

Assessment of Desert Date (*Balanites Aegyptiaca*) Seed Oil as a Potential Raw Material for Biodiesel Production

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Keywords: *Balanites aegyptiaca*, desert date, biodiesel, transesterification, fatty acid profile, non-edible oil, physicochemical properties

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ASSESSMENT OF DESERT DATE (*BALANITES AEGYPTIACA*) SEED OIL AS A POTENTIAL RAW MATERIAL FOR BIODIESEL PRODUCTION

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ABSTRACT

Oil from desert date (*Balanites aegyptiaca*) seeds was extracted via solvent extraction. The chemical and physical properties of the oil were determined to ascertain its suitability for biodiesel production. The results showed saponification value 171.6 mg KOH/g, peroxide value 8.7 meq/kg, iodine value 96.2, acid value 0.9470 mg/g, free fatty acid 0.43%, specific gravity 0.9132, moisture content 9.26%, and fatty acid profile: palmitic acid 14.1%, stearic acid 15.52%, oleic acid 27.64%, linoleic acid 41.0%. Biodiesel was produced through transesterification with a yield of 58.85%. The produced biodiesel exhibited cloud point 8°C, pour point -0.3°C, flash point 78°C, and kinematic viscosity 4.8 mm²/s. These properties compare very well with ASTM D6751 standards, confirming that desert date seed oil is a promising non-edible feedstock for biodiesel production.

KEYWORDS:

Balanites aegyptiaca, desert date, biodiesel, transesterification, fatty acid profile, non-edible oil, physicochemical properties.

1.1 Global Energy Context and the Role of Biodiesel

The global energy landscape faces unprecedented challenges as of 2026. Fossil fuel reserves continue to deplete rapidly, while combustion of petroleum-based diesel contributes significantly to greenhouse gas emissions, air pollution, and climate change. The transport sector, which relies heavily on diesel, accounts for a substantial portion of global CO₂ emissions. Renewable alternatives are essential to meet rising energy demand sustainably, reduce dependence on imported crude oil, and comply with international climate commitments (e.g., Paris Agreement goals and net-zero targets by mid-century) (Gutti *et al.*, 2011; Bambara *et al.*, 2018). Biodiesel has emerged as one of the most viable renewable liquid biofuels for diesel engines. It is produced primarily through transesterification of triglycerides (from oils or fats) with short-chain alcohols (typically methanol), yielding fatty acid methyl esters (FAME) and glycerol as a by-product. Biodiesel offers several advantages over conventional diesel: it is biodegradable, non-toxic, has a higher cetane number (leading to better ignition quality), contains no sulfur, and reduces net CO₂ emissions by approximately 78% over the life cycle when derived from renewable sources (Akaagerger *et al.*, 2016). It can be used in pure form (B100) or blended (e.g., B20, B30) with petroleum diesel without major engine modifications. Global biodiesel production and demand have grown steadily. In 2025–2026, the market is valued at approximately USD 50–55 billion, with projections to reach USD 65–75 billion by the early 2030s, driven by blending mandates in Europe (RED III), Asia (Indonesia's B40/B50 programs), and emerging policies in Africa

and Latin America (Alashwal *et al.*, 2024). However, feedstock availability remains a critical bottleneck. First-generation biodiesel (from edible oils like soybean, rapeseed, and palm) faces criticism for competing with food production, driving up food prices, and contributing to deforestation (e.g., palm oil expansion).

1.2 Shift Toward Non-Edible Feedstocks

To address sustainability concerns, there is a clear global trend toward second- and third-generation feedstocks: non-edible oils, waste oils (used cooking oil, animal fats), and advanced sources (algae, microbial oils). Non-edible plant oils offer distinct advantages:

- No competition with food supply chains, reducing ethical and economic conflicts.
- Ability to grow on marginal, degraded, or arid lands unsuitable for food crops, minimizing land-use change impacts.
- Often lower production costs in regions where the plants grow wild or as underutilized resources.
- Potential for rural economic development through collection, processing, and local value addition.
- Reduced pressure on freshwater resources and agricultural inputs compared to many edible oil crops (Bambara *et al.*, 2018).

