Journal of
Current Opinion in Crop Science
Journal homepage: www.jcocs.com; ISSN(O):2583-0392

RESEARCH ARTICLE

Effect of solvent extraction on phytochemical profile and quantification of bioactive compounds in *Ocimum suave* (wild)

Mercy Sillas Munuo [*, 1], Martin John Martin [2], Lilian Fanuel Shechambo [1], & Imelda Gervas [3]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture, Morogoro, Tanzania; [2]Institute of Pest Management, Sokoine University of Agriculture, Morogoro, Tanzania; [3]Department of Educational Foundations and Management, Sokoine University of Agriculture, Morogoro, Tanzania.

Edited by:

Dr. P. Arjun, PhD., Department of Biotechnology, Saveetha Deemed University, Chennai. India

Reviewed by:

Dr. M. Sarada Devi, PhD., Bharathiar University, Coimbatore, India; Dr. K. Ashokkumar PhD., Gandhigram University, Dindigul, Tamil Nadu, India.

Article history:

Received: February 09, 2025
Accepted: March 21, 2025
Published: March 31, 2025

Citation:
Munuo, M. S., Martin, J. M ., Shechambo, L. F., & Gervas, I. (2025). Effect of solvent extraction on phytochemical profile and quantification of bioactive compounds in *Ocimum suave* (wild). *Journal of Current Opinion in Crop Science, 6*(1), 27-41.
https://doi.org/10.62773/jcocs.v6i1.304

*Corresponding author e-mail address: mercymunuo97@gmail.com (Munuo, M. S)

ABSTRACT

Seasonal aromatic Lamiaceae shrub *Ocimum suave* has insecticidal and therapeutic bioactive compounds. The plant's phytochemical profile and effective solvents for extraction have limited information, despite its potential as a sustainable pest management alternative. The phytochemical composition and quantification of solvent-extracted *Ocimum suave* leaves, stems, roots, and combined samples were examined. The plant samples were obtained at Dakawa-Mvomero. A laboratory-based experimental design was employed to assess the effect of different extraction solvents on the phytochemical profile and quantification of bioactive compounds in Ocimum suave. A completely randomized design (CRD) was used with three replications to minimize experimental error and increase the reliability of the results. Alkaloids, flavonoids, tannins, saponins, terpenoids, and essential oils were detected in plant samples using methanol, dichloromethane (DCM), n-hexane, and distilled water-extraction solvents. Samples underwent standard quantification chemical tests. Saponins ($p=0.027$), essential oils ($p=0.018$), and alkaloids (0.018) showed significant differences. These findings demonstrate that solvent type significantly impacts compound extraction efficiency. Root tannins were concentrated at 3.51mg/l and stem at 3.36mg/l with methanol. Leaf, stem, and root terpenoids were highly concentrated in dichloromethane 7.20% and n-hexane 5.80% extracts. Dichloromethane 6.50%, methanol 6.20%, and n-hexane 6.10% concentrated essential oils from all plant parts. Saponins in roots, stems, and leaves were 5.60% concentrated with distilled water. N-hexane solvent concentrated leaf flavonoids (4.55%) and stem alkaloids (3.25%). The findings emphasise solvent choice in phytochemical yields and suggest *Ocimum suave* may be an eco-friendly pesticide.

Keywords: *Ocimum suave*, extraction solvents, phytochemical, bio-actives.

INTRODUCTION

Medicinal plants are crucial in healthcare and disease management, serving as a rich source of bioactive compounds with therapeutic properties (Ajayi et al., 2017; Ashokkumar et al., 2024). These plants have been extensively utilized in both traditional medicine and pharmaceutical industries for their diverse pharmacological benefits (Alqethami & Aldhebiani, 2021; Ashokkumar et al., 2025). Globally, approximately 80% of the population relies on plant-based remedies or their active constituents for disease treatment and prevention (Sharma et al., 2021). The widespread use of herbal medicine is particularly notable in developing countries, where it serves as a cost-effective alternative for individuals with limited access to conventional healthcare services (Mlozi et al., 2022).

Phytochemicals are naturally occurring compounds synthesized by plants through primary and secondary metabolic pathways (Majdi et al., 2020; Alqethami & Aldhebiani, 2021; Ashokkumar et al., 2023). Their composition and concentration are influenced by genetic factors, environmental conditions, geographical location, seasonal variations, developmental stages, and post-harvest processing (Bouyahya et al., 2021; Runyoro et al., 2010). Among these bioactive compounds, phenols, tannins, terpenoids, flavonoids, and essential oils have been extensively studied for their pharmacological and ecological significance, including applications in insect pest management (Krupanidhi et al., 2021).

The genus Ocimum, commonly referred to as Basil or Tulsi, belongs to the Lamiaceae family and comprises over 150 species distributed across tropical and subtropical regions, with the highest diversity in Africa and India (Ashokkumar et al., 2020; Ashokkumar et al., 2021; Shikha & Kashyap, 2024). This genus is renowned for its medicinal, aromatic, and industrial significance, exhibiting a wide range of biological activities, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic, antihypertensive, anti-carcinogenic, and cardio-protective properties (Opiyo, 2022). Additionally, Ocimum species serve as natural insect repellents, grain protectants, and perfume sources due to their rich secondary metabolite composition, including flavonoids, polyphenols, essential oils, and saponins (Shikha & Kashyap, 2024). The phytochemical profile of Ocimum species is largely dependent on factors such as plant age, environmental stress, and geographical variations (Mlozi et al., 2022).

Among the Ocimum species, *Ocimum suave* (Wild) is a seasonal aromatic shrub widely distributed in high-altitude regions. It is characterized by the presence of essential oils, phenols, eugenol, and flavonoids, which contribute to its insecticidal and medicinal properties (Runyoro et al., 2010). Notably, its insecticidal activity is attributed to its bioactive compounds, which function as natural repellents and toxicants against a broad spectrum of insect pests, while posing minimal risks to humans and the environment (Naidu et al., 2016). This makes O. suave a promising candidate for eco-friendly pest control strategies (Isman, 2019; Seyoum et al., 2003).

Synthetic pesticides, including organochlorines, organophosphates, and carbamates, are widely used in agriculture for pest management. However, these chemical pesticides are associated with significant environmental and health hazards, including bioaccumulation, persistence in ecosystems, and contamination of food chains (Zuleta-Castro et al., 2017; Runyoro et al., 2010). Furthermore, their high costs and restricted accessibility pose challenges for smallholder farmers, necessitating the exploration of safer, cost-effective, and environmentally sustainable alternatives (De Groote et al., 2020; Rezende et al., 2020). Several studies have demonstrated the efficacy of O. suave extracts as a natural pesticide in both laboratory and field trials (Kumar et al., 2020; Chogo & Crank, 1981; Shikha & Kashyap, 2024).

Despite its well-documented bioactivity, limited studies have focused on the phytochemical composition and quantification of naturally occurring O. suave. Most existing research has relied on single-solvent extraction techniques, which may not capture the full spectrum of bioactive compounds present in different plant parts. The efficiency of phytochemical extraction is highly dependent on solvent polarity, plant material used, and extraction methodologies (Sharma et al., 2021; Złotek et al., 2016). Variations in solvent properties significantly influence the solubility and yield of bioactive constituents, necessitating a comparative evaluation of multiple solvent extraction techniques (Egbuna et al., 2018). The study aimed to evaluate the effect of multiple solvent extractions on the phytochemical profile and quantification of Ocimum suave. Specifically, based on determining the best solvent for the extraction of phytochemicals from Ocimum suave and identify the plant part that possesses the highest concentration of phytochemicals.

