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## Physicochemical, Antioxidant, and Antimicrobial Evaluation of a Multifunctional Natural Base Oil

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The increasing demand for natural and sustainable ingredients in cosmetic and pharmaceutical products has spurred interest in underutilized seed oils with multifunctional properties. This study investigates the physicochemical properties, fatty acid composition, antioxidant activity, and antimicrobial efficacy of nine cold-pressed seed oils obtained from Adamawa and Kebbi States, Nigeria. Gas Chromatography-Mass Spectrometer profiling, revealed diverse lipid profiles in the oils, with *Cucumeropsis mannii*<sup>2</sup> containing the highest level of polyunsaturated fatty acids (80.07 %), and *Citrullus lanatus* with a high concentration of monounsaturated fatty acids (64.88 %). Three oil formulations were developed and assessed for their antimicrobial activities against selected bacterial strains (*Staphylococcus aureus*, *Escherichia coli*, *Salmonella typhi*) and fungal strains (*Candida albicans*, *Trichophyton rubrum*). The results showed concentration-dependent antimicrobial activity (Formulation 1; 1.0 mm to 32.0 mm, Formulation 2; 2.0 mm to 24.0 mm, and Formula 3; 2.0 mm to 20.0 mm), with formulation three exhibiting the most consistent broad-spectrum effectiveness. The findings highlight the oils as having bioactive compounds with potential applications in skin care and therapeutic applications.

**Keywords:** Antioxidant, Antimicrobial, Oils, Physicochemical, and seeds.

## 1. Introduction

The increasing demand for natural and sustainable ingredients in cosmetic and pharmaceutical formulations has driven significant research into plant-derived oils, which are rich in bioactive compounds with diverse functional properties (Lee *et al.*, 2023). Among these, nonvolatile seed oils have garnered attention due to their unique physicochemical characteristics, antioxidant potential, and antimicrobial efficacy. Such oils not only serve as emollients and moisturizers but also offer protective benefits against oxidative stress and microbial infections, making them valuable for multifunctional applications in skincare and therapeutic products (Sen *et al.*, 2025).

In recent years, the exploration of indigenous plant resources has revealed promising candidates for cosmetic and medicinal use. For instance, oils extracted from *Sesamum indicum*, *Balanites aegyptiaca*, and *Cucumeropsis mannii* have demonstrated notable fatty acid profiles, including high concentrations of polyunsaturated and monounsaturated fatty acids, which are essential for skin hydration and barrier function (Tobar-Espinoza & Pérez-Correa, 2025). Additionally, the presence of bioactive compounds such as tocopherols, sterols, and phenolic derivatives in these oils contributes to

their antioxidant and antimicrobial activities, further enhancing their utility in formulations aimed at addressing dermatological concerns (Musa *et al.*, 2022).

Despite these advancements, comprehensive studies evaluating the combined physicochemical, antioxidant, and antimicrobial properties of multifunctional seed oils remain limited, particularly for underutilized species native to regions like Northern Nigeria (Runde, 2023). Understanding these properties is critical for optimizing their application in cosmetic and therapeutic products, especially in combating skin infections caused by pathogens such as *Staphylococcus aureus* and *Trichophyton rubrum* (Elbouzidi *et al.*, 2025). Furthermore, the standardization of extraction and analytical methods is essential to ensure reproducibility and efficacy in industrial applications.

This study aims to characterize the physicochemical properties, fatty acid composition, and bioactivity of nine nonvolatile seed oils, including *Sesamum indicum*, *Hyptis spicigera*, and *Citrullus lanatus*, sourced from Adamawa and Kebbi states in Nigeria. By assessing their saponification and iodine values, refractive indices, and antimicrobial efficacy against both gram-positive and gram-negative bacteria, as

well as fungi, we aim to highlight their potential as natural alternatives in cosmetic and pharmaceutical formulations. The findings will contribute to the growing body of knowledge on plant-based oils and their role in developing sustainable, multifunctional products with enhanced therapeutic and moisturizing properties.

**2. Materials and Methods**

**2.1 Plant Materials and Sample Collection**

This study focused on nine oil-bearing seeds collected from Adamawa and Kebbi States, Nigeria. These included *Sesamum indicum* and *Sesamum radiatum* (white and black sesame), *Arachis hypogaea* (red vatal groundnut), *Balanites aegyptiaca* (desert date), *Hyptis spicigera*, *Swietenia macrophylla* (mahogany), *Citrullus lanatus* (watermelon), and two varieties of *Cucumeropsis mannii* (egusi melon). Additionally, shea butter was obtained from a local producer in Zuru, Kebbi State. All plant materials were authenticated at the Department of Plant Science faculty of Science by Abdulazeez Salihu and the voucher specimens were stored at Usmanu Danfodiyo University Sokoto Herbarium for future reference.

