94±21.00^{e}	16819.22±34.20^{c}
Cystine	611371.49±50.00^{b}	615418.83±29.00^{a}	503984.37±84.00^{c}	436919.52±110.00^{d}	339480.67±81.00^{e}	437056.74±46.00^{d}
Glutamine	44308.2±101.30^{a}	41923.47±64.50^{b}	37522.03±100.00^{c}	33361.91±61.90^{e}	29285.45±108.50^{f}	35282.27±104.30^{d}
Glycine	14658.3±0.00^{b}	15193.03±0.10^{a}	13327.26±0.30^{d}	12430.54±0.45^{e}	12683.15±0.18^{e}	14151.02±0.23^{c}
Histidine	2795.56±95.70^{a}	2852.12±12.12^{a}	2725.62±45.60^{ab}	2464.91±14.91^{c}	2440.63 ±40.60^{c}	2648.95±49.00^{b}
Isoleucine	7220.27±39.40^{b}	7615.1±23.20^{a}	6919.42±60.40^{c}	6385.32±23.20^{e}	6515.62±85.30^{d}	6904.16±0.21^{c}
Leucine	12209.25±26.30^{b}	13262.05± 88.70^{a}	11477.93±79.00^{c}	10951.98±45.60^{d}	10315.81±12.33^{d}	10868.24±21.33^{d}
Lysine	6687.73±0.15^{a}	6430.47±0.00^{c}	6213.4±43.00^{bc}	6414.82±43.20^{c}	5874.3±16.19^{d}	6563.4±105.70^{c}
Methionine	427.38±27.40^{ab}	448.28±4.28^{a}	419.92±29.90^{ab}	379.05±24.10^{c}	422.48±0.00^{ab}	424.57±0.00^{ab}
Proline	2031.15±31.20^{b}	2176.82±8.82^{a}	2013.7±13.00^{b}	1861.7±61.30^{c}	1705.91±27.90^{d}	2224.75±100.00^{a}
Serine	6643.25±3.23^{b}	7266.52± 6.52^{a}	6213.4±13.40^{d}	6414.82±100.00^{c}	5874.3±22.30^{e}	6563.4±63.40^{b}
Threonine	5279.16±150.00^{b}	5711.72±0.00^{a}	5273.52±73.50^{b}	5258.47±0.00^{b}	5040.00±23^{b}	5382.24±82.20^{ab}
Tyrosine	5193.3±93.30^{b}	5471.71±8.29^{a}	4958.93 ± 58.10^{c}	4467.42±66.20^{d}	4313.53±24.50^{d}	4838.34±38.30^{c}
Phenylalanine	12623.34±112.50^{b}	13324.03±43.00^{a}	11375.01±95.00^{c}	11050.27±50.20^{d}	10332.24±31.00^{e}	11226.77±66.30^{cd}
Tryptophan	121.37±21.20^{a}	76.77±6.80^{bc}	85.19±6.50^{bc}	65.89±6.20^{c}	136.58±15.25^{a}	109.64±8.36^{ab}
Valine	2346.5±55.00^{b}	2500.35±11.80^{a}	2256.93±56.00^{bc}	2146.6±50.60^{c}	2160.7±47.00^{c}	2266.66±63.40^{bc}

Means not sharing any letters are significantly different.

3.5 Minerals profile

Twenty-one (21) minerals were characterized in the six shapes from the kernel of *B. aegyptiaca*. While in shape BLS, 23 minerals were found (Table 8). The most abundant mineral in *B. aegyptiaca* was potassium (8731.3 (BSH)<K (mg/kg)<10979.2(SSR)) followed by phosphorus (6135.6 (SSR)<P (mg/kg<8712 (BLS)), calcium (1800.1 (BLR) <Ca (mg/kg)<3175.4 (BLS) and magnesium (1904.27 (BLR)<Mg(mg/kg)<2360.53 (BSH)).

In the kernel of *B. aegyptiaca*, potassium was the most abundant mineral. This mineral is essential for regulating normal blood flow, transmitting nerve impulses and supporting the functioning of the central nervous system [32]. Phosphorus was the second most prominent mineral. Working alongside calcium, phosphorus helps build and maintain strong bones and teeth, as well as convert food into energy to support metabolic processes [33]. Calcium was the third most common mineral found in the *B. aegyptiaca* kernel. This mineral is vital for strong bones and teeth, muscle contraction, nerve function, and blood clotting [34]. Magnesium was the fourth most abundant mineral in the *B. aegyptiaca* kernel. According to Al Alawi *et al*. [35], it participates in more than 300 enzymatic reactions, facilitating energy metabolism, synthesis and regulation of various physiological functions. These minerals are the main ones the human body requires[36].