Recent policy developments reinforce this shift. For example, India's National Bio-Energy Mission and RUCO program emphasize used cooking oil and non-edible sources, while Indonesia's B35/B40 mandates increasingly favor sustainable, low-ILUC (indirect land-use change) feedstocks. In Africa, where edible oil demand is rising, non-edible wild plants represent untapped potential for energy security and rural livelihoods (Elfeel and Warrag, 2011).

1.2.1 Desert Date (*Balanites aegyptiaca*) as a Promising Feedstock

Desert date (*Balanites aegyptiaca* L. Delile), a multipurpose tree native to the Sahel-Savannah belt and arid regions of Africa (including Sudan, South Sudan, Uganda's dry zones, and parts of East Africa), is well-adapted to harsh conditions: drought, poor soils, salinity, and livestock pressure. Mature trees produce high fruit yields (up to 10,000 fruits per tree annually), with kernels containing 40–50% oil rich in palmitic, stearic, oleic, and linoleic acids (Gutti *et al.*, 2011; Elfeel and Warrag, 2011). As a non-edible oil source (due to anti-nutritional factors such as tannins, oxalate, and phytic acid), it avoids food-fuel competition and remains available during dry seasons when conventional feedstocks may be scarce. Despite its abundance in drylands and historical use for oil extraction (e.g., zachun oil), *B. aegyptiaca* remains underutilized for modern biofuel applications. Limited studies have explored its biodiesel potential, with reported oil yields of 40–56% and biodiesel properties generally meeting standards, but optimization and regional characterization (especially from South Sudan/Uganda sources) are scarce (Akaagerger *et al.*, 2016; Bambara *et al.*, 2018). This represents a research gap: evaluating locally available, wild-grown non-edible oil for sustainable biodiesel in arid African contexts.



Figure 1: Desert Dates fruits and plant

1.3 Research Gap, Objectives, and Significance

While edible oils dominate current biodiesel production, non-edible alternatives like *B. aegyptiaca* could diversify supply, support rural economies, and align with low-carbon policies. However, detailed characterization of oil from South Sudanese sources and direct comparison of derived biodiesel properties to ASTM standards are limited (Alashwal *et al.*, 2024). This study addresses this by:

- Extracting and characterizing desert date seed oil.
- Producing biodiesel via transesterification.
- Evaluating of key fuel properties against ASTM D6751.
- The work demonstrates the technical feasibility of *B. aegyptiaca* as a biodiesel feedstock, contributing to renewable energy options in arid regions, reducing fossil fuel dependence, and promoting value addition to neglected wild resources.

2. Materials and Methods

2.1 Sample Collection and Preparation

Desert date fruits were collected from Juba, Central Equatoria State, South Sudan. Ripe fruits were gathered from under 10 healthy trees after natural fall, mixed, and a ~2 kg subsample taken. Fruits were screened, soaked overnight in water to remove pulp, sun-dried, cracked with a metal hammer, and kernels ground using a blender.

This study was conducted in two collaborating facilities. Oil extraction from desert date seeds, biodiesel production via transesterification, and determination of most physicochemical properties of both oil and biodiesel were carried out at the Uganda Industrial Research

Institute (UIRI), Kampala, Uganda. Due to the unavailability of advanced chromatographic and certain titration equipment at UIRI during the study period, lipid profiling (fatty acid composition via GC-FID) and iodine value determination were performed at Precision Oil Laboratories, South Africa. All raw data from these outsourced analyses were provided to the author, who independently interpreted and reported the results.

