West African Journal of Life Sciences. Available online at ***http://www.wajls.com*** *ISSN (Print):2992-5150. eISSN:3122-0916*
Volume 2; Issue 2: pages 34-45

Full Length Research

Gas Chromatograpgy – Mass Spectrometry (GC-MS) Profiling of Bioactive Constituents and Antimicrobial Activities of *Chrysophyllum albidum* Seed Extracts

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ABSTRACT

Chrysophyllum albidum (African star apple) is an important West African medicinal plant traditionally used in managing infectious and metabolic disorders. This study investigated the fruit parts (especially seed extracts) of *Chrysophyllum albidum* and their bioactive compounds were screened and characterized using gas chromatography–mass spectrometry (GC–MS). Antibacterial and antifungal activities of methanol, aqueous, and n-hexane (seed oil) extracts were evaluated against *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Bacillus subtilis*, *Candida albicans*, and *Aspergillus fumigatus*. Phytochemical screening revealed high levels of alkaloids and steroids in the pulp and high carbohydrate content in the seed. The methanolic and aqueous seed extracts contained 29 and 25 GC–MS–identified compounds, respectively, while the seed oil contained 40 compounds. Major constituents included n-hexadecanoic acid, linoleic acid, oleic acid, palmitic acid ethyl ester, squalene, stigmasterol, and vitamin E, all known for antioxidant, antimicrobial, anti-inflammatory, and hypolipidemic activities. Antimicrobial assays showed concentration-dependent inhibition, with methanol extract exhibiting the highest inhibitory zones at 40 mg/mL: 23.5 mm (*B. subtilis*), 20.4 mm (*S. aureus*), 18.8 mm (*K. pneumoniae*), 17.3 mm (*P. aeruginosa*), 18.0 mm (*C. albicans*), and 17.5 mm (*A. fumigatus*). Minimum inhibitory concentrations (MICs) ranged from 12–18 mg/mL for methanol extract, 14–20 mg/mL for aqueous extract, and 4–16% v/v for seed oil. The findings indicate that *C. albidum* fruit parts—particularly the seed—harbor promising antimicrobial agents and bioactive phytochemicals supporting their traditional medicinal use.

Keywords: *Chrysophyllum albidum*; phytochemicals; GC–MS; seed oil; antimicrobial activity; bioactive compounds

Received Dec. 2 25, 2025

Received in Revised form, Dec. 8, 2025

Accepted Dec. 9, 2025

Available Online Dec. xxx, 2025

W. Afr. J. Life Sci. 2 (2):34-45

INTRODUCTION

Plants remain an essential source of therapeutic agents, with over 60% of approved drugs derived from or inspired by natural products (Newman & Cragg, 2020). In sub-Saharan Africa, medicinal plants play a central role in primary healthcare, prompting growing scientific interest in characterizing their phytochemical and pharmacological potentials (Oluwafemi *et al*., 2022). *Chrysophyllum albidum* G. Don (Sapotaceae), commonly called African star apple, is a widely consumed fruit in West Africa. Beyond its nutritional value, several plant parts—including the leaves, bark, pulp, and seeds—are used traditionally for treating malaria, diarrhea, wounds, infections, and oxidative stress–related disorders (Adebayo et al., 2021).

Previous studies have reported that *C. albidum* contains flavonoids, phenols, alkaloids, and tannins, which contribute to its antioxidant and antimicrobial properties (Adeyemi et al., 2019; Okoli et al., 2022). However, there is limited comparative evidence on the distribution of phytochemicals between the pulp and seed, and fewer studies have comprehensively profiled the seed's bioactive compounds using advanced analytical techniques such as gas chromatography–mass spectrometry (GC–MS). GC–MS provides a powerful platform for identifying fatty acids, esters, sterols, alkaloids, and other volatile or semi-volatile compounds associated with therapeutic activities (Rizwana et al., 2023).

Microbial resistance to conventional antibiotics continues to rise globally, necessitating the discovery of potent natural antimicrobials (World Health Organization, 2021). Since fruit seeds often contain concentrated bioactive constituents, evaluating *C. albidum* seed extracts for antimicrobial efficacy is both relevant and timely.

This study therefore aims to: compare the phytochemical composition of *C. albidum* pulp and seed;

identify bioactive constituents of seed extracts (methanol, aqueous, and seed oil) using GC–MS. And

assess the antimicrobial activities of the seed extracts against selected bacterial and fungal pathogens.

