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Biocidal Potential of *Parthenium echetrosis*: Formulation, Evaluation, and Comparative Analysis

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Abstract

Background: The invasive weed *Parthenium echetrosis* is a major threat to biodiversity and human health in India because it interferes with other plants and animals in a way that is mostly caused by the sesquiterpene lactone parthenin. **Aim:** This study aimed to evaluate the pharmacognostical, phytochemical, and pesticidal/herbicidal properties of *P. echetrosis* to develop a sustainable management approach. **Methods:** Pharmacognostical characterisation of the leaf, stem, and root confirmed its dicotyledonous nature with bicolateral vascular bundles arranged in a ring. **Results:** Proximate analysis determined loss on drying (3.95 ± 0.25% w/v), total ash (15.67 ± 0.66% w/v), acid-insoluble ash (5.56 ± 0.39% w/v), and water-soluble ash (8.23 ± 0.15% w/v). Alcohol- and water-soluble extractive values were 35 ± 3.5% w/v and 14 ± 0.86% w/v, respectively. Phytochemical screening of the aqueous extract revealed the presence of triterpenoids, carbohydrates, proteins, flavonoids, steroids, and glycosides. A novel emulsion formulation was developed and tested for herbicidal and pesticidal/insecticidal efficacy. The emulsion demonstrated significant herbicidal activity against selective monocot species at 12 mL/L (15.95% w/v) after six days and pesticidal/insecticidal activity on selective dicot species at 10 mL/L (14.24% w/v) after seven days. Comparative analysis with a commercial formulation indicated that the prepared emulsion exhibited no toxicity due to its biodegradable nature while effectively reducing *Parthenium* populations and improving soil nutrient utilisation. **Conclusion:** The formulated emulsion presents an eco-friendly strategy for *P. echetrosis* management by harnessing its bioactive compounds for herbicidal and pesticidal applications. This approach mitigates its invasive nature while promoting sustainable agricultural practices.

Major Findings: The emulsion based on *P. echetrosis* showed definite dose-dependent pesticidal and herbicidal properties, with best results at 10–12 mL/L. Its biodegradable characteristics and lengthy residual effect indicate its potential as a supporting, eco-friendly choice for integrated pest management alongside existing commercial formulations.

Keywords: Herbicidal, Invasive Weed, *Parthenium echetrosis*, Pharmacognostical Study

Abbreviations: CK - Cork Cell; CT - Cortex; **℃** - Degree Celsius; cps - Centipoise; EN - Endodermis; EP - Epidermis; g - gram; HD - Hypodermis; MT - Multicellular Trichomes; MR - Medullary Rays; *µm* - Micrometre; mL or L - Millilitre or Litre; PC - Palisade Cells; rpm - Revolutions Per Minute; XYF - Xylem vessel fibre O/W and W/O - oil-in-water and water-in-oil emulsions; % w/v or % w/w - Percentage Weight by Volume or Percentage Weight by Weight; ST - Stone Cells; T.S. - Transverse Section; VB - Vascular Bundle; XY - Xylem.

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1. Introduction

Because of its quick spread and detrimental impacts on public health, agriculture, and biodiversity, *P. echetrosis*, sometimes referred to as Parthenium weed, is an invasive herbaceous plant that has grown to be a major global issue. This hazardous weed, which originated in the Caribbean, was inadvertently brought to India in the middle of the 1950s by imported food grains. Since then, it has spread throughout the nation, infesting urban areas, meadows, woodlands, and croplands. Because of its aggressive invasion and exceptional adaptability, large seed production capacity, and year-round germination ability, controlling it is extremely difficult[1,2].

The presence of Parthenium weed in agricultural fields leads to a substantial reduction in crop yields, often up to 40%, by competing with cultivated plants for nutrients, water, and sunlight. Furthermore, it serves as an alternate host for various insect pests, exacerbating its negative impact on farming systems. In grazing lands, Parthenium weed diminishes pasture productivity by up to 90%, significantly reducing the availability of fodder for livestock. The plant's allelopathic properties further inhibit the growth of surrounding vegetation, thereby disrupting native ecosystems and causing biodiversity loss[3,4].