Almonds contain various trace elements, showcasing a diverse range of concentrations. Notably, aluminum (Al) levels ranged from 28.09±3.00 to 51.31±1.3 mg/kg, while boron (B) content spanned from 38.68±2.00 to 62.75±1.75 mg/kg. Additionally, barium (Ba) fluctuated between 19.34±0.34 and 31.49±4.00 mg/kg. Cobalt (Co) was present at levels between 0.06±0 and 0.31±0.01 mg/kg, and chromium concentrations ranged from 6.97±0.20 to 18.17±0.12 mg/kg. Furthermore, copper (Cu) content was approximately between 9.44±0.04 and 11.12±0.08 mg/kg. Iron (Fe) levels varied from 15.36±0 to 31.86±0.03 mg/kg, while molybdenum (Mo) was detected at a concentration of 4.19±0.05 mg/kg, found exclusively in the BLS shape. In terms of nickel (Ni), the content was recorded in the range of 1.75±0.01 to 35.39±1.2 mg/kg. BSR-shaped kernels contained the highest concentrations of plumbum (lead, Pb) at 0.63±0.03 mg/kg. Selenium (Se) content varied from 2.05 to 3.26 mg/kg and silicon (Si) levels ranged between 29.46±0 and 64.39±0.7 mg/kg. Moreover, the rubidium (Rb) concentration extended from 18.66±0.16 to 62.23±1.1 mg/kg, while strontium (Sr) was present at levels of 18.77 and 39.9 mg/kg. Yttrium (Y) was detected at 7.35 mg/kg, exclusively in the BLS shape and zinc (Zn) concentrationswas between 23.43 and 38.11 mg/kg. Additionally, strontium (Sr) was present at levels of 18.77 and 39.9 mg/kg. Zirconium (Zr) was present at levels between 0.09 and 0.28 mg/kg, while chromium (Cr) content of seed kernel was approximately between 18.17 mg/kg and 6.19 mg/kg. However, chromium works as insulin [37], which gives the oil dietary properties. The mineral molybdenum (Mo), with a content of 4.19 mg/kg, is found only in the BLS shape. It is a mineral activating several enzymes that break down toxins [38].

The kernel of *B. aegyptiaca* was a rich source of trace elements that contributed to various bodily functions and processes. Iron, essential for oxygen transport in the blood[39] and zinc, crucial for immune function and wound healing [40], were among the vital trace elements found in the kernel. Copper plays a role in forming red blood cells, while selenium acts as an antioxidant, protecting cells from damage[41]. In the same order, Socha *et al*. [42] highlighted that trace elements had antioxidant properties. These trace minerals collectively support overall health and wellness by participating in metabolic processes and enzyme functions and maintaining the body's structural integrity[43]. These trace elements could contribute to the overall composition of the kernel and may have had implications for its nutritional value or environmental importance. The results provided some information about the nutrient composition of the seed, which could be relevant for dietary considerations or other applications.

Table 8. Mineral profile and content (mg/kg) of *B. aegyptiaca* kernels according to seed and fruit shape.