MATERIALS AND METHODS

Sample Collection and Preparation

Fresh *Chrysophyllum albidum* fruits were obtained from Ekpoma market, washed, peeled, and separated into pulp and seed portions. The pulp and seeds were air-dried, oven dried at 65 ºC for two weeks using Hot air oven (size 2, Gallenkamp, U.K.) and pulverized using GCSR Mixer Grinder India pulverized. These were respectively stored in airtight containers until extraction.

Phytochemical Screening

Qualitative phytochemical analyses of the pulp and seed extracts were performed according to standard procedures described by Harborne (1998) and Trease & Evans (2009). The presence of alkaloids, tannins, saponins, flavonoids, carbohydrates, steroids, phenols, and anthraquinones was assessed, and results were recorded using the rating scale:

+++ = highly present, ++ = moderately present, + = trace, − = absent.

Extraction of Seed Material

Fresh fruits of *Chrysophyllum albidum* were washed, manually separated into pulp and seeds, and air-dried at 40 °C to constant weight, following the sample preparation procedures previously described for *C. albidum* fruit parts (Adegbite et al., 2021; Owolabi & Ogunlade, 2019). The dried samples were milled using a laboratory grinder and sieved through a 0.5-mm mesh to achieve uniform particle size, as recommended in plant-material extraction studies (Adewuyi et al., 2020). Three solvents - methanol, distilled water, and n-hexane—were used. Seed oil was extracted using a Soxhlet apparatus with n-hexane (1:10 w/v) for 6 h at 65 °C, consistent with established protocols for *C. albidum* seed-oil recovery (Anang et al., 2019). The solvent was removed under reduced pressure using a rotary evaporator to obtain the crude seed oil. Methanolic and aqueous extracts of both pulp and seed powders were prepared by maceration in 80% methanol and distilled water (1:10 w/v) for 48 h with intermittent shaking, following standard solvent-extraction methods used in phytochemical studies of *C. albidum* (Adebayo *et al.*, 2022; Nwankwo et al., 2020). Filtrates were concentrated at 40 °C using a rotary evaporator for methanolic extracts and freeze-dried for aqueous extracts to yield crude extracts. All extracts were stored at 4 °C in amber vials until analysis to preserve thermo-labile phytoconstituents (Ezeabara et al., 2021).

GC–MS Analysis

Gas chromatography–mass spectrometry (GC–MS) analysis of the extracts was carried out using a Shimadzu GC–MS system (Model QP-2010, Shimadzu, Tokyo, Japan) equipped with a VF-5ms fused-silica capillary column (30 m × 0.25 mm × 0.25 μm). Injection was performed in split mode, and helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. The oven temperature program and mass spectrometric operating conditions were optimized following established GC–MS analytical procedures for plant metabolites (Adah et al., 2021; Singh & Sharma, 2020). The identification of components was achieved by comparing the obtained mass spectra with those in the National Institute of Standards and Technology (NIST) Mass Spectral Library, which contains over 60,000 reference spectra (NIST, 2020). Peak identification was based on similarity index scores ≥90% and supported by fragmentation patterns reported in standard mass spectrometric databases. Quantification of constituents was performed using peak-area normalization to determine the relative percentage composition of each compound (Kumar et al., 2022).

Antimicrobial Assay

Test Organisms

The test microorganisms—*Staphylococcus aureus*, *Klebsiella pneumoniae*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Candida albicans*, and *Aspergillus fumigatus*—were clinical isolates obtained from Irrua Specialist Teaching Hospital (ISTH), Irrua, Edo State, Nigeria. Identification and confirmation of the isolates were carried out in the Microbiology Laboratory of Ambrose Alli University, Ekpoma using standard phenotypic and morphological procedures, including Gram staining, biochemical tests, and sugar assimilation profiles. The identification was verified using updated diagnostic guidelines and laboratory manuals, including the Clinical and Laboratory Standards Institute (CLSI) M100

procedures and the Bergey's Manual of Systematic Bacteriology (2019 edition), as well as recent microbial identification frameworks for pathogenic bacteria and fungi (CLSI, 2023; Guarda et al., 2021; Whitman, 2019).

Agar Well Diffusion Method

Antimicrobial activity of the extracts was assessed using the agar well diffusion method as described by CLSI and modified for plant extracts (CLSI, 2021; Balouiri et al., 2016). Extract concentrations ranging from 10 - 40 mg/mL were introduced into wells bored in Mueller–Hinton agar (for bacteria) and Sabouraud Dextrose agar (for fungi). Plates were incubated under organism-specific conditions, and zones of inhibition were measured in millimeters. Ciprofloxacin (1 µg/mL) served as the bacterial positive control, while ketoconazole (10 µg/mL) served as the antifungal control.