2.2 Determination of Seed Fat Content

- 3.0247 g of dried seed sample was placed in a thimble lined with filter paper.
- A dry aluminum cup (weight 38.8652 g) received 60 mL petroleum ether.
- The thimble was fitted and connected to a Soxhlet extractor, run for 1 hour.
- The extracted fat was dried in an oven for 15 minutes.
- The cup with fat weighed 40.2247 g.
- Fat content was calculated as:

$$\% \text{ Fat} = [(40.2247 - 38.8652) / 3.0247] \times 100$$

$$\% \text{ Fat} = 44\%$$

2.3 Oil Extraction

- 10 g of ground sample was placed in a thimble.
- 85 mL petroleum ether was added to the aluminum cup.
- Soxhlet extraction was performed for 1 hour per cycle;
- 10 cycles were completed to obtain sufficient oil for biodiesel production.
- The extracted oil was dried in an oven.

2.4 Oil Characterization

Analyses were performed using standard methods:

- Color: Visual observation
- Moisture content: Oven drying at 105°C for 4 h
- Specific gravity: Pycnometer method
- Free fatty acid (FFA): POL 015 (based on AOCS Ce 1-6)
- Acid value: Calculated as $\% \text{ FFA} \times 1.99$
- Peroxide value: Titration with 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$ after KI addition
- Saponification value: Reflux with 0.5 M methanolic KOH, back-titration with 0.5 M HCl
- Iodine value: POL 009 (based on AOCS method Cd 1c-85)

- Fatty acid profile: Fatty acid methyl esters (FAME) prepared per AOCS Ce 2-66 (1997); analyzed by GC-FID (Varian CP-3800, FFAP column, helium carrier gas, temperature program: 125°C → 200°C).

2.5 Biodiesel Production (Transesterification)

- 100 mL oil was heated to 65°C. 40 mL methanol was mixed with 10.0231 g calcium oxide (catalyst) and added to the oil.
- The mixture was stirred continuously at 65°C for 2 hours 45 minutes.
- After reaction, the contents were transferred to a separating funnel and allowed to settle overnight.
- The biodiesel layer was separated and washed with warm water.
- Yield was calculated as:

$$\% \text{ Biodiesel yield} = (\text{mass of biodiesel} / \text{mass of oil}) \times 100$$

2.6 Biodiesel Property Determination

Cloud point

The cloud point is defined as the temperature at which visible wax crystals first appear in the fuel, causing a cloudy appearance due to the precipitation of high-melting-point components (ASTM D2500; Knothe, 2005). This property is critical for assessing the low-temperature flow behavior of biodiesel, as crystal formation can restrict fuel flow and lead to filter plugging or injector malfunction in cold conditions.

Procedures

The cloud point of the produced biodiesel was determined using a modified cooling test based on visual observation. Approximately 10 mL of biodiesel was placed in a transparent improvised glass bottle. A thermometer was inserted and secured using cotton wool and laboratory gloves to ensure stability and prevent leakage. The bottle was then placed in a domestic refrigerator and cooled gradually. The sample was inspected at regular intervals (every 1–2°C drop in temperature) for the first appearance of haze or distant cloudiness at the bottom or throughout the liquid. The temperature at which this cloud formation became clearly visible was recorded as the cloud point. All observations were performed in triplicate to ensure reliability, and the mean value is reported.

Pour point

The pour point refers to the lowest temperature at which there is no movement of the fuel when the container is tipped. Compared to petrol-diesel, biodiesel tends to have a much narrower range of temperatures between the cloud point and the pour point.

Procedures

An improvised bottled was filled with the biodiesel to a 10ml level. A thermometer was attached using a cotton wool and gloves. The bottle was then placed in the refrigerator and

was tilted at regular interval. the temperature at which the biodiesel stopped flowing was recorded and taken as the pour point

3.6.2.4 Flash point.

Flash point, the lowest temperature at which a liquid (usually a petroleum product) will form a vapour in the air near its surface that will “flash,” or briefly ignite, on exposure to an open flame. The flash point is a general indication of the flammability or combustibility of a liquid.