MATERIALS AND METHODS

Study Area and Design

This study was conducted at the Chemistry Laboratory of Sokoine University of Agriculture (SUA), Morogoro, Tanzania. SUA is located at a latitude of 6°50' South and a longitude of 37°39' East, with an altitude of 502 meters above sea level. The university is well-equipped with laboratory facilities suitable for phytochemical analysis and extraction techniques, ensuring the accuracy and reliability of the research findings. A laboratory-based experimental design was employed to assess the effect of different extraction solvents on the phytochemical profile and quantification of bioactive compounds in *Ocimum suave*. A completely randomized design (CRD) was used with three replications to minimize experimental error and increase the reliability of the results.

Plant Materials

Fresh plant parts (leaves, stems, and roots) of Ocimum suave were collected from the wild, in Morogoro region, Tanzania, specifically at dakawa-Mvomero district. Fresh plant parts of Ocimum suave in the samples were washed with tap water, followed by distilled water to remove dust (Rioba and Stevenson, 2020). The samples were then dried in the shade at room temperature for 10-15 days (about 2 weeks), after which they were ground into fine powder using an electric grinder. The grounded leaves were further dried in the shade for 5 days and pulverised into powder, and sieved using a 0.25 mm (about 0.01 in) mesh (Prasoona et al., 2022).

Extraction procedures

Methanol, Dichloro-methane, N-hexane, and water solvent were used to extract Ocimum suave powder, leaf, stem, and root mixtures. 100g of leaf, stem, roots, and combination samples were weighed and placed in four flat-bottom flasks. Each round flask with 100g of leaf samples received organic solvents. Flat-bottom flasks 1,2,3, and 4 received 1000 ml of methanol, DCM, N-hexane, and water. We macerated all samples for 48 hours. Each flask was wrapped in aluminum foil and kept at ambient temperature in the lab. Extract was filtered using cotton wool and cheesecloth. To get a crude extract, the filtrate was evaporated in a vacuum rotary evaporator at each solvent's boiling point (Abubakar and Haque, 2020). After reducing the filtrate to one-third of the initial volume, it was placed into petri dishes for facile evaporation and kept in glass bottles as solvent-free crude extract (Seyoum et al., 2002). Dichloro-methane, N-hexane, and water solvents extracted the four samples similarly.

Phytochemical screening

The phytochemical screening of the plant's secondary metabolites was performed following established protocols and as outlined in prior research (Złotek et al., 2016; Sharma et al., 2021; Ajayi et al., 2017). A detailed account of each method is presented below.

Table 2.1. Shows the individual chemical method used to taste each bioactive presence

Parameters	Procedure	Observation	Method
Alkaloids	Few mL filtrate + 2 drops of Mayer's reagent (Along the sides of the test tube)	yellow precipitate	Mayer's
Flavonoid	1 mL aqueous extract solution + 0.1gm metallic zinc + 8mL conc. H_2SO_4	A red colour	Pew's test
Tannin	1 mL plant extract + 4mL 10% NaOH + shaken well	Formation of emulsion	Aqueous NaOH Test
Saponin	To 1 ml of the extracts, 5 ml distilled water was added and shaken vigorously.	Formation of foam indicated the presence of saponins	Foam Test
Terpenoids	Extract (5 ml) was mixed with chloroform (2 ml), and concentrated sulphuric acid (3 ml) was carefully added to form a layer.	A reddish-brown coloration of the interface was formed to show positive results for the presence of terpenoids.	Salkowski test
Essential oil	A small quantity of plant extract is pressed in between to filter papers	Oil stain on the paper	Spot test

Phytochemical quantification

Quantification of phytochemicals was conducted according to standard procedures and as described by previous studies (Sofowora, 1982) and (Mlozi et al., 2022).

Estimation of terpenoids content

The 0.5 g of desiccated botanical extract was immersed in 9 mL of ethanol for 24 hours (Indumathi et al., 2014). The filtrate was extracted using 10 mL of petroleum ether in a 25 mL separating funnel. The ether extract was extracted in pre-weighed glass vials and permitted to dry thoroughly. Petroleum ether underwent evaporation. The percentage yield of total terpenoid content was calculated using the formula.

Total terpenoid content (%) = Weight of terpenoid/ Weight of crude sample taken x 100.

Estimation of tannin content

100 mg of sample extract was measured into a 50 ml plastic container. 50 ml of distilled water was added and agitated for one hour in a mechanical shaker. The solution was transferred to a 50 ml volumetric flask and adjusted to the calibration mark. 2 ml of the filtrate was combined with 8 ml of 0.1 M FeCl3 in 0.1 N HCl and 0.008 M potassium ferrocyanide in a test tube.

Estimation of saponin content

0.5 grammes of each crude sample were placed in a 50 cm3 conical flask with 10 cm3 of 20% aqueous ethanol. The mixture was heated in a 55°C water bath for 4 hours while stirred. After filtering, the mixed residue was reextracted with 10 cm^3 of 20% aqueous ethanol and heated at 55°C for 4 hours with continuous stirring. Use a 90°C water bath to evaporate the combined extract to 5 cm^3. Twenty cubic centimetres of diethyl ether were added to the concentration in a 250 cubic centimetre separator funnel and vigorously agitated to recover the aqueous layer and discard the ether layer. Purification occurred twice. Ten cubic centimetres of 5% sodium chloride solution removed 60 cubic centimetres of n-butanol twice. The remaining solution was heated in a water bath for 30 minutes after sodium chloride removal. The solution was then placed in a crucible and oven-dried until a consistent weight. A proportion of saponin was calculated:

Saponin (%) = Weight of Saponin/ Weight of sample x 100

Estimation of lipid content

Each dry wood powder (1.50 g) was added to a thimble linked to a Soxhlet extractor chamber with a reweighed flat bottom and connected to a condenser. Petroleum ether (80 ml) was added to the flask to induce reflux, and the lipid from the wood sample was extracted for 3 hours by heating on an electric hot plate at 50°C. The extractant, petroleum ether, was distilled off, and the lipid was recovered by cooling the flask in a desiccator. Its value was calculated by reweighing the flask and its contents.

Lipid (%) = Weight of Lipid/ Weight of sample x 100

Estimation of flavonoid content

0.5 g of the crude sample was extracted with 20 ml of 80% aqueous methanol at ambient temperature. The mixture was filtered through filter paper into a pre-weighed beaker. The filtrate was subjected to a water bath, evaporated to dryness, and then weighed. The proportion of flavonoids was calculated using the weight of the extracted dry matter.