Minimum Inhibitory Concentration (MIC)

MIC values were determined using the broth dilution method for methanolic and aqueous extracts according to CLSI guidelines (CLSI, 2020; Andrews, 2020). Serial dilutions of the extracts were prepared in nutrient broth for bacteria and Sabouraud broth for fungi, inoculated with standardized microbial suspensions, and incubated at appropriate temperatures. For the seed oil, MICs were determined using **v/v** dilution in broth, following established protocols for hydrophobic plant oils (Jain & Sharma, 2021). The MIC was recorded as the lowest concentration showing no visible microbial growth.

STATISTICAL ANALYSIS

Data were expressed as mean ± SEM for triplicate determinations (n=3). Comparisons of the data were performed by Analysis of Variance (ANOVA) followed by Least Significant Difference (LSD) post hoc test at 5% ($p<0.05$) probability.

RESULTS

Results showed that aqueous extract produced the highest yield (19.39%), followed by methanol (16.20%) and n-hexane (8.75%), indicating higher solubility of constituents in polar solvents. This is shown in Table 1. The phytochemical composition of pulp and seed is shown in Table 2. It revealed that pulp contained high quantities of alkaloids and steroids, moderate tannins and saponins, and trace flavonoids and phenols. Seeds contained abundant carbohydrates, moderate flavonoids, and trace phenols and alkaloids. The GC-MS identified compounds were 29 from methanol extract of seed, 25 from aqueous extract of seed and 40 from n-Hexane extract of seed oil. This is shown in Figures 1-3. The key identified bioactive compounds as shown in Table 3 included n-Hexadecanoic acid (antioxidant, hypocholesterolemic), Linoleic acid (anti-inflammatory), Oleic acid (antioxidant), Dodecanoic acid (antioxidant), Squalene (antioxidant, anticancer potential), Stigmasterol (anti-inflammatory, hypolipidemic) and Vitamin E (strong antioxidant).

Table 1: Yields of *C. albidum* seed extracts

Extraction Solvent	Weight of plant material (g)	Weight of extract (g)	Percentage yield
Methanol	359.7 (360)	58.26 (58.2)	16.20
Aqueous	320.4 (360)	62.13 (69.8)	19.39
Hexane (for seed oil)	200.0 (360)	17.5 (31.5)	8.75

Table 2: Phytochemical compounds in the pulp and seed of *C. albidum*

Plant constituent	Pulp	Seed
Carbohydrates	++	+++
Alkaloids	+++	+
Anthraquinones	-	-
Tannins	++	+
Saponins	++	-
Phenols	+	+
Steroids	+++	+
Flavonoids	+	++

Key: +++ = Highly present, ++ = moderately present, + = trace, - = absent

Peak#	Name	Peak#	Name
1	2-Butanone, 4-hydroxy-3-methyl-	16	11-Octadecenoic acid, methyl ester
2	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy	17	Tetradecanoic acid, 12-methyl-, methyl ester
3	Hexanoic acid, octyl ester	18	(E)-9-Octadecenoic acid ethyl ester
4	5-Methyl-2-methylamino-2-thiazoline	19	9,12-Octadecadienoic acid (Z,Z)-
5	Benzonitrile, 2,4,6-trimethyl-	20	Ethyl 14-methyl-hexadecanoate
6	1,2,4-Cyclopentanetrione, 3-butyl-	21	1H-Indole, 4-(3-methyl-2-butenyl)-
7	Adenosine, N6-phenylacetic acid	22	cis-11-Eicosenoic acid
8	d-Glycero-d-galacto-heptose	23	Hexadecanoic acid, 2-hydroxy-1-(hydroxym
9	N-t-Butyl-N'-2-[2-thiophosphatoethyl]amino	24	Propyleneglycol monoleate
10	6H-Purine-6-thione, 9-amino-1,9-dihydro-	25	(E)-9-Octadecenoic acid ethyl ester
11	Hexadecanoic acid, methyl ester	26	Squalene
12	N,N'-Diisopropyl-N"-3-[2-thiophosphatoeth	27	1-Dimethylthexylsilyloxyhexane
13	Hexadecanoic acid, ethyl ester	28	Vitamin E
14	9H-Pyrido[3,4-b]indole, 1-methyl-	29	Stigmasterol
15	9,12-Octadecadienoic acid, methyl ester		