Procedures

A 100ml conical flask was filled with 10ml biodiesel and was heated on a hot plate mildly at a constant rate. The lowest temperature at which the vapours ignited on application of flame at the surface was recorded taken as the flash point

3.6.2.5 Viscosity

Engine diesel viscosity refers to how easily oil pours at a specified temperature. Thin oils have lower viscosity and pour more easily at low temperatures than thicker oils that have a higher viscosity. Thin oils reduce friction in engines and help engines start quickly during cold weather.

Kinematic Viscosity is a very important property since it directly affects combustion of the fuel in the engine. Higher viscosity fuel flows with difficulty while fuels with lower viscosity flow more easily. The quality of spray on injection is also attributed to the viscosity of the fuel.

Procedures

The viscosity of the biodiesel produced will be measured using a digital viscometer. To carry out the viscosity measurement, 10ml of the biodiesel will be poured into a 50mL beaker, and a spindle with a number of 7 will be immersed into the oil until the level gets to the mark on the spindle. Thereafter, it will be positioned such that it would not touch the wall of the beaker. The value of the viscosity of the biodiesel will then be read from the viscometer and recorded.

4.0 Results and Discussion

4.1 Oil Yield and Physicochemical Properties

Table 1: Oil Yield and Physicochemical Properties

Property	Value
Fat content	44%
Moisture content	8.7%
Specific gravity	0.9470
Free fatty acid	0.43
Iodine value	96.2g/100g
Peroxide value	9.26meq
Saponification value	171.6mgKOH/g
Color	Pale yellow

Acid value	0.9132mgKOH/g
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Multiple extraction runs indicated a high oil content of approximately 44% in the kernels, confirming desert date seeds as a potentially economical source of oil for industrial applications. This yield is comparable to reported values of 41.5–45.2% using n-hexane Soxhlet extraction (Prakash Maran and Priya, 2016) and slightly lower than some optimized methods achieving up to 50% (Elfeel and Warrag, 2011). The physicochemical properties of the extracted oil are summarized in Table 2. The saponification value of 171.6 mg KOH/g indicates the presence of moderately long-chain fatty acids with average molecular weight suitable for biodiesel production. The peroxide value of 8.7 meq/kg shows low primary oxidation, indicating freshness and good initial stability; combined with an iodine value of 96.2 g I₂/100 g, this reflects moderate unsaturation (semi-drying oil category), similar to 9.37 meq/kg reported in other studies (Mari et al., 2022). The acid value of 0.947 mg KOH/g (equivalent to 0.43% FFA) is well below the typical threshold of 1.5–2 mg KOH/g recommended to minimize soap formation during alkaline transesterification and to prevent engine corrosion, aligning with low FFA values in literature (e.g., 1.45 mg KOH/g in related non-edible oils) (Alashwal *et al.*, 2024). The specific gravity (0.9132) and low moisture content (9.26%) are close to values typical of vegetable oils used for biodiesel and support good miscibility and reaction efficiency (Gutti *et al.*, 2011).