Estimation of alkaloid content

Alkaloids were quantitatively determined using Harborne's approach. In a 100 cm^3 beaker, each 0.50 g crude sample was combined with 10 cm^3 of 10% acetic acid in ethanol and allowed to stand for four hours. 15 drops of concentrated ammonium hydroxide were added to the extract dropwise until precipitation was complete, right after filtering, after the extract had been concentrated in a water bath to 25% of its initial volume. Following three hours of mixed sedimentation, the precipitates were cleaned with 20 cm3 of 0.1 M ammonium hydroxide and filtered, while the supernatant was disposed away. After the residue was dried in an oven, the alkaloid percentage can be calculated numerically as

Alkaloid (%) = Weight of alkaloid/Weight of sample x 100

Data analysis

A laboratory-based experimental design was employed to assess the effect of different extraction solvents on the phytochemical profile and quantification of bioactive compounds in *Ocimum suave*. A completely randomized design (CRD) was used with three replications to minimize experimental error and increase the reliability of the results. Descriptive analysis was used analyze the data set in metrics mg/L and the proportions or percentages (%). Observational analysis was mainly used to assess the extent of reactions across different phytochemicals by reagents of whether it was considered low positive (+), fairly positive (++), highly positive (+++), and negative (-) based on color codes during laboratory analysis. The key data metrics included the mg/L and the proportions or percentages (%).

RESULTS

Phytochemical Composition of Ocimum suave Extracts

The phytochemical screening of *Ocimum suave* extracts revealed the presence of six bioactive compounds across different plant parts (leaf, stem, and root) and solvents (n-hexane, dichloromethane (DCM), methanol, and distilled water (DW). Key bioactive constituents identified included alkaloids, flavonoids, tannins, saponins, terpenoids, and essential oils (EO). Alkaloids and terpenoids were detected in moderate to high concentration in n-hexane and moderate detection in dichloromethane extracts across all plant parts, while tannins were notably present in the methanol and distilled water extracts, particularly from the roots and stems. Flavonoids were moderately detected in the n-hexane and dichloromethane extracts across all plant parts. Essential oil was highly detected in n-hexane and methanol, moderately detected in DCM and distilled water across all plant parts, and saponins were moderately to highly detected by distilled water across all plant parts. The result summary is shown in Table 1 and Figure 1.

Table 1. Phytochemical Composition of Ocimum suave extracts from different solvents

Sample Name	Solvent used	Alkaloid	*Flavonoid*	*Tannin*	*Saponin*	*Terpenoid*	*Essential oil*
Root	n-hexane	+	++	-	-	+	+++
Leaf	n-hexane	+	++	-	-	+	+++
Stem	n-hexane	+	++	-	-	+	+++
Root	DCM	-	++	-	-	+	+
Leaf	DCM	-	++	-	-	+	+
Stem	DCM	-	-	-	-	+	+
Root	Methanol	-	-	+++	-	+	+++
Leaf	Methanol	-	-	+	-	-	+++
Stem	Methanol	+	-	+++	-	-	+++
Root	DW	-	-	++	++	-	+
Leaf	DW	-	-	+++	+++	-	+-
Stem	DW	-	-	++	+	-	+-
Root + Leaf + Stem	n-hexane	+	+	-	-	+++	+++
Root + Leaf + Stem	DCM	-	_	-	-	+++	+++
Root + Leaf + Stem	Methanol	+	+	+++	-	-	+++
Root + Leaf + Stem	DW	-	-	+++	+++	-	+
Method	*Maceration*	*Mayer's*	*Pew's test*	*Aqueous NaOH Test*	*Foam Test*	*Salkowski test*	*Spot test*

Note: +++ - Highly detected, ++ - Moderately detected, + -Low detection

Quantitative analysis of phytochemicals

The quantitative analysis provided insights into the concentration of bioactive compounds across different sample parts and solvents, which are visually summarized in Table 2 (descriptive statistics).

Table 2. Phytochemical Composition concentration by Plant Part and Solvent type

Plant Part	Solvent	Tannin (mg/L)	Terpenoid (%)	Saponin (%)	Essential Oil (%)	Alkaloid (%)	Flavonoid (%)
Root	n-hexane	ND	1.8	0.4	5.5	2.125	2.55
	DCM	ND	ND	ND	1.1	ND	2.36
	Methanol	ND	ND	0.2	4.3	ND	0.36
	DW	2.64	ND	3.6	2.1	ND	0.36
Leaf	n-hexane	ND	2.8	ND	5.4	2.5	4.55
	DCM	ND	1.4	0.2	1.8	0.125	3.82
	Methanol	1.71	ND	ND	5	ND	0.18
	DW	2.89	ND	4.4	1.8	ND	ND
Stem	N-hexane	ND	2	0.2	5.6	3.25	2.909
	DCM	ND	1	ND	1.4	ND	ND
	Methanol	3.36	ND	ND	5.5	1.25	ND
	DW	2.327	ND	2.6	2.6	0.125	0.182
Combined Root + Leaf+ Stem	n-hexane	ND	5.8	ND	6.1	2.25	1.27
	DCM	0.52	7.2	ND	6.5	0.125	ND
	Methanol	2.79	ND	ND	6.2	2.75	2.55
	DW	3.2	ND	5.6	1.4	ND	0.36

Note: ND = Not Detected

Statistical analysis of compound variability

ANOVA tests were conducted to determine the impact of different solvents on compound concentrations. Significant differences in concentration were observed for saponins ($p=0.027$), essential oils ($p=0.018$), and alkaloids ($p=0.018$). These findings indicate that solvent type has a statistically significant effect on the extraction efficiency of these compounds. Conversely, tannins, terpenoids, and flavonoids did not exhibit statistically significant variations in concentration across different solvents (Table 3).

Post-hoc analysis with Tukey's HSD

For compounds with significant ANOVA results, Tukey's HSD post-hoc tests were conducted to identify specific solvent pairs with notable differences in extraction efficiency: For Saponin, DW yielded significantly higher concentrations compared to n-hexane, supporting the potential of aqueous solvents for saponin extraction. On the other hand, for Essential Oil, both DCM and n-hexane showed higher extraction yields than DW, with n-hexane achieving the highest concentrations in the combined sample. Also, for Alkaloid, n-hexane and DCM provided significantly greater yields than DW, highlighting alkaloids' affinity for nonpolar solvents.

Table 3. The ANOVA summary

Compound	ANOVA F-Statistic	P-value	Significant?	Post-hoc Significant Solvent Comparisons
Tannin	4.79	0.062	No	-
Terpenoid	0.55	0.607	No	-
Saponin	10.12	0.027	Yes	DW > n-hexane
Essential Oil	4.76	0.018	Yes	n-hexane > DW, DCM > DW
Alkaloid	9.11	0.018	Yes	n-hexane > DW, DCM > DW
Flavonoid	3.12	0.090	No	-

Correlation analysis of phytochemicals

To understand the possible synergistic relationships among the compounds, a correlation analysis was performed. The correlation coefficients of the compounds are displayed in Table 4. Tannins and alkaloids have shown a moderate positive correlation (r = 0.65) that may propose an interactive effect between these two groups of compounds. On the contrary, terpenoids showed negative relations with tannins, with a correlation coefficient of -0.91, which might mean that different compound profiles favour different solvents.