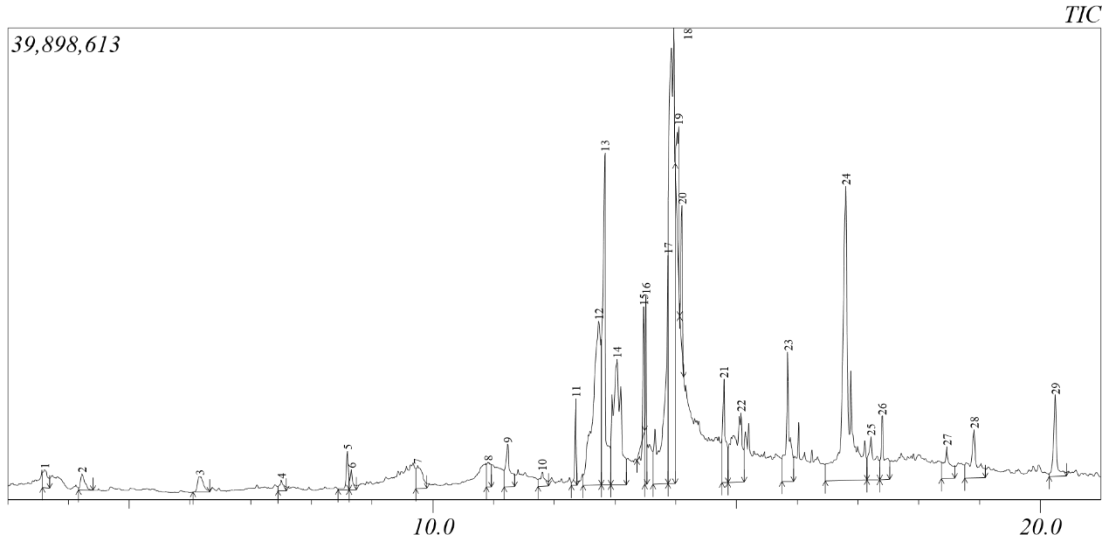

Figure 1: GC-MS of Methanol seed extract of *C. albidum*

Peak#	Name	Peak#	Name
1	Glycerin	14	Pyrrolidine, 5-heptyl-2-hexyl-1-methyl-
2	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy	15	2,4-Dihydroxy-5,6-dimethylpyrimidine
3	d-Mannitol, 1,4-anhydro-	16	9,12-Octadecadienoic acid (Z,Z)-
4	Piperazine, 3-butyl-2,5-dimethyl-	17	1H-1,2,3-Benzotriazole, 1-(3,3-dimethyl-1-b
5	5-Methyl-2-methylamino-2-thiazoline	18	4-Cyanobenzoic acid, undec-10-enyl ester
6	1,2,4-Cyclopentanetrione, 3-butyl-	19	Hexadecanoic acid, 2-hydroxy-1-(hydroxym
7	Ethyl .alpha.-d-glucopyranoside	20	9-Octadecenoic acid (Z)-, 2-hydroxy-1-(hyd
8	N-t-Butyl-N'-2-[2-thiophosphatoethyl]amin	21	Octadecanoic acid, 2,3-dihydroxypropyl est
9	Urea, N,N'-bis(1,1-dimethylethyl)-	22	2(1H)Naphthalenone, 3,5,6,7,8,8a-hexahydr
10	Rizatriptan	23	Vitamin E
11	n-Hexadecanoic acid	24	Ergosta-7,22-dien-3-ol, (3.beta.,22E)-
12	9H-Pyrido[3,4-b]indole, 1-methyl-	25	2H-3,9a-Methano-1-benzoxepin, octahydro
13	9H-Pyrido[3,4-b]indole		