4.2 Fatty Acid Profile (Lipid Composition)

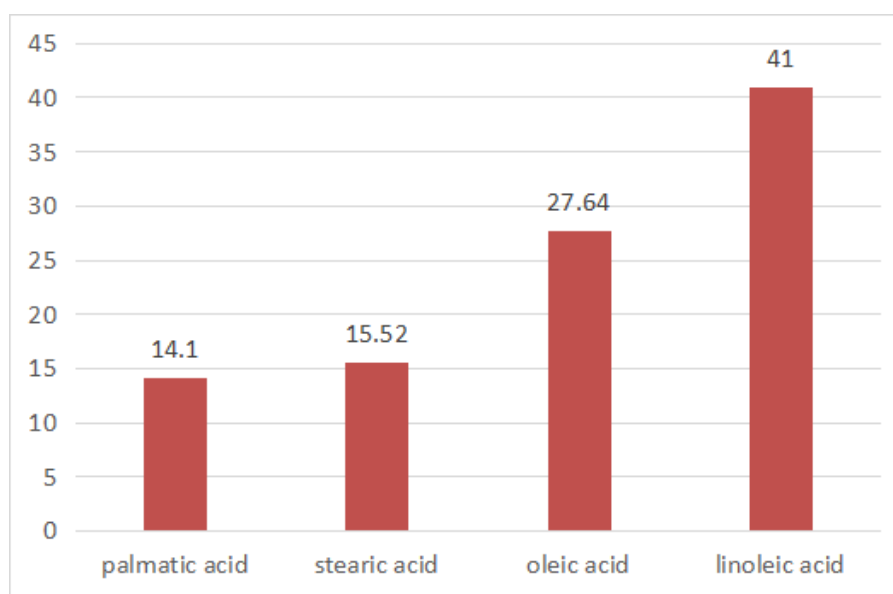


Figure 2: Fatty Acid Profile (Lipid Composition)

The fatty acid composition (Table 1) revealed four major fatty acids: linoleic acid (41.0%), oleic acid (27.64%), stearic acid (15.52%), and palmitic acid (14.1%). These four components accounted for nearly all (>98%) of the total fatty acids detected. Linoleic acid (C18:2, polyunsaturated) was the predominant component, followed by oleic acid (C18:1, monounsaturated). This profile indicates a relatively high degree of unsaturation compared to many saturated-rich non-edible oils, but still moderate overall. The high linoleic acid content contributes to improved cold flow properties (lower cloud and pour points) due to reduced tendency to form wax crystals compared to highly saturated oils (Elfeel and Warrag, 2011). It

also provides reasonable oxidative stability, as the polyunsaturated content is balanced by significant monounsaturated (oleic) and saturated fractions. The potential for acceptable cetane number and combustion characteristics is supported, as oleic and linoleic acids are common in oils (e.g., soybean, sunflower) that produce good-quality biodiesel (Bambara et al., 2018). The presence of ~41% linoleic acid is notably higher than in many other non-edible oils commonly studied for biodiesel (e.g., *Jatropha*, neem), which often have higher oleic content. This composition explains why desert date oil remains liquid at room temperature and suggests biodiesel derived from it should exhibit good low-temperature performance, an important advantage in regions with cooler nights or variable climates (Alashwal *et al.*, 2024). Compared to literature, the linoleic content here is on the higher side of reported ranges for *B. aegyptiaca* (typically 31–51%), while oleic and stearic are within expected limits (Gutti *et al.*, 2011; Mari *et al.*, 2022). For instance, similar profiles show oleic up to 26% in related studies (Prakash Maran and Priya, 2016). The balanced saturated-to-unsaturated ratio supports the conclusion that this oil is well-suited for biodiesel production without major risk of poor oxidative stability or cold-flow issues (OnePetro, 2024).

Biodiesel Production and Properties

4.3 Biodiesel was produced with a yield of 58.85% (Table 3).



Figure 3: Biodiesel was produced with a yield of 58.85%

While this yield is moderate (likely due to the use of heterogeneous CaO catalyst and non-optimized methanol-to-oil ratio), it demonstrates successful conversion under the applied conditions (Akaagerger *et al.*, 2016). This is lower than optimized yields of 82–90% in literature using KOH or CaO catalysts (Prakash Maran and Priya, 2016; Mari et al., 2022), suggesting potential for improvement through parameter optimization (e.g., higher catalyst loading or temperature). The properties of the produced biodiesel are presented in Table 4 and compared with ASTM D6751 standards. The cloud point (8°C) and pour point (-0.3°C) indicate acceptable low-temperature behavior, consistent with the relatively high unsaturated fatty acid content, and match or exceed values like 2°C cloud and -4°C pour in other CaO-