Table 4. Correlation matrix of phytochemicals

Compounds	Tannin (mg/L)	Terpenoid (%)	Saponin (%)	Essential Oil (%)	Alkaloid (%)	Flavonoid (%)
Tannin	1.00	-0.91	0.58	-0.27	0.65	0.21
Terpenoid	-0.91	1.00	-0.39	0.10	-0.31	0.10
Saponin	0.58	-0.39	1.00	-0.11	-0.54	-0.77
Essential Oil	-0.27	0.10	-0.11	1.00	0.13	-0.17
Alkaloid	0.65	-0.31	-0.54	0.13	1.00	0.29
Flavonoid	0.21	0.1	-0.77	-0.17	0.29	1.00

Concentration values varied significantly depending on both the plant part and the solvent used, highlighting specific extraction conditions that optimize yield. The mean concentration of the major bioactive phytochemicals that include tannins, terpenoids, saponins, essential oil, alkaloids, and flavonoids present in different plant parts with various solvents is shown in Table 4. High extraction of tannins was concentrated in roots, 3.51mg/l and stem, 3.36mg/l, when extracted with methanol solvent. Terpenoids were highly concentrated in the mixture of all plant parts (leaves, stem and roots) when extracted with dicloromethane 7.20% and n-hexane 5.80%. Essential oils were highly concentrated in dicloromethane 6.50%, methanol 6.20% and n-hexane 6.10% when all plant parts were used. Saponins was highly concentrated 5.60% in mixture of all plant parts (roots, stem and leaves) when using distilled water. Flavonoids (4.55%) in leaves and 3.25% concentration of alkaloid in stem were highly concentrated by n-hexane solvent. Figures below illustrate the distribution of tannins, terpenoids, saponins, essential oils, alkaloids, and flavonoids in various solvents.

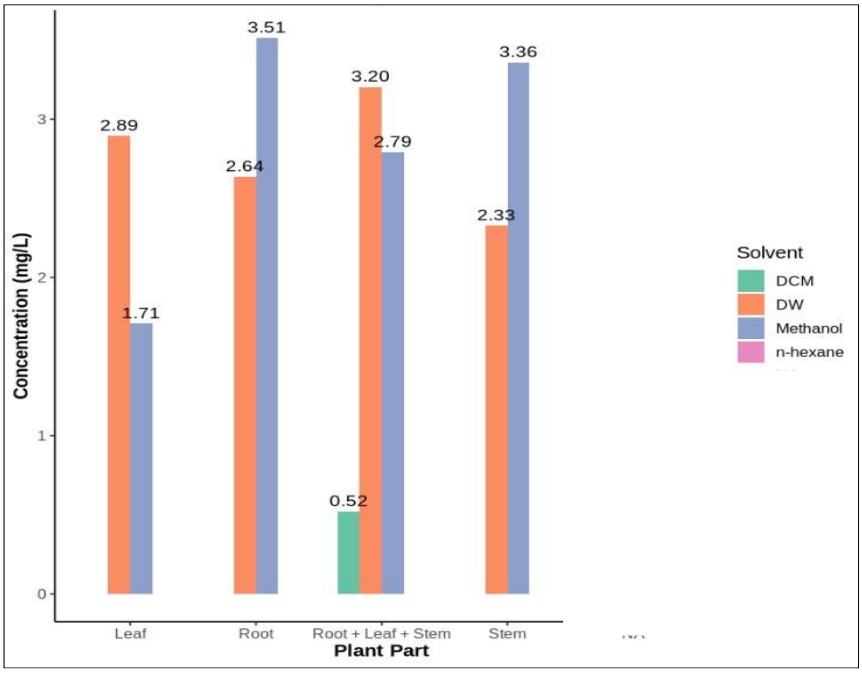

Figure 1. Showing tannin concentration in mg/l by solvent and plant part.

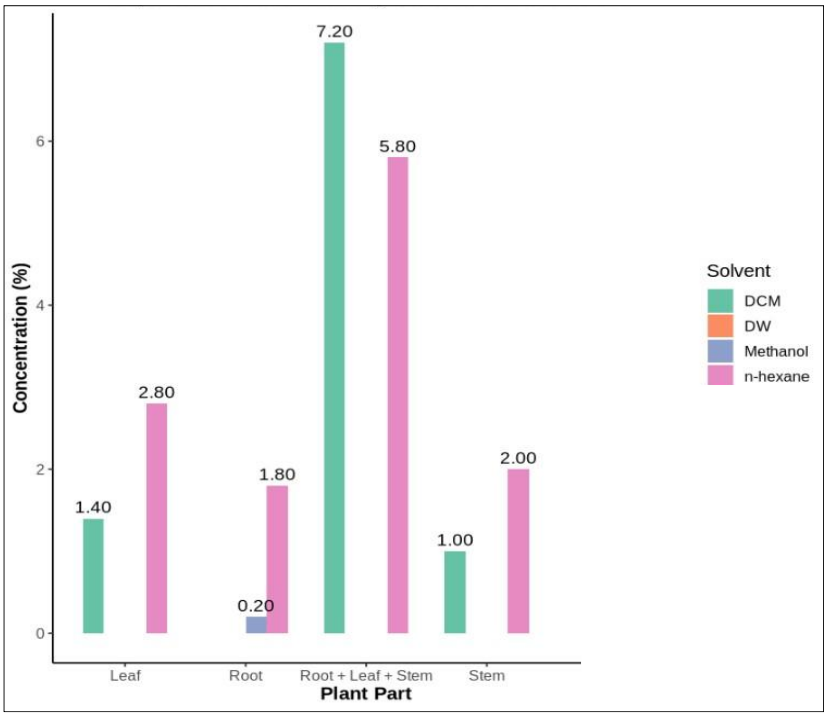

Figure 2. Showing terpenoid concentration in percentage by solvent and plant part.

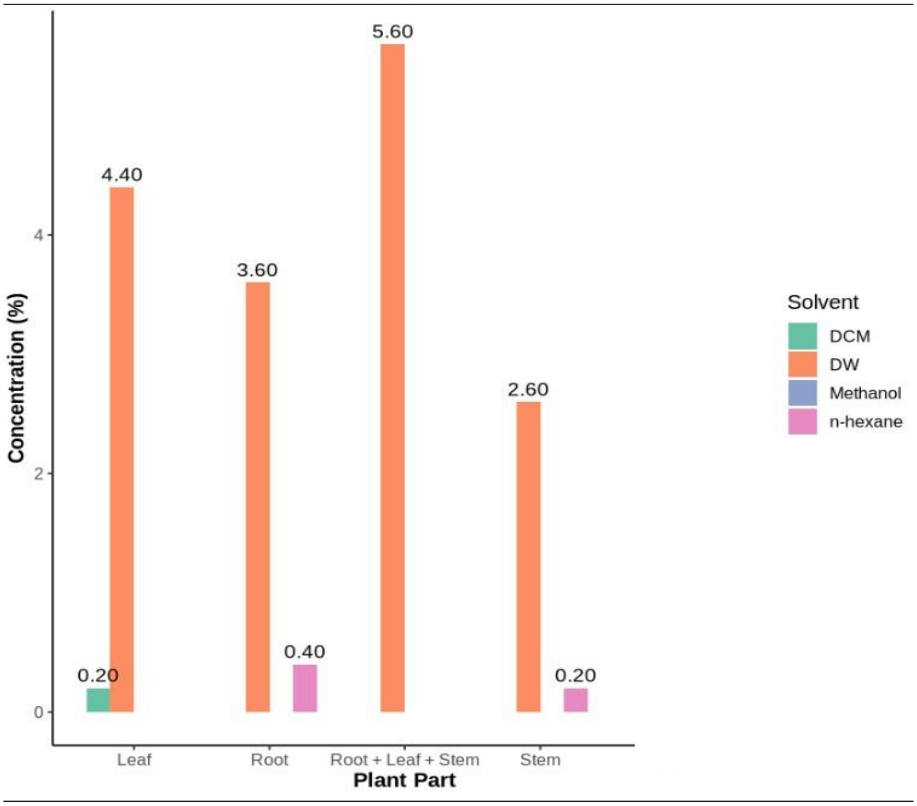

Figure 3. Showing saponin concentration in percentage by solvent and plant part.