Minerals	BLS	BSR	SLR	BSH	SSR	BLR
Al	42.77± 2.00^{ab}	38.18±6.00^{bc}	34.61±4.00^{bd}	51.31±1.31^{a}	28.09±3.00^{d}	30.09±0.00^{cd}
B	58.24±2.24^{a}	47.89±4.00^{b}	48.26±0.26^{b}	62.75±1.75^{a}	44.16±4.16^{bc}	38.68 ± 2.00^{c}
Ba	20.77±0.00^{b}	20.68±0.68^{b}	21.49±1.49^{b}	31.49±4.00^{a}	27.00±1.00^{a}	19.34±0.34^{b}
Ca	3175.4±119.40^{a}	2870.0±42.50^{b}	2901.8±92.30^{b}	2055.7±54.80^{d}	2593±0.00^{d}	1800.1±100.00^{e}
Co	0.31±0.01^{a}	0.15± 0.00^{b}	0.06±0.00^{c}	0.14±0.14^{bc}	0.11±0.01^{bc}	0.10±0.03^{bc}
Cr	18.17±0.12^{a}	12.32±0.41^{b}	8.41±0.19^{c}	7.94±0.04^{c}	6.19 ±0.20e	6.97±0.00^{d}
Cu	10.65±0.05^{b}	11.09±0.02^{a}	11.12±0.08^{a}	9.79±0.10^{d}	10.02± 0.00^{c}	9.44± 0.04^{e}
Fe	23.73±0.00^{b}	31.86±0.03^{a}	22.7±0.27^{c}	17.99±0.10^{e}	15.36 ± 0.00^{f}	20.09±0.00^{d}
K	9976.97±154.00^{c}	9540.6±59.60^{d}	9275.6±67.80^{e}	8731.3±70.90^{f}	10979.20±95.00^{a}	10634.4±46.20^{b}
Mg	2093.62±3.22^{c}	2222.5±24.10^{b}	2257.5±57.20^{b}	2360.53±10.35^{a}	2036.6 ± 36.50^{c}	1904.27±6.77^{d}
Mn	50.37±0.37^{a}	24.94±1.00^{b}	21.69±0.30^{c}	15.62±0.62^{d}	14.47±0.17^{d}	12.27±0.15^{e}
Mo	4.19±0.05	ND	ND	ND	ND	ND
Na	257.5±0.01^{ab}	218.6±17.9^{c}	221.21±10.10^{bc}	272±20.00^{a}	192.89±17.00^{c}	185.7±0.01^{c}
Ni	35.39±1.20^{a}	6.06±0.05^{b}	2.7 ±0.02^{c}	1.75±0.01^{d}	1.88±0.68^{d}	3.4±0.02^{c}
P	8712.00±0.00^{a}	7478.90±73.60^{c}	8398.00 ± 22.00^{b}	7547± 0.00^{c}	6135.6±51.10^{d}	7485.9±81.60^{c}
Pb	0.27±0.04^{c}	0.63±0.03^{a}	0.09±0.00^{d}	0.35±0.00^{b}	ND	0.06±0.00^{d}

Minerals	BLS	BSR	SLR	BSH	SSR	BLR
Rb	53.19±0.26^{b}	36.7±0.05^{d}	18.66±0.16^{f}	62.23±1.10^{a}	49.76±0.03^{c}	25.48±0.18^{e}
Se	2.9±0.00^{ab}	2.05±0.01^{c}	2.77 ±0.37^{b}	3.26±0.04^{a}	1.62±0.03^{d}	2.2±0.05^{c}
Si	51.33±0.33^{b}	48.87±1.10^{b}	42.77±1.97^{c}	64.39±0.70^{a}	34.01±0.22^{d}	29.46±0.00^{e}
Sr	39.9±1.20^{a}	38.83±0.2^{a}	33.3±0.30^{b}	18.77±1.00^{d}	30.4±0.03^{b}	22.65±2.10^{c}
Y	7.35±0.20	ND	ND	ND	ND	ND
Zn	38.11±0.18^{a}	32.46±0.30^{c}	32.76 ±0.02^{c}	25.18±0.30^{d}	23.43±0.20^{e}	36.62±0.73^{b}
Zr	0.28±0.00^{ab}	0.21±0.01^{cd}	0.18±0.00^{d}	0.32±0.00^{a}	0.25±0.04^{bc}	0.09±0.00^{e}

Means not sharing any letters are significantly different.Al:Aluminium, B: Boron, Ba: Barium, Ca: Calcium, Co: Cobalt, Cr: Chromium, Cu: Copper, Fe: Iron, K: Potassium, Mg: Magnesium, Mn: Manganese, Mo: Molybdenum, Na: Sodium, Nickel, P: Phosphorus, Pb: Plumbum, Rb: Rubidium, Se: Selenium, Si: Silicon, Sr: Strontium, Y: Yttrium, Zn: Zinc, Zr: Zirconium. ND: Not Detected

3.6 Biplot-Principal component analysis (PCA)

Figure 3A indicates a biplot-principal component analysis (PCA) of shapes with physicochemical parameters. According to the biplot analysis, axes 1 and 2 correspond to about 87.3%. Regarding axes 1 and 2, BLS BSR and SSR shapes present no link with physiological parameters. The SLR shape was linked to ash, moisture, and carbohydrate. BLR and BSH shapes were linked to energy value. In a biplot analysis, we explored the relationship between fruit shape and fatty acids (Figure 3B). Axis 1 and Axis 2 collectively account for 68.60% of the variability. Several correlations emerged between the shapes observed in *B. aegyptiaca* and their corresponding fatty acid profiles. The BLR shape was positively correlated with the following fatty acids: cis-9-Oleic acid, lauric acid and cis-11-Arachidonic acid. The SSR shape showed a strong association with behenic acid and heptadecanoic acid. The BLS shape is linked to elevated levels of cis-9,12,15-linolenic acid and stearic acid.