catalyzed studies (OnePetro, 2024). The flash point of 78°C is sufficiently high for safe handling and storage (well above typical minimum requirements), though lower than 136–170°C reported in optimized processes (Mari et al., 2022; Alashwal *et al.*, 2024). The kinematic viscosity of 4.8 mm²/s falls within the ASTM specification range (1.9–6.0 mm²/s), ensuring good fuel atomization and engine performance, similar to 4.5–5.2 mm²/s in comparable studies (Prakash Maran and Priya, 2016; OnePetro, 2024). Overall, the biodiesel properties align closely with standard requirements, confirming that desert date seed oil is a technically viable feedstock, with performance comparable to or better than other non-edible oils in terms of safety and cold-weather usability (Elfeel and Warrag, 2011; Bambara *et al.*, 2018).

5.1 Conclusion

The results demonstrate that desert date seed oil is an economically viable non-edible feedstock for biodiesel production, with high oil content (~44%) and favorable physicochemical properties. The fatty acid profile, dominated by linoleic and oleic acids, supports production of biodiesel with good cold-flow characteristics and acceptable stability. The produced biodiesel (58.85% yield) meets key ASTM D6751 specifications for cloud point, pour point, flash point, and viscosity, indicating its potential as a renewable diesel substitute with environmental benefits over petroleum diesel. Compared to other studies, the oil yield and fatty acid profile are consistent with literature, while biodiesel yield and properties show room for optimization but remain competitive for arid-region applications.

5.2 Recommendations

The findings of this study highlight the strong potential of desert date (*Balanites aegyptiaca*) seed oil as a sustainable non-edible biodiesel feedstock, with high oil content (44%) and favorable physicochemical and fatty acid properties. To further advance its viability and practical application, the following recommendations are proposed:

1. Optimize transesterification process by Systematically investigating key parameters (methanol-to-oil ratio 6:1–12:1, CaO catalyst loading 0.5–3 wt%, temperature 50–70°C, time 1–4 h) using response surface methodology (RSM) to increase biodiesel yield beyond the current 58.85% while preserving fuel quality.
2. Compare alternative catalysts and extraction methods . Evaluate homogeneous bases (KOH, NaOH), improved heterogeneous catalysts (e.g., calcined eggshell CaO), and biocatalysts (lipase), alongside alternative oil extraction techniques (mechanical pressing, supercritical CO₂, enzymatic) to improve yield, oil quality, and production economics.
3. Conduct comprehensive fuel and engine testing. Perform full ASTM D6751 characterization (cetane number, oxidation stability via Rancimat, cold filter plugging point) at accredited labs, followed by engine performance and emission tests (B20–B100 blends) to validate real-world applicability and environmental benefits.
4. Assess scale-up and economic feasibility by Carrying out techno-economic analysis (capital/operating costs, EROI, life-cycle GHG emissions) and pilot-scale trials in

rural South Sudan/Uganda to evaluate supply chain logistics, community involvement, and commercial potential.

5. Improve laboratory infrastructure. Universities in resource-limited settings should invest in essential equipment (digital viscometer, closed-cup flash point tester, Rancimat, GC-MS) and foster collaborations with national institutes (e.g., UIRI) to support accurate biofuel research.
6. Promote policy and community engagement. Governments and development partners should develop policies supporting wild harvesting or cultivation of *B. aegyptiaca* for biofuel, along with community programs for seed collection and local biodiesel production to enhance rural livelihoods and contribute to national renewable energy goals.