**2.2 Equipment and Reagents**

Oil extraction and analysis were conducted using standard laboratory instrumentation. A TBVECHI-610W mechanical oil press was used for extraction, followed by purification with a centrifuge (Searchtech Instrument 90-2). Other tools included an analytical balance (Mettler Toledo), an Abbe-60 refractometer (NYRL 3\_Leica), a reflux apparatus, a water bath, and basic glassware. Analytical reagents comprised alcoholic potassium hydroxide, hydrochloric acid, phenolphthalein, chloroform, iodine crystals, potassium iodide, sodium thiosulfate, EDTA, methanol, and cyclohexane. HPLC-grade solvents were used throughout.

**2.3 Oil Extraction Process**

Using the method adopted by Bhatia *et al.*, (2024), Seed samples, ranging between 100-500 g, were first cleaned, air-dried, and manually dehulled where necessary. Oil extraction was carried out at temperatures not exceeding 50 °C using a cold-

press technique. The crude oils obtained were purified by centrifugation at speeds ranging from 2,000 to 39,000 rpm for 20 minutes. Yield, temperature, and color of the oils were recorded for comparative purposes.

**2.4 Physicochemical Analyses**

By adopting the method as described by De Oliveira *et al.*, (2025), the saponification value (SV) was determined by refluxing oil samples with alcoholic potassium hydroxide, followed by titration with standard hydrochloric acid in the presence of phenolphthalein. The iodine value (IV) was assessed using the Hanus method, where oil samples were treated with chloroform and iodine solution, then titrated with sodium thiosulfate after reacting with potassium iodide and water. The refractive index of each oil was measured at 25°C using an Abbe refractometer. Fatty acid composition was characterized through gas chromatography-mass spectrometry (GC-MS) with an Agilent 7890A-5975C system equipped with an HP/5MS column. The identification of fatty acids was achieved by adopting the method as described by Ahmad *et al.*, (2024), by comparing retention times and spectra with those from the NIST database.

**2.5 Method for oil formulation**

Six prototype creams were formulated as shown in Tables 1 and 2 below.

In Table 1, the formulation of the organic formulated products was based on the concentration of the various components of the cream. However, shea butter, which served as both the medium and an active component, had the highest concentration.

In Table 2, the most effective formula type or prototype from Table 1 was used to formulate the prototypes in Table 2 by excluding some of the components. The ingredients (shea butter and carrot oil) were measured and heated to 50 °C, then mixed until a homogeneous mixture was obtained. The mixture was then allowed to cool while monitoring changes in viscosity. Essential oil was added at the lowest possible temperature to avoid loss of its volatile components, stirred thoroughly, and stored in an airtight container.

**Table 1:** Formulation of Organic skin oil product at varying concentration of components

| Sample Constituents | Formula 1 (g) | Formula 2 (g) | Formula 3 (g) |
|---------------------|---------------|---------------|---------------|
| Shear Butter        | 250           | 250           | 250           |
| Carrot Oil          | 0.5           | 0.4           | 0.3           |
| Essential Oil       | 0.5           | 0.4           | 0.3           |
| Non-volatile oils   | +             | +             | +             |

**Table 2:** Formulation of Organic Sunscreen by Component Exclusion

| Sample Constituents | Formula 1 (g) | Formula 2 (g) | Formula 3 (g) |
|---------------------|---------------|---------------|---------------|
| Shear Butter        | 250           | 250           | 250           |
| Carrot Oil          | +             | -             | +             |

|                   |   |   |   |
|-------------------|---|---|---|
| Essential Oil     | - | + | + |
| Non-volatile oils | + | + | + |

2.6 Bioactivity Evaluation

Antimicrobial properties of the oils were tested against selected Gram-positive and Gram-negative bacteria (*Staphylococcus aureus*, *Streptococcus pyogenes*, *Escherichia coli*, *Salmonella typhi*) as well as fungi (*Candida albicans*, *Trichophyton rubrum*). The agar well diffusion method was employed on appropriate media: Mueller-Hinton agar for bacteria and Potato Dextrose agar for fungi. Wells, 6 mm in diameter, were filled with oil samples (dissolved in DMSO at concentrations ranging from 62.5 to 500 mg/mL). Zones of inhibition were measured after incubation at 37°C for 24 h (bacteria) and 25°C for 48 h (fungi). Chloramphenicol and Griseofulvin served as positive controls, while DMSO acted as the negative control.

Minimum inhibitory concentrations (MICs) were determined via broth dilution as described by Giello *et al.*, (2024), where oils were serially diluted and inoculated with 10<sup>5</sup> CFU/mL bacterial or fungal suspensions. The lowest concentration that showed no visible growth was recorded as the MIC. To establish minimum bactericidal and fungicidal concentrations (MBC/MFC), samples from the MIC tests were sub cultured onto fresh agar plates. The MBC/MFC was defined as the lowest concentration resulting in no microbial growth after incubation.

2.7 Statistical Analysis

All experiments were performed in triplicate. Results are presented as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used to assess statistical significance, with p-values less than 0.05 considered significant.