Beyond its detrimental agricultural impact, Parthenium weed poses severe health hazards to humans and livestock. Its airborne pollen and volatile compounds are potent allergens, causing respiratory disorders such as asthma, bronchitis, and allergic rhinitis, particularly among individuals with prolonged exposure. Contact with the plant can result in dermatitis, eczema, and eye irritation. In livestock, ingestion of Parthenium weed leads to weight loss, reduced milk yield, alopecia, and systemic toxicity affecting the liver and kidneys. The immunosuppressive effects of its secondary metabolites have also been observed in experimental studies[5-7].

The toxicological properties of Parthenium weed are attributed to its bioactive compounds, primarily sesquiterpene lactones such as parthenin, along with phenolic acids like caffeic acid, vanillic acid, and chlorogenic acid. These compounds interfere with cellular processes, leading to reduced photosynthetic efficiency, inhibition of gibberellin and indole acetic acid functions, and oxidative stress in plants. Given these characteristics, Parthenium weed exhibits potential applications in agriculture as a natural herbicide and pesticide. Research suggests that its allelopathic interactions can be leveraged for weed management, either through direct application or by modifying its bioactive compounds for the development of eco-friendly herbicides[8-10].

Despite extensive efforts to control Parthenium weed through mechanical, chemical, and biological means, its eradication remains a significant challenge. Manual removal, although effective, is labour-intensive and costly. Chemical herbicides, while providing temporary relief, pose environmental and health risks. In recent years, biological control measures, including the introduction of antagonistic plant species such as *Cassia sericea*, have shown promise in suppressing Parthenium infestations. Additionally, research into the potential utilisation of Parthenium weed for green manure, compost, and soil amelioration offers a sustainable approach to mitigating its impact[11]

The alarming rate of Parthenium invasion necessitates an integrated weed management strategy that combines physical, chemical, and biological control measures. This review aims to explore the ecological, agricultural, and health implications of *P. echetrosis* while evaluating its potential applications as a natural herbicide and pesticide. Furthermore, it highlights innovative strategies for sustainable management, emphasising the need for continued research and policy interventions to curb its proliferation and mitigate its adverse effects[12].

2. Materials and Methods

2.1 Plant Material Collection and Authentication

The *P. echetrosis* plant specimen was gathered from Kadi, Gujarat, India. Following the completion of the authentication process, the authenticated specimens were placed at the Department of Pharmacognosy at the Indrashil University School of Pharmacy in Rajpur, Kadi, Gujarat, India.

2.2 Preparation of Plant Material

The entire plant was cleaned, left to dry in the shade, and then chopped into tiny pieces. A 40# sieve was used to filter the dried material after it had been

ground into a powder using a mechanical blender. For future research, the powdered substance was kept in an airtight container.

2.3 Pharmacognostical Study

2.3.1 Morphological Study

The physical attributes of the plant, such as its nature, odour, colour, taste, size, shape, width, and length, were assessed.

2.3.2 Microscopic Analysis

2.3.2.1 Transverse Section (T.S.) Study

Fresh leaf, stem, and root sections were collected, washed with water, and subjected to transverse sectioning. The sections were boiled with chloral hydrate solution, stained using Phloroglucinol and HCl, and mounted with glycerin before observation under a microscope at 10× magnification[13].

2.3.3 Powder Microscopy

A little amount of powdered drug was examined under a microscope at 10× magnification after being treated with chloral hydrate solution, stained with Phloroglucinol and HCl, and mounted with glycerin[14].

2.4 Proximate Analysis

2.4.1 Loss on Drying

A 3 g sample of the air-dried powder, precisely weighed, was put in a Petri dish, baked at 105°C, and then weighed again until the weight remained constant. The drying loss percentage was computed[15-18].