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Appendixes



Precision Oil Laboratories



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Certificate of Analysis

Report no: R21/615

Kudum Jacob Alier
Tel: +25677105729
Kudumalierbiar@gmail.com

Date: 16/9/2021

Order Number: None supplied

Sample Description: Desert Date Kernels

Sample: 1

Lab no: P21/615

Analyses:

Received: 2/9/2021

Commenced: 15/9/2021

Completed: 16/9/2021

Methods used:

Method name	Method number	Method
Petroleum Ether Lipid Extraction*	POL 019	Based on AOCS Method AOCS Ba3-38

*Not Sanas accredited

Results:

The results are applicable to sample condition at receipt. The results relate only to the items tested.
This certificate shall not be reproduced except in full, without the written approval of the Laboratory.

Sample:	Result
Oil Content (g/100g)	39.4

Do not hesitate to contact me should you need any additional information.

Dr. Mathilda Mostert, Pri.Sci.Nat
Technical Signatory and Laboratory manager



Certificate of Analysis

Report no: R21/682

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Kampala, Uganda
Tel: +25677105729
Kudumalierbiar@gmail.com

Date: 04/10/2021

Order Number: None supplied

Sample Description: Desert Date Kernels seeds

Sample: 1

Lab no: P21/682

Analyses:

Received: 23/9/2021

Commenced: 29/9/2021

Completed: 04/10/2021

Methods used:

Method name	Method number	Method
Fatty Acid Profile	POL 015	Based on AOCS Method Ce 2-66
Iodine Value	POL 009	AOCS Method Cd 1c-85
Petroleum Ether extraction*	POL 019	AOCS Method Ba 3-38

*Not Sanas accredited

Results:

The results are applicable to sample condition at receipt. The results relate only to the items tested. This certificate shall not be reproduced except in full, without the written approval of the Laboratory.

The results are reported with the expanded relative uncertainty at a confidence level of 95% using a factor of $k=2$.

LOQ = limit of quantitation

Sample:	Result	Uncertainty	LOQ
Iodine Value	96.2	± 1.8	1.1

Sample: 1**Report no: R21/682**

Limit of detection (LOD) = 0.09 g Fatty acid/100g Fatty acids.

Limit of quantitation (LOQ) = 0.28 g Fatty acid/100g Fatty acids.

Values below the limit of quantitation cannot be accurately quantified.

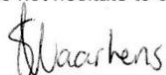
Fatty Acid	g Fatty acids/100g Fatty Acids	Uncertainty
C4:0 Butyric acid	None detected	
C6:0 Caproic acid	None detected	
C8:0 Caprylic acid	None detected	
C10 Capric acid	None detected	
C12:0 Lauric acid	None detected	
C14:0 Myristic acid	None detected	
C16:0 Palmitic acid	14.1	± 1.6
C16:1 n7 Palmitoleic acid	Lower than LOQ	
C17:0 Margaric acid	Lower than LOQ	
C17:1 n7 Glinkgolic acid	None detected	
C18:0 Stearic acid	15.52	± 0.79
C18:1 n9 trans Oleic acid	None detected	
C18:1 n9 cis Oleic acid	27.64	± 0.83
C18:2 n6 trans Linoleic acid	None detected	
C18:2 n6 cis Linoleic acid	41.0	± 1.1
C18:3 n6 Linolenic acid	None detected	
C18:3 n3 Linolenic acid	None detected	
C20:0 Arachidic acid	0.411	± 0.087
C20:1 n9 Eicosenoic acid	Lower than LOQ	
C20:5 n3 Eicosapentaenoic acid	Lower than LOQ	
C21:0 Heneicosanoic acid	None detected	
C22:0 Behenic acid	None detected	
C22:1 n9 Erucic acid	None detected	
C24:0 Lignoceric acid	Lower than LOQ	
C24:1 n9 Nervonic acid	None detected	
Unknown	0.28	

Limit of detection (LOD) = 2.2 mg/kg.

Limit of quantitation (LOQ) = 7.5 mg/kg.

Values below the limit of quantitation cannot be accurately quantified.

Do not hesitate to contact me should you need any additional information.

Sonja Maartens
Technical SignatoryDr Lindie Marais
Technical Signatory and Quality Manager