3. Results and Discussion

3.1 Fatty Acid Composition of Natural Base Oils

The analysis of fatty acid profiles across the various plant-derived oils (Table 1) reveals a predominance of C<sub>16</sub> and C<sub>18</sub> chain lengths, comprising saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA). Among the oils analyzed, *Cucumeropsis mannii* (Egusi melon<sup>2</sup>) exhibited the highest total fatty acid content at 87.38%, composed of 7.31% saturated and 80.07% polyunsaturated fatty acids, but notably lacked MUFAs. This lipid profile suggests a strong potential for use as a moisturizing agent in cosmetic applications due to the high PUFA content, which is known to enhance skin hydration and barrier function (Chifomboti & Chimphango, 2025).

*Swietenia macrophylla* (Mahogany) ranked second in total fatty acid content (77.48%), largely attributable to MUFAs (45.85%) and diverse saturated fatty acids including C<sub>12</sub>, C<sub>14</sub>, C<sub>15</sub>, and C<sub>16</sub>. Although it lacks PUFAs, its rich composition of MUFAs aligns with previous findings that suggest the presence of vaccenic acid, which may impart antimicrobial properties. The high MUFA and SFA content makes Mahogany oil a good humectant base (Binazir *et al.*, 2024).

Conversely, *Cucumeropsis mannii* (Egusi melon<sup>1</sup>) was entirely composed of PUFAs (76.66%) and did not contain detectable amounts of SFAs or MUFAs, reinforcing its potential role as a lightweight, non-greasy emollient in dermatological products.

*Balanites aegyptiaca* (Desert date) displayed the lowest total fatty acid content (44.16%), with a moderate PUFA level (37.67%) and low SFA content (2.89% C<sub>16</sub>; 3.6% C<sub>17</sub>). The relatively low lipid content may limit its stand-alone utility, but it could still serve as a secondary additive (Singh & Gaur, 2024).

The fatty acid diversity among these oils underscores their suitability for formulation into multifunctional topical products, particularly in cosmetics and dermatology, where specific fatty acid profiles are often tailored to target hydration, barrier repair, or antimicrobial functions (Geng *et al.*, 2023).

3.2 Physicochemical Properties of Selected Oils

Table 2 presents the saponification values (SV), iodine values (IV), and refractive indices (RI) of selected oils. Saponification values ranged from 145.3g for Egusi melon 1 to 197.8g for watermelon oil, with all samples falling within or close to their expected standard ranges. This suggests high triglyceride content and suitability for soap-making and emulsifying applications (Nasiri *et al.*, 2025).

Iodine values, which reflect the degree of unsaturation (Wu *et al.*, 2022), ranged from 82.91 (Mahogany) to 142.2 (Egusi melon<sup>1</sup>). Egusi melon<sup>1</sup>'s high IV indicates its oil is highly unsaturated, further supporting its use as a lightweight moisturizer (Nguyen *et al.*, 2025). On the other hand, Mahogany oil's lower IV is consistent with its high SFA/MUFA profile, indicating greater oxidative stability, which is an advantageous trait for formulations intended for long shelf-life or exposure to heat.

Refractive indices ranged between 1.3 and 1.6, aligning with the typical values for vegetable oils and indicating that the samples are pure, unadulterated, and optically stable.

**Table 3:** Fatty Acids Analysis of Oil Samples

| Oil Source Type   | % of Saturated fatty acid and chain length | % of mono-unsaturated fatty acid chain length | % of unsaturated fatty acid chain length | Total fatty acids content (%) |
|---|--|---|--|-------------------------------|
| White sesame seed oil ( <i>Sesamum indicum</i> )        | 1.61(16)                                   | 7.17(18)                                      | 76.85 (18)                               | 85.63                         |
| Black sesame ( <i>Sesamum radiatum</i> )                | 0.41(17)                                   | 14.37 (18)                                    | 36.97 (18)                               | 51.75                         |
| Red Vatal ground nut ( <i>Arachis hypogaea</i> )        | 4.25(16),5.39(18)                          | 6.67(18)                                      | 44.46(18)                                | 60.77                         |
| Desert date ( <i>Balanites aegyptiaca</i> Del)          | 2.89(16), 3.6(17)                          |   | 37.67(18)                                | 44.16                         |
| Black “sesame” ( <i>Hyptis spicigera</i> Lam)           | 3.85(16)                                   | 3.99(18)                                      | 47.13(18), 4.95(20)                      | 59.92                         |
| Mahogany ( <i>Swietenia macrophylla</i> )               | 4.31(12),0.56(15), 0.65(14),26.11(16),     | 45.85(18)                                     |  | 77.48                         |
| Watermelon ( <i>Citrullus lanatus</i> )                 | 10.64(16)                                  | 64.88(18)                                     |  | 75.52                         |
| Egusi Melon <sup>1</sup> ( <i>Cucumeropsis mannii</i> ) |  |   | 76.66(18)                                | 76.66                         |
| Egusi melon <sup>2</sup> ( <i>Cucumeropsis mannii</i> ) | 7.31(16)                                   |   | 80.07(18)                                | 87.38                         |