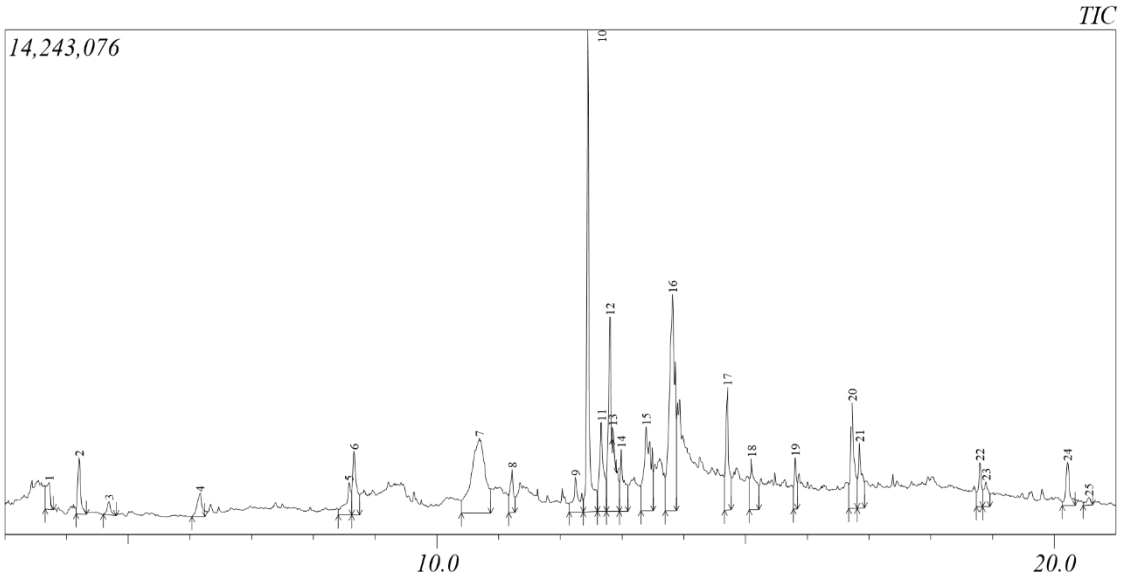

Figure 2: GC-MS of Aqueous seed extract of *C. albidum*

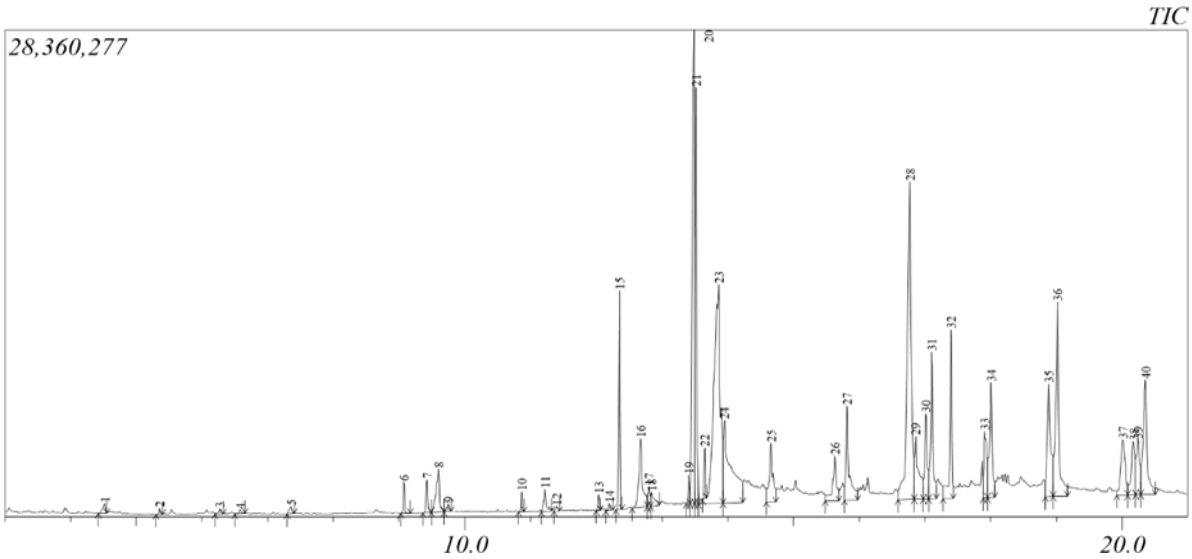

Figure 3: GC-MS of n-Hexane extract of C. albidum seed oil

Peak#	Name	Peak#	Name
1	Octanoic acid	21	11-Octadecanoic acid, methyl ester
2	Thymoquinone	22	Methyl stearate
3	Carbamic acid, N-[1,1-bis(trifluoromethyl)p	23	17-Octadecynoic acid
4	Tetradecanoic acid, 12-methyl-, methyl ester	24	17-Octadecynoic acid
5	n-Decanoic acid	25	9,12-Octadecadienoic acid (Z,Z)-
6	Dodecanoic acid, methyl ester	26	cis-9-Hexadecenal
7	Ethanone, 1-(2-hydroxy-5-methoxyphenyl)	27	Hexadecanoic acid, 2-hydroxy-1-(hydroxym
8	Dodecanoic acid	28	Oleoyl chloride
9	Hexadecanoic acid, ethyl ester	29	Octadecanoic acid, 2,3-dihydroxypropyl est
10	Tridecanoic acid, 12-methyl-, methyl ester	30	Dodecanoic acid, ethenyl ester
11	Tetradecanoic acid	31	Dodecanoic acid, 2-hydroxy-1-(hydroxymet
12	Nonanoic acid, 9-oxo-, ethyl ester	32	Squalene
13	1-Hexadecanol	33	Ethyl stearate, 9,12-diepoxy
14	9-Decenoic acid	34	Dodecanoic acid, 2,3 dihydroxypropyl ester
15	Hexadecanoic acid, methyl ester	35	Dodecanoic acid, ethenyl ester
16	n-Hexadecanoic acid	36	Dodecanoic acid, 1-(hydroxymethyl)-1,2-eth
17	Nonanoic acid, 9-oxo-, ethyl ester	37	Dodecanoic acid, ethenyl ester
18	2-Isobutyl-4,6,6-trimethyl-1,3,2-oxaazabori	38	Dodecanoic acid, ethenyl ester
19	1-Eicosanol	39	gamma.-Sitosterol
20	9,12-Octadecadienoic acid (Z,Z)-, methyl ester	40	Myristic anhydride