2.4.2 Ash Value

2.4.2.1 Total Ash

In a crucible covered with tar, a 3 g sample of air-dried powder was fired at 450°C until a consistent weight was achieved. It was determined how much ash there was overall[19-21].

2.4.2.2 Acid-insoluble Ash

25 millilitres of hydrochloric acid were used to treat the whole ash, which was then heated for five minutes, filtered, and cleaned with hot water. After drying and being ignited at 450°C, the residue was chilled in a desiccator and weighed. The amount of acid-insoluble ash was determined[21-24].

2.4.3 Extractive Values

2.4.3.1 Alcohol-soluble Extractive

For 24 hours, a 5 g sample was macerated with 100 mL of ethanol while being shaken occasionally. After filtering the extract, 25 millilitres of the filtrate were dried in a water bath and weighed.

2.4.3.2 Water-soluble Extractive

For a full day, a 5 g sample was macerated in 100 mL of distilled water with two to three drops of chloroform. After the extract was filtered, 25 millilitres of the filtrate were dried, evaporated until completely dry, and weighed[25,26].

2.5 Phytochemical Screening

To ascertain the presence of phytoconstituents such as alkaloids, glycosides, carbohydrates, phenolics, tannins, phytosterols, fixed oils, lipids, proteins, amino acids, flavonoids, and saponins, preliminary phytochemical tests were conducted on the aqueous extract of *P. echinosus*[27].

2.5.1 Preparation of Extract

The dried plant powder was extracted with hot water (60–80°C) for 2 hours, filtered, and used for the phytochemical test.

2.5.2 Qualitative Phytochemical Tests

Qualitative phytochemical screening of *P. echetrosis* was conducted using standard procedures, revealing the presence of carbohydrates (Molisch's, Fehling's, Iodine tests), alkaloids (Dragendorff's, Hager's tests), flavonoids (Shinoda test), tannins (Ferric chloride, Vanillin hydrochloride tests), proteins (Biuret test), amino acids (Ninhydrin test), steroids (Liebermann-Burchard test), glycosides (Baljet's, Keller-Killiani tests), and saponins (Foam test), with results systematically recorded[28-30].

2.5.3 Development of Herbal Formulation

A biphasic liquid emulsion (o/w type) was prepared using the dry gum method[31].

2.5.4 Preparation of Aqueous Extract

150 g of *Parthenium echetrosis* powder was boiled in 1 L of water for 3 hours, filtered, and used as the aqueous extract.

2.5.5 Preparation of Oil Phase

Jatropha oil was produced from *Jatropha curcas* seeds with petroleum ether as the oil phase and acacia gum as the emulsifier.

2.5.6 Method of Emulsion Preparation (Dry Gum Method)

Oil, water, and gum were combined in a 4:2:1 ratio to create the emulsion using the dry gum method. After combining the gum and oil in a mortar, water was added, and the mixture was vigorously triturated until it made a clicking sound and turned white[32-37]. After diluting the primary emulsion with the residual aqueous phase to make it pourable, water was added to adjust the final volume[38-51].

2.5.7 Formulation for 100 mL Emulsion

The stability and effectiveness of the formulation, which included 5.5 g of acacia gum, 26 mL of Jatropha oil, and an 16% w/v aqueous extract, were assessed.

2.6 Evaluation of Developed Emulsion

2.6.1 Physicochemical Evaluation

2.6.1.1 Determination of Emulsion Type

The classification of the emulsion was performed using the following standard methods:

2.6.1.1.1 Dilution Method

The emulsion type was determined based on its dilution behaviour. An oil-in-water (O/W) emulsion was expected to dilute freely with water, while a water-in-oil (W/O) emulsion would dilute with oil but not water[52-55].