**Table 4:** Saponification, Iodine Values, and Refractive Indices of the Oils

| Oil source               | Saponification Value (SV) g | Standard SV Range (g) | Iodine Value (IV) | Standard IV Range (g) | Refractive Index |
|--------------------------|-----------------------------|-----------------------|-------------------|-----------------------|------------------|
| White sesame             | 189.7                       | 188 - 195             | 97.01             | 96-112                | 1.5              |
| Mahogani                 | 194.8                       | NA                    | 82.91             | 80-100                | 1.6              |
| Water melon              | 197.8                       | 190 - 198             | 122.74            | 103-130               | 1.4              |
| Hyptis seeds             | 182.4                       | 188 - 195             | 125.52            | 103-130               | 1.3              |
| Desert date seed         | 186.7                       | NA                    | 89                | 78-90                 | 1.5              |
| Egusi melon <sup>1</sup> | 145.3                       | NA                    | 142.2             | 133-143               | 1.4              |
| Arachi oil               | 195.7                       | 188 to 196            | 123.92            | 115-125               | 1.4              |
| Black sesame             | 162                         | NA                    | 85.01             | 85-99                 | 1.5              |
| Egusi melon <sup>2</sup> | 185.2                       | NA                    | 97.01             | 96-112                | 1.4              |

**Table 5:** Formulation of Organic prototype materials at varying concentration of component

| Component  | Formula 1 (g)  | Formula 2 (g)  | Formula 3 (g)  |
|--|----------------|----------------|----------------|
| Shea Butter  | 250            | 250            | 250            |
| Carrot oil   | 15             | 10             | 5              |
| Essential oils   | 0.05           | 0.04           | 0.3            |
| Formulation of organic sunscreen from formulation 1 by component exclusion |                |                |                |
| Shea Butter  | 250            | 250            | 250            |
| Carrot oil   | +              | +              | -              |
| Essential oils   | +              | -              | +              |
| Additives  | Formula 1 (ml) | Formula 2 (ml) | Formula 3 (ml) |

|                            |   |   |   |
|----------------------------|---|---|---|
| Desert date oil            | 5 | 5 | 5 |
| Black sesame oil           | 5 | 5 | 5 |
| White sesame oil           | 5 | 5 | 5 |
| Egusi melon small seed oil | 5 | 5 | 5 |
| Egusi melon big seed oil   | 5 | 5 | 5 |
| Water melon seed oil       | 0 | 5 | 5 |
| Hiptis seed oil            | 5 | 0 | 5 |

Table 5 presents the formulation details of organic prototype materials at varying concentrations of components. The formulation is divided into three sections: the primary formulation of three organic creams (Formula 1, Formula 2, and Formula 3), a modified formulation derived from Formula 1 through component exclusion, and a section detailing the additives used in each formula.

In the first section of the table, the core components Shea butter, carrot oil, and essential oils were used in different concentrations across the three formulations. Shea butter, which serves as both the base and an active ingredient due to its emollient and moisturizing properties, was used at a constant amount of 250 grams in all three formulas. Carrot oil, valued for its antioxidant and skin-rejuvenating properties, was incorporated at decreasing concentrations: 15 g in Formula 1, 10 g in Formula 2, and 5 g in Formula 3. This gradient suggests an intention to evaluate the effect of carrot oil concentration on the characteristics or efficacy of the product. Essential oils were included in all three formulas in varying amounts: 0.05 g in Formula 1, 0.04 g in Formula 2, and notably increased to 0.3 g in Formula 3, to enhance aroma and contribute to antimicrobial activity.

The second part of the table describes the formulation of organic products based on Formula 1 through the exclusion of certain components. In this section, Shea butter remains constant at 250 g across the three variants. Carrot oil is retained in Formula 1 and Formula 2 but excluded from Formula 3, while essential oils are included in Formula 1 and Formula 3 but excluded from Formula 2. This exclusion strategy was employed to evaluate the individual contribution of each component by observing the performance of the resulting products in their absence.

The final section of Table 5 lists various plant-based oils used as additives in the three formulations. These include desert date oil, black sesame oil,

white sesame oil, egusi melon small seed oil, and egusi melon big seed oil—all of which were consistently included at 5 ml in each formula, suggesting they are fundamental to the product's intended functionality, possibly contributing emollient, antioxidant, or antimicrobial properties. However, watermelon seed oil was excluded in Formula 1 and included at 5 ml in Formulas 2 and 3, while Hiptis seed oil was included in Formulas 1 and 3 but excluded from Formula 2. These variations offer an opportunity to assess the influence of these specific additives on the final product characteristics.