The key identified bioactive compounds as shown in Table 3 included n-Hexadecanoic acid (antioxidant, hypocholesterolemic), Linoleic acid (anti-inflammatory), Oleic acid (antioxidant), Dodecanoic acid (antioxidant), Squalene (antioxidant, anticancer potential), Stigmasterol(anti-inflammatory, hypolipidemic) and Vitamin E (strong antioxidant).

Table 3: Bioactive Compounds from Methanolic, Aqueous and n-Hexane Extracts of *C. albidum* Seeds and their Activities

Compound name	Activity	Source of Component
n-Hexadecanoic acid	Antioxidant, Hypocholesterolemic	B and C
Octadacanoic acid	Antifungi, Antitumor	B and C
Methyl ester	Hypocholesterolemic	A and C
11- octadecenoic acid	Hypolipidemic	A and C
Hexadecanoic acid, ethyl ester	Antioxidant, Hypocholesterolemic	A and C
9, 12 octadecadienoic acid (Linoleic acid)	Anti-inflammatory	A, B and C
Dodecanoic acid	Antioxidant	C
9 octadecenoic acid (Oleic acid)	Antioxidant	B
1- Eicosanol	Antifungi, Antitumor	C
Squalene	Antioxidant, anti-inflammatory, anticancer potential, skin protectant	A
Stigmasterol	Anti-inflammatory, anticancer, hypolipidemic, Hypocholesterolemic effect	A and C
Vitamin E	Strong antioxidant, anti-inflammatory, immunomodulatory	A and B

Key: A= Methanol extract of seed, B = Aqueous extract of seed and C= n-Hexane extract of seed oil

Figure 4 showed the antibacterial activity of the methanol, aqueous and n-Hexane seed extract of *C. albidum* at different concentrations, indicated by the inhibitory zone diameters (IZDs). The highest IZD at 40mg/ml for *P. aeruginosa* was 17.3±0.7mm (methanol) against 15.8±0.2mm and 12.6±0.4mm for n-hexane and aqueous extracts respectively. Also, the highest IZD at 40mg/ml for *K. pneumoniae* was 18.8±1.3mm (methanol) against 17.0±0.0mm and 14.3±0.2mm for n-hexane and aqueous extracts respectively. Similar pattern of IZDs were recorded at 40mg/ml for *S. aureus* at 20.4±0.6mm (methanol) against 17.8±1.3mm and 15.5±1.5mm for n-hexane and aqueous extracts respectively. The highest IZD at 40mg/ml for *B. subtilis* was 23.5±1.5mm (methanol) against 21.3±0.2mm and 17.8±0.2mm for n-hexane and aqueous extracts respectively. The positive control ciprofloxacin (1µg/ml) recorded higher IZDs than even the highest concentration of the extracts considered.