2.6.1.1.2 Conductivity Method

A conductivity test was performed using an electrode apparatus. The ability to conduct electricity confirmed an O/W emulsion due to water's conductivity, whereas a non-conductive system indicated a W/O emulsion[56-60].

2.6.1.1.3 Dye-solubility Method

The solubility of the emulsion in oil- and water-soluble dyes was examined using Scarlet Red C and Amaranth dyes. A homogenous colour dispersion with Amaranth indicated an O/W emulsion, while Scarlet Red C staining confirmed a W/O emulsion[61-64].

2.6.2 Physical Evaluation

The physical characteristics of the developed emulsion were evaluated for colour, odour, and appearance through visual and olfactory assessments[65-67].

2.6.2.1 Particle Size Analysis

The globule size of the emulsion was determined using a microscopic method. A drop of the emulsion was placed on a glass slide, and the particle size was measured using a stage micrometre under a compound microscope[68].

2.6.2.2 Phase Separation by Centrifugation

The stability of the emulsion was evaluated by centrifugation at 2000–3000 rpm for 10 minutes at room temperature. Observations were made for any visible phase separation[69].

2.6.2.3 Agitation Stability

The emulsion was subjected to mechanical agitation for 24–48 hours using a reciprocating shaker at approximately 60 cycles per minute at ambient temperature. The formulation was then examined for stability changes, such as phase separation or coalescence[69].

2.6.2.4 Viscosity Measurement

The viscosity of the emulsion was determined using a Brookfield Viscometer, employing spindle No. 4. Measurements were recorded at a rotational speed of 0.3 rpm for 2 minutes[70].

2.6.3 Evaluation for Pesticidal and Herbicidal Activity

The developed emulsion was applied to crops after dilution with 1 litre of water at varying concentrations (2 mL, 4 mL, and 6 mL). The effectiveness of the formulation was assessed in terms of pesticidal and herbicidal activity[71-76].

2.6.4 Comparative Study with Marketed Formulation

The pesticidal and herbicidal efficacy of the formulated emulsion was compared against a commercially available formulation. Performance parameters such as effectiveness, stability, and application efficiency were recorded.

2.7 Results and Discussion

2.7.1 Pharmacognostical evaluation of Parthenium echetrosis

The pharmacognostical evaluation of *P. echetrosis* revealed distinct morphological characteristics across its plant parts. The leaves are green, aromatic, and bitter in taste, exhibiting a basal rosette arrangement with bipinnatifid or pinnatifid margins, measuring 3–20 cm in length and 2–10 cm in width. The stem is light green, aromatic, and bitter, unbranched in the lower region but branched in the upper part, with a longitudinally striate and hirsute texture, reaching a height of 1.5–2 m. The root system is greyish-brown to grey, odourless, with an astringent and bitter taste, displaying a branched structure with 7–8 root tips. The flowers are small, whitish-cream in colour, and arranged in open panicles, with a sweet odour and an astringent taste; the ray florets measure approximately 0.6 mm in length, while the disk corollas are cream-colored and about 1 mm long. These morphological features contribute to the identification and characterisation of *P. echetrosis* in pharmacognostical studies.

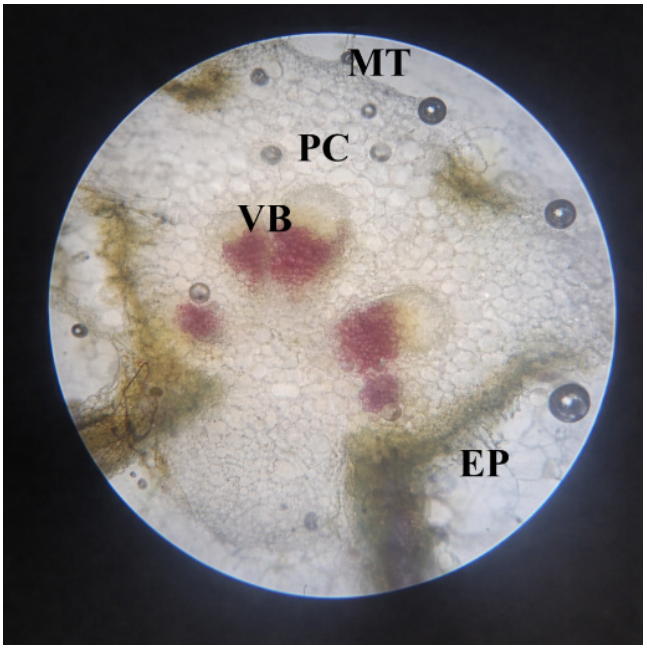
2.7.2 Microscopy of Parthenium echetrosis