3.3 Antimicrobial Activity of Formulated Oils

The antimicrobial efficacy of three oil-based formulations (Formulations 1-3) was evaluated against representative Gram-positive bacteria (*Staphylococcus aureus*, *Streptococcus pyogenes*), Gram-negative bacteria (*Escherichia coli*, *Salmonella typhi*), and fungi (*Candida albicans*, *Trichophyton rubrum*). Results are summarized in Tables 3-6 and Figures 10-15. The rationale for selecting both Gram-positive and Gram-negative strains lies in their structural differences and clinical significance. Gram-positive pathogens like *S. aureus* are major agents in skin infections, while Gram-negative bacteria such as *E. coli* and *S. typhi* contribute to gastrointestinal and urinary tract infections (Markowska-Szczupak et al., 2024). Similarly, *T. rubrum* and *C. albicans* were selected for their roles in cutaneous and opportunistic fungal infections, respectively.

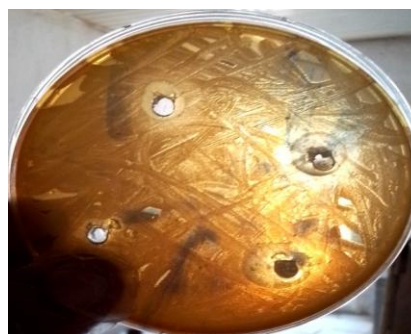
3.3.1 Formulation 1

Formulation 1 demonstrated notable antifungal activity, particularly against *T. rubrum*, with a zone of inhibition of 32.0 ± 3.00 mm at 500 mg/ ml (Table 3; Figure 1). Moderate antibacterial activity was observed against *S. aureus* (24.0 ± 0.0 mm) and *S. typhi* (16.0 ± 1.00 mm), although activity diminished with decreasing concentrations.

Table 6: Diameter zone of Inhibition (mm) of Formulation 1 against the microorganisms

| Test Organisms                | Concentration (mg/ml) |           |          |          |
|-------------------------------|-----------------------|-----------|----------|----------|
|                               | 500                   | 250       | 125      | 62.50    |
| <b>Gram-Positive Bacteria</b> |                       |           |          |          |
| <i>Staphylococcus aureus</i>  | 24.0±0.0              | 10.0±0.00 | 4.0±0.00 | 2.0±0.00 |
| <i>Streptococcus pyogenes</i> | 10.0±0.00             | 6.0±0.00  | 6.0±0.00 | 4.0±0.00 |
| <b>Gram-Negative Bacteria</b> |                       |           |          |          |
| <i>Escherichia coli</i>       | 6.0±0.00              | 5.0±0.00  | 4.0±0.00 | 4.0±0.00 |

|                            |           |           |          |          |
|----------------------------|-----------|-----------|----------|----------|
| <i>Salmonella typhi</i>    | 16.0±1.00 | 14.0±0.50 | 6.0±0.00 | 4.0±0.00 |
| <b>Fungi</b>               |           |           |          |          |
| <i>Candida albicans</i>    | 18.0±0.00 | 6.0±0.00  | 2.0±0.00 | 1.0±0.00 |
| <i>Trichophyton rubrum</i> | 32.0±3.00 | 16.0±1.00 | 8.0±0.50 | 6.0±2.00 |

Figure 1: Formulation 1 against *Staphylococcus aureus*.Figure 2: Formulation 1 against *Salmonella typhi*Figure 3: Formulation 1 against *Trichophyton rubrum*

Interestingly, the relatively strong antifungal performance compared to its antibacterial activity could be attributed to the presence of essential oils rich in terpenes and terpenoids-compounds well-documented for their fungistatic and fungicidal actions (Usman *et al.*, 2025). The synergistic interaction of these compounds with the fatty acid matrix might explain this differential efficacy.

### 3.3.2 Formulation 2

Formulation 2 exhibited generally reduced antimicrobial activity compared to Formulation 1 (Table 4). The largest inhibition zone was recorded against *T. rubrum* ( $24.0 \pm 1.00$  mm at 500 mg/ ml), while antibacterial effects against *S. aureus* and *S. typhi* were modest ( $12.0 \pm 0.0$  mm and  $12.0 \pm 0.0$  mm, respectively). The presence of essential oils in this formulation was limited, which may account for the lower activity profile.