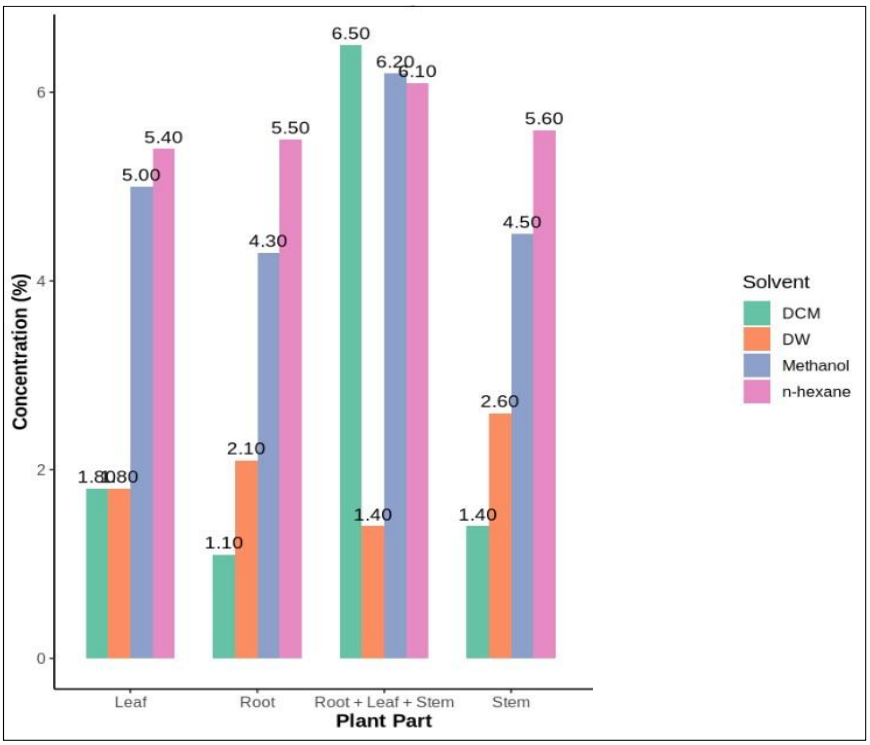

Figure 4. Showing essential oil concentration in percentage distribution by solvent and plant parts.

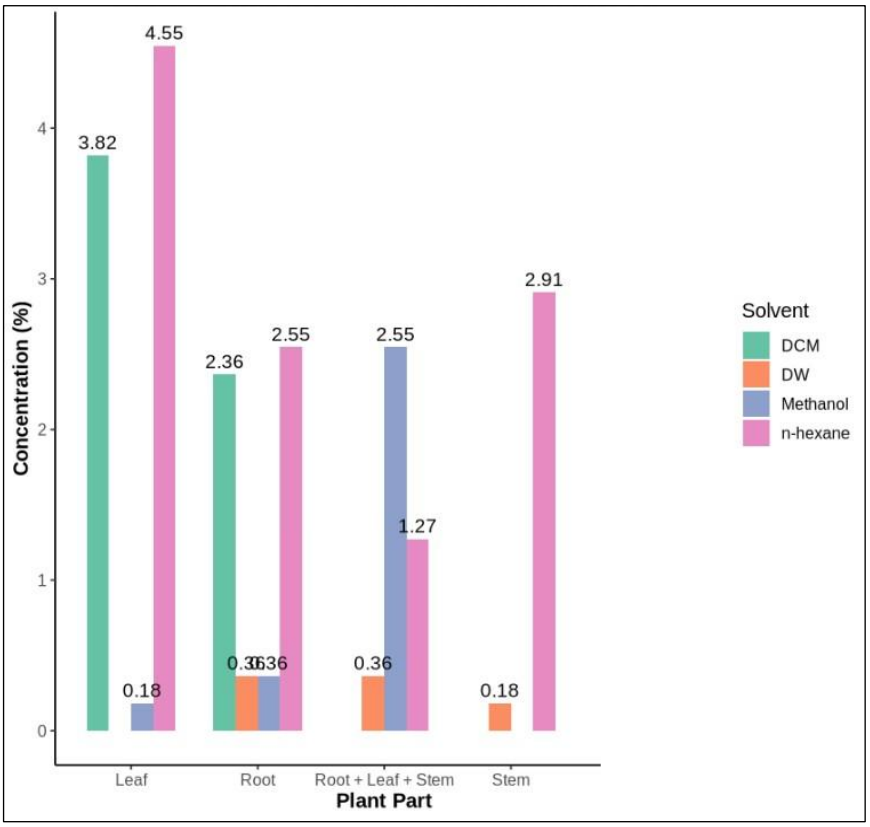

Figure 5. Showing flavonoid concentration in percentage by solvent and plant part.

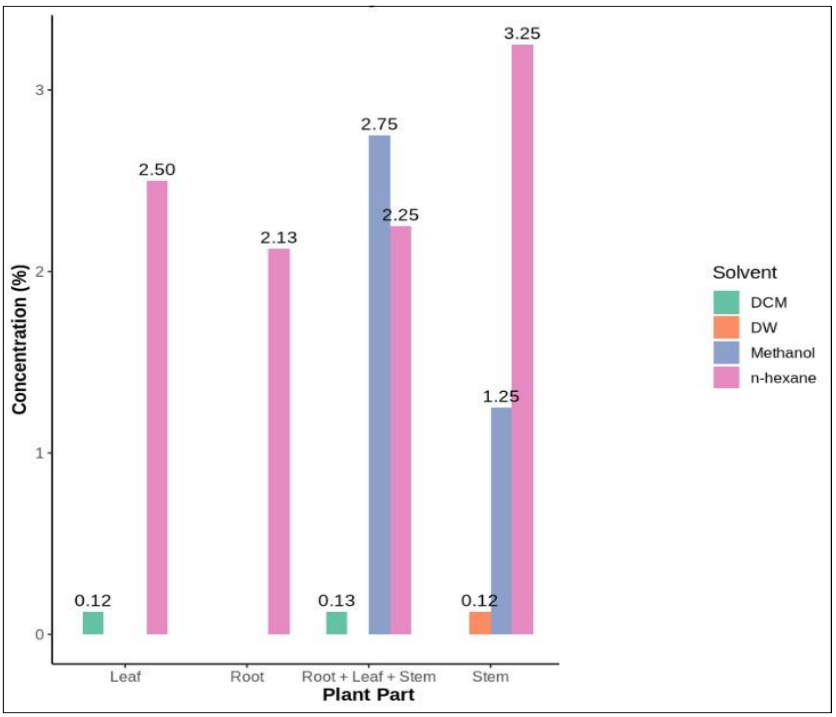

Figure 6. Showing alkaloid concentration in percentage by solvent and plant part.