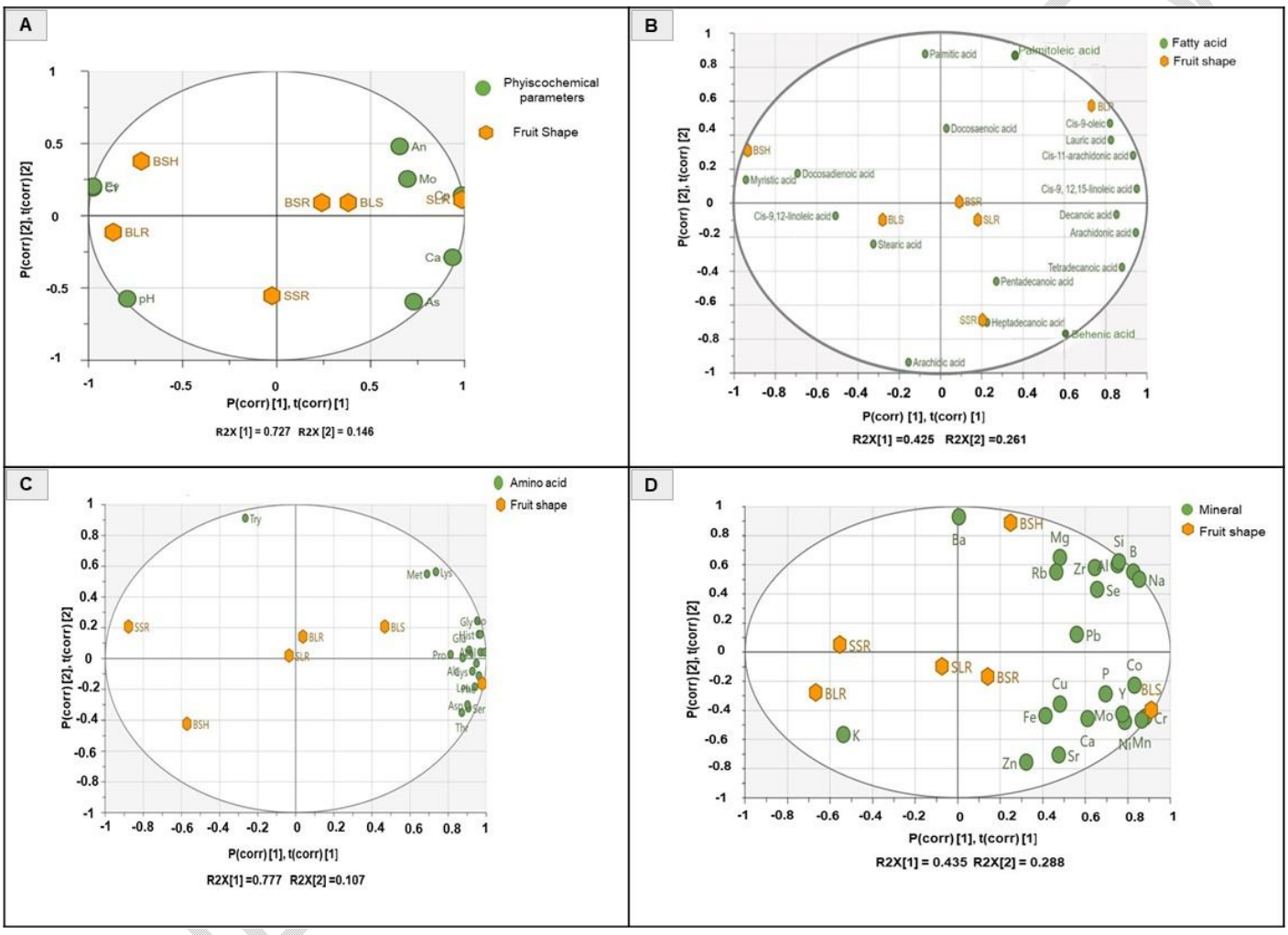

Figure 3. Biplot-principal component analysis. A: Shape and physicochemical parameters. B: shapes and fatty acids C: Shape and amino acids, D: Shapes and minerals.
Legend: Physicochemical parameters: An: Acid number, As: Ash, Ca: Carbohydrates, Cf: Crude fat, Cp: Crude protein, Ev: Energetic Value, Mo: Moisture. Amino acids: Ala: Alanine, Arg: Arginine, Asp: Aspartic acid, Cys: Cystine, Glu: Glutamine, Gly: Glycine, His: Histidine, Iso: Isoleucine, Leucine: Leu, Lys: Lysine, Met: Methionine, Pro: Proline, Ser: Serine, Thr: Threonine, Tyr: Tyrosine, Phe: Phenylalanine, Try: Tryptophan, Val: Valine. Minerals**:** Al:Aluminium. B: Boron. Ba: Barium. Ca: Calcium. Co: Cobalt. Cr: Chromium. Cu: Copper, Fe: Iron, K: Potassium, Mg: Magnesium, Mn: Manganese. Mo: Molybdenum, Na: Sodium, Nickel, P: Phosphorus, Pb: Plumbum, Rb: Rubidium. Se : Selenium, Si : Silicon, Sr: Strontium, Y: Yttrium, Zr: Zirconium.

The BSH shape demonstrated a relationship with increased concentrations of myristic acid and docosadienoic acid. Additionally, another biplot analysis involving shape and amino acids (depicted in Figure 3C) was performed. Axis 1 and axis 2 account for 88.4% of the variability. Interestingly, only the BSR shape correlated with two amino acids, excluding lysine and methionine. This result suggests that the BSR shape is particularly representative regarding amino acid content.

Biplot-PCA was also done with shapes and minerals (Figure 3D). Axis 1 and 2 contributed to 72.3% of variability. The BLS shape was correlated to calcium, cobalt, phosphorus, copper, nickel, chromium and manganese. The BSH shape was correlated to barium. The BLR shape was correlated to potassium. These correlation studies allow the link between shapes and biochemical value, which can facilitate the best choice when selecting a desired chemical compound.
Biochemical variability was observed between fruit shapes and this can be explained by some factors such as temperature, pluviometry or soil composition. In fact, in Fenner's [44]work, it was shown that temperature variation could influence seeds' morphological and biochemical characteristics, such as seed size, fatty acid and protein