**Table 7:** Diameter zone of Inhibition (mm) of Formulation 2 against the microorganisms

| Test Organisms                | Concentration (mg/ ml) |           |          |          |
|-------------------------------|------------------------|-----------|----------|----------|
|                               | 500                    | 250       | 125      | 62.50    |
| <b>Gram-Positive Bacteria</b> |                        |           |          |          |
| <i>Staphylococcus aureus</i>  | 12.0±0.0               | 10.0±0.00 | 4.0±0.00 | 2.0±0.00 |
| <i>Streptococcus pyogenes</i> | 8.0±0.00               | 6.0±0.00  | 6.0±0.00 | 4.0±0.00 |
| <b>Gram-Negative Bacteria</b> |                        |           |          |          |
| <i>Escherichia coli</i>       | 6.0±0.00               | 6.0±1.00  | 4±0.00   | 2.0±0.00 |
| <i>Salmonella typhi</i>       | 12.0±0.00              | 12.0±1.00 | 6.0±0.00 | 4.0±0.00 |



**Fungi**

|                            |           |           |           |          |
|----------------------------|-----------|-----------|-----------|----------|
| <i>Candida albicans</i>    | 16.0±0.00 | 8.0±0.00  | 8.0±0.00  | 4.0±0.00 |
| <i>Trichophyton rubrum</i> | 24.0±1.00 | 22.0±1.50 | 14.0±0.00 | 2.0±0.00 |

**3.3.3 Formulation 3**

Formulation 3 demonstrated the most balanced and potent antimicrobial activity among the formulations (Table 5). Against *S. aureus*, it achieved an

inhibition zone of  $8.0 \pm 0.0$  mm at 500 mg/L, while its action against *T. rubrum* was significant ( $20.0 \pm 2.00$  mm). Figures 4-6 clearly illustrate the broad-spectrum efficacy of this formulation.

**Table 8:** Diameter zone of Inhibition (mm) of Formulation 3 against the microorganisms

| Test Organisms                | Concentration (mg/ ml) |           |           |           |
|-------------------------------|------------------------|-----------|-----------|-----------|
|                               | 500                    | 250       | 125       | 62.50     |
| <b>Gram-Positive Bacteria</b> |                        |           |           |           |
| <i>Staphylococcus aureus</i>  | 8.0±0.0                | 8.0±0.00  | 6.0±0.00  | 4.0±0.00  |
| <i>Streptococcus pyogenes</i> | 12.5±0.50              | 10.0±1.00 | 8.0±0.00  | 2.0±0.00  |
| <b>Gram-Negative Bacteria</b> |                        |           |           |           |
| <i>Escherichia coli</i>       | 12.0±0.00              | 8.0±1.00  | 3.5±0.50  | 2.0±0.00  |
| <i>Salmonella typhi</i>       | 14.0±1.00              | 13.0±0.50 | 8.0±0.00  | 4.0±0.00  |
| <b>Fungi</b>                  |                        |           |           |           |
| <i>Candida albicans</i>       | 18.0±0.00              | 4.5±0.00  | 2.0±0.00  | 2.0±0.00  |
| <i>Trichophyton rubrum</i>    | 20.0±2.00              | 18.0±1.00 | 16.0±0.50 | 10.0±2.00 |

Each value represents the mean  $\pm$  standard deviation from the mean.



Figure 4: Formulation 3 against *Escherichia coli*



Figure 5: Formulation 3 against *Streptococcus pyogenes*



Figure 6: Formulation 3 against *Candida albicans*

3.3.4 Standard Control Comparison

This formulation did not include carrot extract, thus eliminating carotenoids as the contributing agents. However, the presence of bioactive components such as lauric acid,  $\beta$ -sitosterol, hydroxy-tyrosol, and tocopherols in the base oils likely contributed to its dual antibacterial and antifungal potency. These compounds are known to disrupt microbial membranes and interfere with cell signaling, leading to microbial cell death (Dahiru *et al.*, 2023).

For benchmarking, chloramphenicol and griseofulvin were used as positive controls for bacterial and fungal pathogens, respectively (Table 6). Chloramphenicol achieved a maximum inhibition of  $29.0 \pm 1.00$  mm against *S. typhi*, while griseofulvin showed a zone of  $30.0 \pm 0.00$  mm against *C. albicans*. Notably, Formulation 3 showed comparable inhibition zones, especially against *T. rubrum* ( $20.0 \pm 2.00$  mm), suggesting promising clinical relevance.

**Table 6:** Diameter zone of Inhibition (mm) of control against the microorganisms

| Test Organisms                   | Concentration (mg/ ml) |           |           |           |
|----------------------------------|------------------------|-----------|-----------|-----------|
|                                  | 500                    | 250       | 125       | 62.50     |
| <b>Chloramphenicol (Control)</b> |                        |           |           |           |
| <b>Gram-Positive Bacteria</b>    |                        |           |           |           |
| <i>Staphylococcus aureus</i>     | 28.0±0.0               | 21.0±0.00 | 16.0±0.00 | 8.0±0.00  |
| <i>Streptococcus pyogenes</i>    | 21.0±0.00              | 18.0±1.00 | 12.0±0.00 | 5.0±0.00  |
| <b>Gram-Negative Bacteria</b>    |                        |           |           |           |
| <i>Escherichia coli</i>          | 28.5±0.00              | 25.0±0.50 | 17.5±0.00 | 9.0±0.00  |
| <i>Salmonella typhi</i>          | 29.0±1.00              | 26.0±1.00 | 19.0±0.00 | 11.0±0.00 |
| <b>Griseofulvin (Control)</b>    |                        |           |           |           |
| <b>Fungi</b>                     |                        |           |           |           |
| <i>Candida albicans</i>          | 30.0±0.00              | 25.0±0.00 | 19.0±0.00 | 12.0±0.00 |
| <i>Trichophyton rubrum</i>       | 22.0±1.00              | 18.0±1.00 | 16.0±0.50 | 10.0±2.00 |

Each value represents the mean  $\pm$  standard deviation from the mean.