Figure 7 illustrates the distribution of the extraction solvent efficiency of phytochemicals of n-hexane, DCM, Methanol, and DW solvents. From the analysis, n-hexane is the most effective solvent, followed by DCM, Methanol, and DW solvents in the extraction of tannins, terpenoids, saponins, essential oils, alkaloids, and flavonoids.

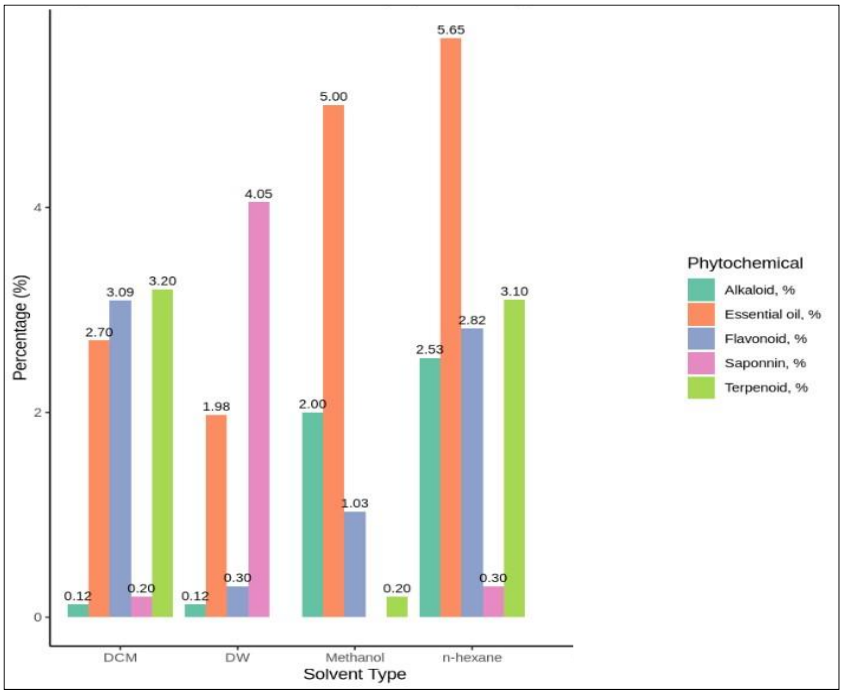

Figure 7. The bar graph shows phytochemical extraction efficiency by solvent type.

DISCUSSION

The efficacy of pesticidal plants such as *Ocimum suave* is primarily dictated by their ability to synthesize secondary metabolites with diverse functional properties. These metabolites play a critical role in plant defense mechanisms, enabling survival by enhancing chemical interactions with the environment. In addition to their defensive functions, secondary metabolites contribute to plant growth, development, innate immunity, and responses to environmental stresses (Pang et al., 2021). Furthermore, they facilitate symbiotic interactions with microbes, influence microbial community structures, and deter herbivores and pathogens (Wawrosch & Zotchev, 2021).

Phytochemical profile of Ocimum suave extracts

The phytochemical screening of *O. suave* extracts confirmed the presence of diverse bioactive compounds, including alkaloids, flavonoids, tannins, saponins, terpenoids, and essential oils. Quantitative analysis revealed variations in the concentration and distribution of these compounds across different plant parts and extraction solvents. These findings underscore the plant's significant potential as a natural source of bioactive compounds with applications in pest management, medicine, and industry. Variability in phytochemical composition is influenced by multiple factors, including seasonal and maturity variations, geographical origin, genetic diversity, growth stages, plant parts utilized, and post-harvest processing conditions (Wm et al., 2019; Wawrosch & Zotchev, 2021). The observed differences in phytochemical yields across different solvent extracts highlight the necessity of optimizing extraction protocols to maximize bioactive compound recovery.

Effect of solvent polarity on phytochemical extraction

Polar Solvents: Extraction of Hydrophilic Compounds

The study demonstrated that polar solvents, particularly methanol and distilled water (DW), effectively extracted tannins and saponins, predominantly from roots and leaves. The highest concentrations of tannins (3.51%) were recorded in methanol extracts, while saponins (5.6%) were most concentrated in distilled water extracts. This outcome aligns with the well-established affinity of polar solvents for hydrophilic compounds, facilitating the extraction of antioxidant and antimicrobial secondary metabolites (Sharma et al., 2021).

Tannins are known for their ability to inhibit larval development, impact fecundity, and disrupt the growth cycle of various insect pests (Petchidurai et al., 2023). Similarly, saponins interfere with the molting process, feeding behavior, and hormonal regulation in insects, often leading to mortality at different developmental stages (Iovinella et al., 2023). Additionally, saponins are effective against stored grain pests and cosmopolitan insect species (Qasim et al., 2020). The presence of tannins and saponins in distilled water and methanol extracts further underscores their potential for oxidative stress tolerance and pest management applications (Bouyahya et al., 2021).

Non-Polar Solvents: Extraction of Lipophilic Compounds

Non-polar solvents exhibited high efficiency in extracting lipophilic compounds such as terpenoids, alkaloids, and essential oils. Notably, terpenoids were extracted in high concentrations from all plant parts using non-polar solvents, supporting previous findings on the solubility of these compounds in non-polar media (Egbuna et al., 2018; Złotek et al., 2016). These bioactive compounds are widely recognized for their pesticidal, antimicrobial, and antioxidant properties, making them valuable candidates for environmentally friendly pest control formulations (Isman, 2019; Naidu et al., 2016).

Flavonoid extraction and bioactivity

Flavonoids exhibited moderate solubility in semi-polar solvents, with n-hexane (4.55%) and DCM (3.82%) yielding the highest concentrations. These compounds are well-known for their antioxidant activity and their ability to enhance the efficacy of plant-based bioactive formulations. Previous studies have demonstrated a significant increase in larval mortality when insects were exposed to flavonoid-rich plant extracts, largely due to damage inflicted on the peritrophic membrane that protects the insect midgut (Chatterjee *et al*., 2022). The strong pesticidal activity of flavonoids highlights their potential as feeding deterrents, making them promising candidates for eco-friendly pest control strategies.

The relatively lower concentrations of flavonoids in methanol and distilled water extracts suggest that highly polar solvents may be less effective in extracting flavonoids, possibly due to solubility constraints or

variations in extraction conditions such as temperature and duration (Runyoro *et al*., 2010; Bouyahya *et al*., 2021). These observations emphasize the importance of fine-tuning extraction parameters to achieve optimal recovery of phytochemicals from *O. suave*.

Efficiency of n-Hexane and DCM in terpenoid and essential oil extraction

Non-polar solvents, particularly n-hexane and dichloromethane (DCM), consistently yielded the highest concentrations of terpenoids and essential oils, reinforcing their effectiveness in isolating non-polar bioactives. These solvents are widely used in oilseed extractions due to their high miscibility with lipophilic compounds, low boiling points (~68°C), and ease of recyclability (Siddiqui *et al*., 2024).

The combination of multiple plant parts (leaves, stems, and roots) in extraction significantly increased terpenoid and essential oil yields, supporting an integrated extraction approach to maximize bioactive compound recovery. Essential oils derived from *O. suave* exhibit antimicrobial, antihelminthic, antiviral, antiulcer, antioxidant, anti-inflammatory, insecticidal, and larvicidal properties, making them valuable in diverse applications, including medicine and pest management (Isman, 2019; Liu *et al*., 2024; Subaharan *et al*., 2021).