composition. The variability of the seed in fatty acids, minerals, amino acid content and physicochemical parameters could contribute to the valorization (marketing, exploitation, domestication, etc.) of *B. aegyptiaca* seed. This was supported by the work of Paravar*et al*. [45] which mentions that the composition of biochemical parameters influences the commercial value of seeds. This variability of *B. aegyptiaca* in morphological, physicochemical and biochemical aspects can be an added value for industrial exploitation. This was what Paravar*et al.*[45] explained, indicating that the biochemical composition of seeds is the potential resource used by the food and pharmaceutical industries. Regarding all these nutritional values, *B. aegyptiaca* seeds can be considered a raw material for the food industry, especially since toxicological studies have shown that seed oil is not dangerous for human consumption[9].

1. Conclusion

This study highlights the differences between the six identified shapes of *B. aegyptiaca* fruits and seeds. The length, width, thickness and weight of 100 fruits were variable with respect to shapes. Kernels and its oil exhibit variations in their physicochemical properties, fatty acid composition, amino acid profile, and mineral content, making them a valuable source of various active ingredients. Specific traits are associated with certain shapes. The BSH shape has a high crude fat content and high energy value, while the BLS shape has the least favorable profile due to its high moisture and acid number. But it is the shape correlated with a significant number of minerals, cis-9,12,15-linolenic acid and stearic acid. The BLR shape correlates with most amino acids. Understanding these correlations between shapes and biochemical aspects can help to better understand the distribution of nutritional values of *B. aegyptiaca* fruit and seed types. Further investigation on antinutritional factors, toxicity of the fruit and seed kernel and genetic mechanisms related to fruit shape will contribute to better use of this species.

. Disclaimer (Artificial intelligence)
Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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