3.4 Minimum Bactericidal and Fungicidal Concentrations

The MBC and MFC assays confirmed the microbicidal potency of the oil formulations. MBCs were lowest in formulations rich in medium-chain fatty acids and essential oils, which are known to permeate bacterial membranes efficiently. Similarly, MFCs revealed that fungal clearance was most effective in formulations with higher terpene content and tocopherols, supporting earlier inhibition zone data.

4. Conclusion

This study demonstrates the potential of locally sourced, nonvolatile seed oils from Northern Nigeria as valuable ingredients in cosmetic and therapeutic formulations. The physicochemical characterization revealed that oils such as *Cucumeropsis mannii* and *Citrullus lanatus* possess high levels of polyunsaturated and monounsaturated fatty acids, respectively, which are associated with desirable functional properties in topical applications. The

antioxidant and antimicrobial evaluations further confirmed that the oils contain bioactive compounds capable of inhibiting a range of bacteria and fungi. Among the formulated products, Formulation 3 showed the most consistent broad-spectrum antimicrobial activity, with inhibition zones ranging from 2.0 mm to 20.0 mm. This was followed by Formulation 1 (1.0 mm to 32.0 mm) and Formulation 2 (2.0 mm to 24.0 mm). The antimicrobial activity was concentration-dependent, and the variations in formulation components—especially the presence or absence of essential oils and carrot oil—were shown to influence efficacy. Although the results suggest that these oils have significant bioactivity and formulation potential, conclusions regarding their effects on skin hydration, barrier function, or therapeutic performance in humans remain speculative, as no in vivo or clinical studies were conducted. Therefore, further studies involving dermatological assessments, stability testing, and safety profiling are recommended to validate their applicability in commercial skincare and medicinal products.

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## Conflict of Interest

The authors declare no conflict of interest.