Terpenes, particularly carvacrol, carvone, eugenol, geraniol, and thymol, have demonstrated strong antibacterial activity against Staphylococcus aureus by disrupting cellular function and inhibiting protein and DNA synthesis (Siddiqui *et al*., 2024). The potential of these compounds in pesticidal formulations further reinforces the relevance of *O. suave* extracts in developing sustainable pest control alternatives.

Potential applications and future directions

Among the solvent extracts tested, n-hexane and distilled water extracts from roots, leaves, and combined plant parts exhibited a well-balanced phytochemical profile, making them strong candidates for further bioactivity testing. These extracts hold promise for application against agricultural pests such as *Spodoptera frugiperda*, a globally significant pest affecting staple crops. The findings align with ongoing research efforts focused on developing sustainable, plant-based alternatives to synthetic pesticides, which are often associated with environmental degradation and public health concerns (Rezende et al., 2020; De Groote et al., 2020).

CONCLUSION

The findings of this study underscore the significant potential of *Ocimum suave* as a source of diverse bioactive compounds with promising applications in sustainable pest management. Phytochemical screening revealed the presence of alkaloids, flavonoids, tannins, saponins, terpenoids, and essential oils across different plant parts, with their extraction efficiency varying according to solvent polarity. Non-polar solvents such as n-hexane were most effective in isolating terpenoids, alkaloids and essential oils from roots, stems and leaves, while polar solvents like methanol and distilled water excelled in extracting tannins and saponins, particularly from roots and leaves. Quantitative analysis further demonstrated that combined extraction from multiple plant parts enhances the yield of key bioactive compounds.

These findings emphasize the importance of selecting appropriate solvents and extraction protocols to optimize the yield and bioactivity of phytochemicals. The high concentrations of terpenoids, tannins, and essential oils, known for their pesticidal and antimicrobial properties, highlight the potential of *Ocimum suave* extracts as eco-friendly alternatives to synthetic pesticides. Future research should focus on evaluating the bio-efficacy of these extracts against specific agricultural pests and exploring their formulation for practical application.

ACKNOWLEDGEMENTS

The author wishes to thank all collaborators at Sokoine University of Agriculture (SUA) for their technical and guidance support during the development of this study.

AUTHORS CONTRIBUTIONS

All authors contributed to the development, design, execution of the study, analysis of results, and drafting of the manuscript.

.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Not applicable

FUNDING

No funds were obtained for this study.

REFERENCES

Ajayi, A. M., Naluwuge, A., Buyinza, P., & Luswata, I. (2017). Comparative physicochemical, phytochemical and acute toxicity studies of two Ocimum species in Western Uganda. *Journal of Medicinal Plants Research*, *11*(1), 1–10. https://doi.org/10.5897/JMPR2015.6025

Alqethami, A., & Aldhebiani, A. Y. (2021). Medicinal plants used in Jeddah, Saudi Arabia: Phytochemical screening. *Saudi Journal of Biological Sciences*, *28*(1), 805–812. https://doi.org/10.1016/J.SJBS.2020.11.013

Ashokkumar, K., Vellaikumar, S., Murugan, M., Dhanya, M. K., Aiswarya, S., & Nimisha, M. (2020). Chemical composition of Ocimum gratissimum essential oil from the South Western Ghats, India. *Journal of Current Opinion in Crop Science*, *1*(1), 27–30. https://doi.org/10.62773/jcocs.v1i1.14

Ashokkumar, K., Pandian, A., Murugan, M., Dhanya, M. K., & Vellaikumar, S. (2021). Phytochemistry and pharmacological properties of Ocimum gratissimum (L.) extracts and essential oil - A critical review. *Journal of Current Opinion in Crop Science*, *2*(1), 138–148. https://doi.org/10.62773/jcocs.v2i1.47

Ashokkumar, K., Pandian, A., Baskar, M., Karthik, M., Murugan, M., Semwal, R. B., & Semwal, D. K. (2023). Withania somnifera–a journey from traditional rejuvenator to anti-SARS-CoV-2 remedy. *Herba Polonica*, *69*(2), 37-51. https://doi.org/10.5604/01.3001.0053.7210

Ashokkumar, K., Dharshini, M., Janani, T., Shrravani Sri, V., & Subhasidha, R. (2024). *Nyctanthes arbor-tristis* Linn. (Night Jasmine): extraction techniques, phytochemical constituents, and biological impacts of extracts and essential oil. Future Journal of Pharmaceutical Sciences, 10(1), 117. https://doi.org/10.1186/s43094-024-00694-2

Ashokkumar, K., Murugan, M., Murugesan, P., & Venkatesh, T. (2025). *Millingtonia hortensis* Lf (tree jasmine): botany, ethnopharmacology, chemical constituents, biological activities of extracts and essential oils—an updated review. *Discover Plants*, *2*(1), 1-19. https://doi.org/10.1007/s44372-025-00107-5

Bouyahya, A., El Omari, N., Elmenyiy, N., Guaouguaou, F. E., Balahbib, A., Belmehdi, O., Salhi, N., Imtara, H., Mrabti, H. N., El-Shazly, M., & Bakri, Y. (2021). Moroccan antidiabetic medicinal plants: Ethnobotanical studies, phytochemical bioactive compounds, preclinical investigations, toxicological validations and clinical evidences; challenges, guidance and perspectives for future management of diabetes worldwide. *Trends in Food Science & Technology*, *115*, 147–254. https://doi.org/10.1016/J. TIFS.2021.03.032

Chemical composition and antimicrobial activity of the essential oils of four Ocimum species growing in Tanzania. *Food Chemistry*, *119*(1), 311–316. https://doi.org/10.1016/J.FOODCHEM.2009.06.028

Chogo, J. B. (1980). *Chemical and biological studies of the African plants" Ocimum suave Wild" and" Lippia ukambensis Vatke"*. University of New South Wales.

Chogo, J. B., & Crank, G. (1981). Chemical composition and biological activity of the tanzanian plant *Ocimum suave*. *Journal of Natural Products*, *44*(3), 308–311. https://doi.org/10.1021/np50015a012

De Groote, H., Kimenju, S. C., Munyua, B., Palmas, S., Kassie, M., & Bruce, A. (2020). Spread and impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) in maize production areas of Kenya. *Agriculture, Ecosystems & Environment*, *292*, 106804. https://doi.org/10.1016/J.AGEE.2019.106804

Egbuna, C., Ifemeje, J. c., Kryeziu, T. l., Mukherjee, M., shah, H., Narasimha Rao, G. M., Gido, L.

Ezeonu CS, Ejikeme CM. Qualitative and Quantitative Determination of Phytochemical Contents of Indigenous Nigerian Softwoods. New Journal of Science, 2016, 1-9.

Gul R, Jan SU, Syed F, Sherani F, Nusrat Jahan. Preliminary Phytochemical Screening, Quantitative Analysis of Alkaloids, and Antioxidant Activity of Crude Plant Extracts from Ephedra intermedia Indigenous to Balochistan. The Scientific World Journal, 2017, 1-7.