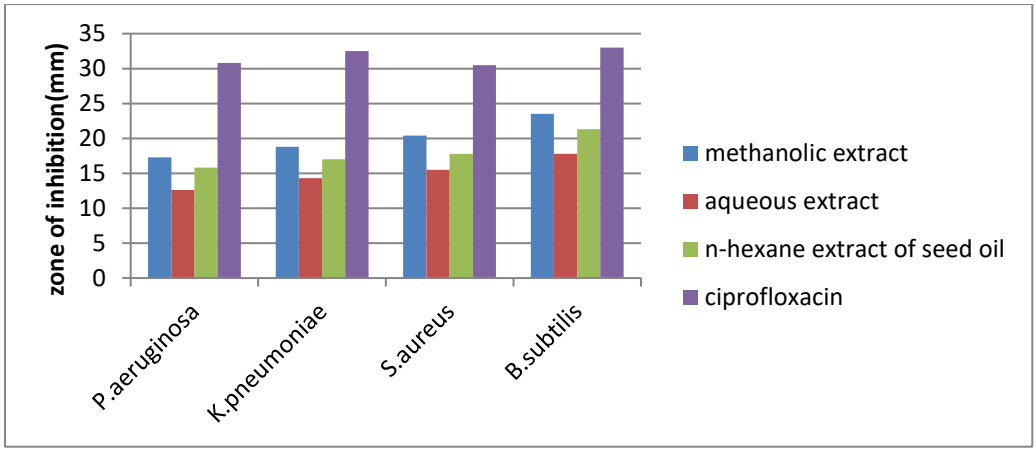

Figure 4: Antibacterial Activity of seed Extracts of *C. albidum* (Methanol, Aqueous and n-hexane)

Figure 5 showed the antifungal activity of the methanol, aqueous and n-Hexane seed extract of *C. albidum* at different concentrations. The highest IZD of *C. albicans* at 40mg/ml was 18.0±0.0mm (methanol) against 16.5±0.5mm and 13.0±0.0mm for n-hexane and aqueous extracts respectively. Also, the highest IZD at 40mg/ml for *A. fumigatus* was 17.5±1.5mm (methanol) against 16.0±0.0mm and 12.0±0.1mm for n-hexane and aqueous extracts respectively. The positive control ketoconazole (10µg/ml) recorded higher IZDs than even the highest concentration of the extracts considered.

Table 4 showed the summary of the MICs of the various seed extracts of *C. albidum* against the test organisms. The MIC of the methanol extract ranged from 12 – 18 mg/mL, aqueous extract 14 – 20 mg/mL and n-Hexane seed oil extract 4 – 16% v/v. The lowest MIC was 4% (seed oil) against *B. subtilis*, indicating strong sensitivity.

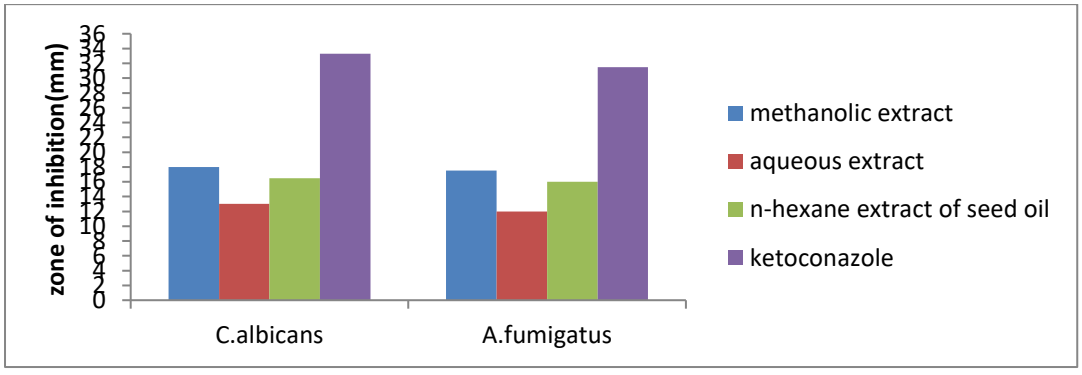

Figure 5: Antifungal activity of seed extracts of *C. albidum* (Methanol, Aqueous and n-hexane)

Table 4: MICs of extracts against the test organisms

Organisms	Methanol extract	aqueous extract	Hexane extracted oil
	MICs (mg/ml)		MICs ($^{v}/_{v}$ %)
P. aeruginosa	18	20	16
K. pneumoniae	14	18	14
S. aureus	12	16	8
B. subtilis	12	14	4
C. albicans	14	18	12
A. fumigatus	16	20	14

DISCUSSION

The phytochemical analysis of *Chrysophyllum albidum* revealed clear variations in the distribution of secondary metabolites between the pulp and seeds of the fruit. The pulp contained higher levels of alkaloids and steroids, both of which are widely recognized for their pharmacological activities, including antimicrobial, anti-inflammatory, and antioxidant effects. In contrast, the seeds were richer in carbohydrates and contained moderate amounts of flavonoids. This pattern supports previous studies reporting that different anatomical parts of *C. albidum* accumulate diverse bioactive metabolites of medicinal value (Adeyemi et al., 2019; Okoli et al., 2022). Such variations may reflect differences in physiological roles of the tissues, as well as differences in biosynthetic pathways active within each fruit component.