## References

- Ahmad, I., Mashwani, Z.-U.-R., Younas, Z., Yousaf, T., El-Sheikh, M. A., & Ahmad, P. (2024). Comprehensive approaches of phytonanoparticles for stress tolerance, growth performance, and improving oil yield in Sesame (*Sesamum indicum*): Mechanism, applications and future prospects. *Plant Stress*, 12, 100498. <https://doi.org/10.1016/j.stress.2024.100498>
- Bhatia, S., Shah, Y. A., Al-Harrasi, A., Alhadhrami, A. S., ALHashmi, D. S. H., Jawad, M., Diblan, S., Al Dawery, S. K. H., Esatbeyoglu, T., Anwer, M. K., Koca, E., & Aydemir, L. Y. (2024). Characterization of biodegradable films based on guar gum and calcium caseinate incorporated with clary sage oil: Rheological, physicochemical, antioxidant, and antimicrobial properties. *Journal of Agriculture and Food Research*, 15, 100948. <https://doi.org/10.1016/j.jafr.2023.100948>
- Binazir, E., Ghanbarzadeh, B., Hanifan, S., Gharekhani, M., Kafil, H. S., & Falcone, P. M. (2024). Development and optimization of thyme-pennyroyal essential oils based active nanostructured lipid carrier (NLC) containing saffron extract with antioxidant and antimicrobial properties. *Food Bioscience*, 61, 104992. <https://doi.org/10.1016/j.fbio.2024.104992>
- Chifomboti, L. P., & Chimphango, A. F. A. (2025). Development and optimization of a two-step co-extraction process for the recovery of pumpkin seed oil and in-situ enrichment with  $\beta$ -carotene compounds from pumpkin peel. *Food and Bioproducts Processing*, 149, 211–223. <https://doi.org/10.1016/j.fbp.2024.11.015>
- Dahiru, M. M., Musa, N., Abaka, A. M., & Abubakar, M. A. (2023). Potential Antidiabetic Compounds from *Anogeissus leiocarpus*: Molecular Docking, Molecular Dynamic Simulation, and ADMET Studies. *Borneo Journal of Pharmacy*, 6(3), 249–277. <https://doi.org/10.33084/bjop.v6i3.5027>
- De Oliveira, D. C. S., Nunes, F. A., Bilek, T., Murakami, C., Grombone-Guaratini, M. T., & Moreno, P. R. H. (2025). Chemical composition and antimicrobial properties of essential oils from two *Guadua* species (Poaceae, Bambusoideae). *Advances in Bamboo Science*, 12, 100171. <https://doi.org/10.1016/j.bamboo.2025.100171>
- Elbouzidi, A., Haddou, M., Baraich, A., Taibi, M., El Hachlafi, N., Pareek, A., Mesnard, F., & Addi, M. (2025). Biochemical insights into specialized plant metabolites: Advancing cosmeceutical applications for skin benefits. *Journal of Agriculture and Food Research*, 19, 101651. <https://doi.org/10.1016/j.jafr.2025.101651>
- Geng, L., Zhou, W., Qu, X., Sa, R., Liang, J., Wang, X., & Sun, M. (2023). Iodine values, peroxide values and acid values of Bohai algae oil compared with other oils during the cooking. *Heliyon*, 9(4), e15088. <https://doi.org/10.1016/j.heliyon.2023.e15088>
- Giello, M., Miele, N. A., Volpe, S., Di Monaco, R., Cavella, S., Villani, F., & Torrieri, E. (2024). Design of an active edible coating: Antimicrobial, physical, and sensory properties of sodium caseinate-guar gum blends enriched in essential oils. *Food Packaging and Shelf Life*, 46, 101395. <https://doi.org/10.1016/j.fpsl.2024.101395>
- Lee, Y., Gou, Y., Pan, X., Gu, Z., & Xie, H. (2023). Advances of multifunctional hydrogels for periodontal disease. *Smart Materials in Medicine*, 4, 460–467. <https://doi.org/10.1016/j.smaim.2023.02.001>
- Markowska-Szczupak, A., Paszkiewicz, O., Wesolowska, A., Kordas, M., & Rakoczy, R. (2024). Optimization of antimicrobial properties of essential oils under rotating magnetic field. *Chemical Engineering and Processing - Process Intensification*, 205, 110041. <https://doi.org/10.1016/j.cep.2024.110041>
- Musa, N., Banerjee, S., Maspalma, G. A., Usman, L. U., & Hussaini, B. (2022). Assessment of the phytochemical, antioxidant and larvicidal activity of essential oil extracted from Simpleleaf Chastetree [*Vitex trifolia*] leaves obtained from Ganye Local Government, Adamawa State-Nigeria. *Materials Today: Proceedings*, 49, 3435–3438. <https://doi.org/10.1016/j.matpr.2021.03.375>
- Nasiri, M., Amirmohseni, L., Abbasi, M. F., Yarahmadi, F., Zonoori, S., Torkaman, M., Sadeghi Moghimi, E., Ardaneh, M., & Asadi, M. (2025). Is the topical application of sesame oil (*Sesamum indicum* L.) combined with standard care valuable and safe for managing infusion-related phlebitis: Evidence from a systematic review with meta-analysis of randomized controlled trials. *Complementary Therapies in Medicine*, 88, 103122. <https://doi.org/10.1016/j.ctim.2024.103122>
- Nguyen, D., Sae-Eaw, A., Chompreeda, P., Siripatrawan, U., & Suppakul, P. (2025). Optimal synergistic formulation of essential oils: Antimicrobial and physical-mechanical properties of cinnamon-oregano oils-incorporated cassava starch films for fresh Vietnamese bread preservation. *Journal of Agriculture and Food Research*, 21, 101897. <https://doi.org/10.1016/j.jafr.2025.101897>
- Runde, M. (2023). Determination of Phyto-Constituents of Leaves and Tuber-like Roots of

- Momordica cymbalaria (Bworhauyala) Grown in Admawa State, Nigeria. Asian Journal of Research in Chemistry, 344–348. <https://doi.org/10.52711/0974-4150.2023.00055>
- Sen, S., Sahu, R., Dua, T. K., Paul, P., & Nandi, G. (2025). Advancements of multifunctional hydrogels in treating periodontal diseases: A concise review. Next Materials, 8, 100825. <https://doi.org/10.1016/j.nxmte.2025.100825>
- Singh, S., & Gaur, S. (2024). Edible seeds pioneered in preparing modern age bakery food products: Recent challenges and applications. Food Chemistry Advances, 4, 100684. <https://doi.org/10.1016/j.focha.2024.100684>
- Tobar-Espinoza, B. D., & Pérez-Correa, J. R. (2025). Advances in seed mucilage: Chemical characterization, functional properties, extraction, and applications in edible coatings for meat preservation. Applied Food Research, 5(1), 100886. <https://doi.org/10.1016/j.afres.2025.100886>
- Usman, I., Sana, S., Afzaal, M., Imran, A., Jaffar, H. M., Sukhera, S., Munir, M., Asghar, A., & Urugo, M. M. (2025). Phytochemicals in plant food waste: Innovative insight and implications. Journal of Agriculture and Food Research, 20, 101779. <https://doi.org/10.1016/j.jafr.2025.101779>
- Wu, L., Zhao, J., Wu, L., Zhang, Y., & Li, J. (2022). Simultaneous determination of squalene, tocopherols and phytosterols in edible vegetable oil by SPE combined with saponification and GC-MS. LWT, 169, 114026. <https://doi.org/10.1016/j.lwt.2022.114026>