Krupanidhi, S., Abraham Peele, K., Venkateswarulu, T. C., Ayyagari, V. S., Nazneen Bobby, M., John Babu, D., Venkata Narayana, A., & Aishwarya, G. (2021). Screening of phytochemical compounds of *Tinospora*

cordifolia for their inhibitory activity on SARS-CoV-2: an in silico study. *Journal of Biomolecular Structure and Dynamics*, 1–5. https://doi.org/10.1080/07391102.2020.1787226.

Kumar, A., Shukla, A. K., Shasany, A. K., & Sundaresan, V. (2018). *Systematic Position, Phylogeny, and Taxonomic Revision of Indian Ocimum*. 61–72. https://doi.org/10.1007/978-3-319-97430-9_5

Kumar, B., Bajpai, V., Tiwari, S., & Pandey, R. (2020). *Phytochemistry of plants of genus Ocimum*. CRC Press. https://doi.org/10.1201/9781003014850

Liu, A., Zhang, Y. C., Qi, Y. T., Wang, J. Z., Wang, D., & Du, S. S. (2024). Chemical characterization and insecticidal activities of the essential oils from the different parts of *Ocimum gratissimum* var. *suave* (Willd.) Hook. f. *Chemistry & Biodiversity*, e202401218. https://doi.org/10.1002/CBDV.202401218

Majdi, C., Pereira, C., Dias, M. I., Calhelha, R. C., Alves, M. J., Frih, B., Charrouf, Z., Barros, L., Amaral, J. S., & Ferreira, I. C. F. R. (2020). Phytochemical characterization and bioactive properties of cinnamon basil (*Ocimum basilicum* cv. '*Cinnamon*') and Lemon Basil (*Ocimum* × *citriodorum*). *Antioxidants. 9*(5), 369. https://doi.org/10.3390/ANTIOX9050369

Mlozi, S. H., Mmongoyo, J. A., & Chacha, M. (2022). GC-MS analysis of bioactive phytochemicals from methanolic leaf and root extracts of *Tephrosia vogelii*. *Scientific African*, *16*, e01255. https://doi.org/10.1016/J.SCIAF.2022.E01255

Opiyo, S. A. (2022). *Stored Grains Protection Activity of Ocimum suave Extracts and Compounds on Larger Grain Borer*. http://repository.mut.ac.ke:8080/xmlui/handle/123456789/6117

Pang, Z., Chen, J., Wang, T., Gao, C., Li, Z., Guo, L., Xu, J., & Cheng, Y. (2021). Linking plant secondary metabolites and plant microbiomes: a review. *Frontiers in Plant Science*, *12*, 621276. https://doi.org/10.3389/FPLS.2021.621276/PDF

Raaman N. Phytochemical Techniques. New India Publishing Agency, New Delhi, 2006, 19- 24.

Rezende, W. S., Beyene, Y., Mugo, S., Ndou, E., Gowda, M., Sserumaga, J. P., Asea, G., Ngolinda, I., Jumbo, M., Oikeh, S. O., Olsen, M., Borém, A., Cruz, C. D., & Prasanna, B. M. (2020).

Runyoro, D., Ngassapa, O., Vagionas, K., Aligiannis, N., Graikou, K., & Chinou, I. (2010). Chemical composition and antimicrobial activity of the essential oils of four *Ocimum species* growing in Tanzania. *Food Chemistry*, *119*(1), 311–316. https://doi.org/10.1016/j.foodchem.2009.06.028

Sampson, B. J., Tabanca, N., Kirimer, N., Demirci, B., Baser, K. H. C., Khan, I. A., Spiers, J. M., & Wedge, D. E. (2005). Insecticidal activity of 23 essential oils and their major compounds against adult Lipaphis pseudobrassicae (Davis) (Aphididae: Homoptera). *Pest Management Science*, *61*(11), 1122–1128. https://doi.org/10.1002/PS.1100.

Sharma, S., Kumari, A., Dhatwalia, J., Guleria, I., Lal, S., Upadhyay, N., Kumar, V., & Kumar, A. (2021). Effect of solvents extraction on phytochemical profile and biological activities of two Ocimum species: A comparative study. *Journal of Applied Research on Medicinal and Aromatic Plants*, *25*, 100348. https://doi.org/10.1016/J.JARMAP.2021.100348

Sheel, R., Nisha, K., Kumar, J. (2014). Preliminary Phytochemical Screening of Methanolic Extract of Clerodendron infortunatum. *IOSR Journal of Applied Chemistry, 7*(1), 10-13.

Shikha, D., & Kashyap, P. (2024). Ocimum Species. *Harvesting Food from Weeds*, 183–215. https://doi.org/10.1002/9781119793007.CH6

Siddiqui, T., Khan, M. U., Sharma, V., & Gupta, K. (2024). Terpenoids in essential oils: Chemistry, classification, and potential impact on human health and industry. *Phytomedicine Plus*, *4*(2), 100549. https://doi.org/10.1016/J.PHYPLU.2024.100549

Silva, G. O., Abeysundara, A. T., Aponso, M. M. (2017). Extraction methods, qualitative and quantitative techniques for screening of phytochemicals from plants. *American Journal of Essential Oils and Natural Products, 5*(2), 29-32.

Subaharan, K., Senthoorraja, R., Manjunath, S., Thimmegowda, G. G., Pragadheesh, V. S., Bakthavatsalam, N., Mohan, M. G., Senthil-Nathan, S., David, K. J., Basavarajappa, S., & Ballal, C. (2021). Toxicity, behavioural and biochemical effect of *Piper betle* L. essential oil and its constituents against housefly, Musca domestica L. *Pesticide Biochemistry and Physiology*, *174*, 104804. https://doi.org/10.1016/J.PESTBP.2021.104804

Tan, P. V., Mezui, C., Enow-Orock, G., Njikam, N., Dimo, T., & Bitolog, P. (2008). Teratogenic effects, acute and sub chronic toxicity of the leaf aqueous extract of *Ocimum suave* Wild (Lamiaceae) in rats. *Journal of Ethnopharmacology*, *115*(2), 232–237. https://doi.org/10.1016/J.JEP.2007.09.022

Wawrosch, C., & Zotchev, S. B. (2021). Production of bioactive plant secondary metabolites through in vitro technologies—status and outlook. *Applied Microbiology and Biotechnology, 105*(18), 6649–6668. https://doi.org/10.1007/S00253-021-11539-W

Wm, N., Ne, N., & Saotoing P. (2019). Adulticidal and repellent activity of the methanolic leaf extract and essential oils of Hyptis suaveolens and *Lippia adoensis* against Anopheles gambiae ssp Giles 1902 (Diptera: Culicidae). *~ 41 ~ International Journal of Mosquito Research*, *6*(4), 41–48.

Złotek, U., Mikulska, S., Nagajek, M., & Świeca, M. (2016). The effect of different solvents and number of extraction steps on the polyphenol content and antioxidant capacity of basil leaves (*Ocimum basilicum* L.) extracts. *Saudi Journal of Biological Sciences*, *23*(5), 628– 633. https://doi.org/10.1016/J.SJBS.2015.08.002

Zuleta-Castro, C., Rios, D., Hoyos, R., & Orozco-Sánchez, F. (2017). First formulation of a botanical active substance extracted from neem cell culture for controlling the armyworm. *Agronomy for Sustainable Development*, *37*(5). https://doi.org/10.1007/S13593-017-0448-4