The GC–MS analysis further demonstrated the chemical richness of the extracts by revealing a broad spectrum of fatty acids, esters, sterols, terpenoids, and phenolic derivatives. Many of these compounds are well documented for their antimicrobial, antioxidant, and anti-inflammatory characteristics. Major constituents identified—such as oleic acid, linoleic acid, palmitic acid esters, squalene, and stigmasterol—have been linked to significant broad-spectrum antimicrobial activity and are frequently cited in literature for their ability to inhibit pathogenic microorganisms (Rizwana et al., 2023; Oyebode et al., 2020). Their presence in substantial proportions strongly suggests that they contributed synergistically to the antimicrobial activities recorded in this study.

Among the different solvent extracts, the methanol extract consistently demonstrated the highest antimicrobial potential. This observation can be attributed to methanol's ability to efficiently solubilize a wide range of polar and moderately non-polar compounds, including phenolics, sterols, terpenoids, and fatty acid derivatives. These phytochemical groups are known to possess potent antimicrobial properties, and their enhanced recovery in methanol likely explains the superior biological activity observed. Conversely, the aqueous extract showed comparatively lower antimicrobial effects, a result consistent with its reduced chemical diversity on GC–MS profiling. Water, being highly polar, is limited in its ability to extract many lipophilic bioactive components, which may account for its weaker antibacterial and antifungal properties.

The n-hexane seed oil also exhibited strong antibacterial and antifungal activities. This activity is supported by its high concentration of unsaturated fatty acids such as oleic and

linoleic acids. These compounds have been reported to disrupt microbial cell membranes by increasing membrane fluidity, altering permeability, and inducing leakage of intracellular components, ultimately leading to microbial cell death (Leaper & Harding, 2021). The significant activity observed in the seed oil highlights the therapeutic relevance of the lipid fraction of *C. albidum* and suggests its potential utility in the development of plant-based antimicrobial agents.

The MIC values obtained across the extracts further reinforce the antimicrobial potential of *C. albidum*. The ability of the extracts—especially the methanol extract and hexane seed oil—to inhibit both Gram-positive and Gram-negative bacteria, as well as fungi, demonstrates the presence of potent bioactive compounds with broad-spectrum activity. This supports the traditional use of *C. albidum* in treating infections and positions the plant as a promising candidate for further pharmacological and drug-development research.

CONCLUSION

This study demonstrates that *Chrysophyllum albidum* possesses a rich repertoire of phytochemicals with significant antimicrobial potential. The pulp and seed extracts exhibited distinct phytochemical profiles, with the pulp containing higher levels of alkaloids and steroids, while the seeds were richer in carbohydrates and moderate flavonoids. GC–MS profiling further confirmed the presence of important bioactive compounds such as fatty acids, esters, sterols, and phenolic derivatives many of which are well documented for their antimicrobial, antioxidant, and anti-inflammatory properties. The methanol extract showed the strongest antimicrobial activity, likely due to its superior ability to extract phenolics, fatty acid esters, and sterols, while the n-hexane seed oil also demonstrated remarkable antibacterial and antifungal effects attributed to high concentrations of oleic and linoleic acids.

The broad-spectrum antimicrobial activities and favorable MIC values recorded validate the traditional medicinal use of *C. albidum* in the treatment of bacterial and fungal infections. The findings also highlight the therapeutic potential of its various phytochemical classes—particularly fatty acids, sterols, and phenolic compounds—indicating that *C. albidum* can serve as a promising source for natural antimicrobial agents. Overall, this study provides a strong scientific foundation for the continued exploration, standardization, and possible pharmaceutical development of *C. albidum*–based therapies. For instance, GC-MS revealed compounds such as stigmasterol, squalene, oleic and linoleic esters may serve as lead molecules for developing new antimicrobial drugs, particularly in an era of increasing antimicrobial resistance. Also, the potent methanol extract and seed oil can be incorporated into antimicrobial creams, ointments, tinctures, or herbal preparations for potential clinical testing.

Future studies should isolate, purify, and structurally characterize individual compounds that demonstrated strong antimicrobial effects to determine their specific mechanisms of action.

AUTHORS' CONTRIBUTIONS

1. Akpe, A. R contributed to the conceptualization, supervision, and final approval of manuscript.
2. Abu, D. M coordinated sample collection, data extraction, laboratory experiments, and funding acquisition.
3. Umanu, G performed the instrumentation (e.g., GC–MS) and data processing.
4. Okwu, G. I contributed to the drafting of the literature review.
5. Maduka, K. I coordinated the experimentation, project administration, and logistics.

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