2.7.2.1 Microscopy of Parthenium echetrosis Leaf

The leaf anatomy revealed a distinct lamina and midrib structure. The epidermis was single-layered with wavy parenchymatous cells, bearing multicellular covering trichomes (3–6 cells) with warty surfaces and pointed apices. The hypodermis consisted of 1–2 layers of thick-walled parenchyma. The midrib exhibited 3–4 layers of collenchyma beneath the epidermis, with parenchymatous ground tissue containing bicolateral vascular bundles comprising lignified xylem (5–6 rays), phloem on both sides, and groups of pericyclic fibres (Figure 1).

2.7.2.2 Microscopy of Parthenium echetrosis Stem

The transverse section exhibited a single-layered epidermis with thick-walled parenchymatous cells and multicellular covering trichomes. The hypodermis comprised 9–11 layers of collenchymatous cells, followed by a cortex with thick-walled outer and large parenchymatous inner layers. The stele displayed a distinct endodermis over the pericycle, which contained lignified, polygonal, thick-walled fibres.



MT: Multicellular Trichomes; HD: Hypodermis; PC: Palisade Cells; EP: Epidermis; VB: Vascular Bundle

Figure 1. Microscopy of *Parthenium echetrosis* leaf.

The bicolateral vascular bundles formed a ring, with phloem comprising polygonal and radially arranged rectangular cells, and xylem with meta-xylem toward the epidermis and proto-xylem toward the centre. Xylem fibres were thick-walled but non-lignified, while the vessels were lignified. The centrally located pith consisted of round parenchymatous cells, occupying nearly half of the section (Figure 2).

2.7.2.3 Microscopy of Parthenium echetrosis Root

The transverse section revealed an outer cork layer composed of 2–3 layers of polygonal cells. The cortex consisted of 6–9 layers of parenchymatous cells with sparsely distributed lignified stone cells. The phloem was organised into 7–8 layers, while the xylem vessels were radially arranged in groups of 2–3, forming a distinct ring with primary xylem at the centre. Xylem fibres were thick-walled, polygonal, and non-lignified. Calcium oxalate prisms were observed as cellular inclusions (Figure 3).

2.7.3 Powder Microscopy

Powder microscopy of *P. echetrosis* revealed lignified vessels, pitted vessels, lignified fibres, pollen sac and covering trichomes were observed (Figure 4).

2.7.4 Proximate Analysis of Parthenium echetrosis

Proximate analysis study showed a loss on drying of 3.95 ± 0.25% w/w, indicating very low moisture content. The total ash content was found to be 15.67 ± 0.66% w/w, with acid-insoluble and water-soluble ash at 5.56 ± 0.39% w/w and 8.23 ± 0.15% w/w, respectively, reflecting the presence and fraction of inorganic matter. As the alcohol-soluble extractive value (35 ± 3.5% w/w) is higher than that of the water-soluble extractive value (14 ± 0.86% w/w), it indicates more solubility of phytoconstituents in alcohol than in water (Table 1).



EN: Endodermis; HD: Hypodermis; PC: Palisade Cells; EP: Epidermis; VB: Vascular Bundle

Figure 2. Microscopy of *P. echetrosis* stem.

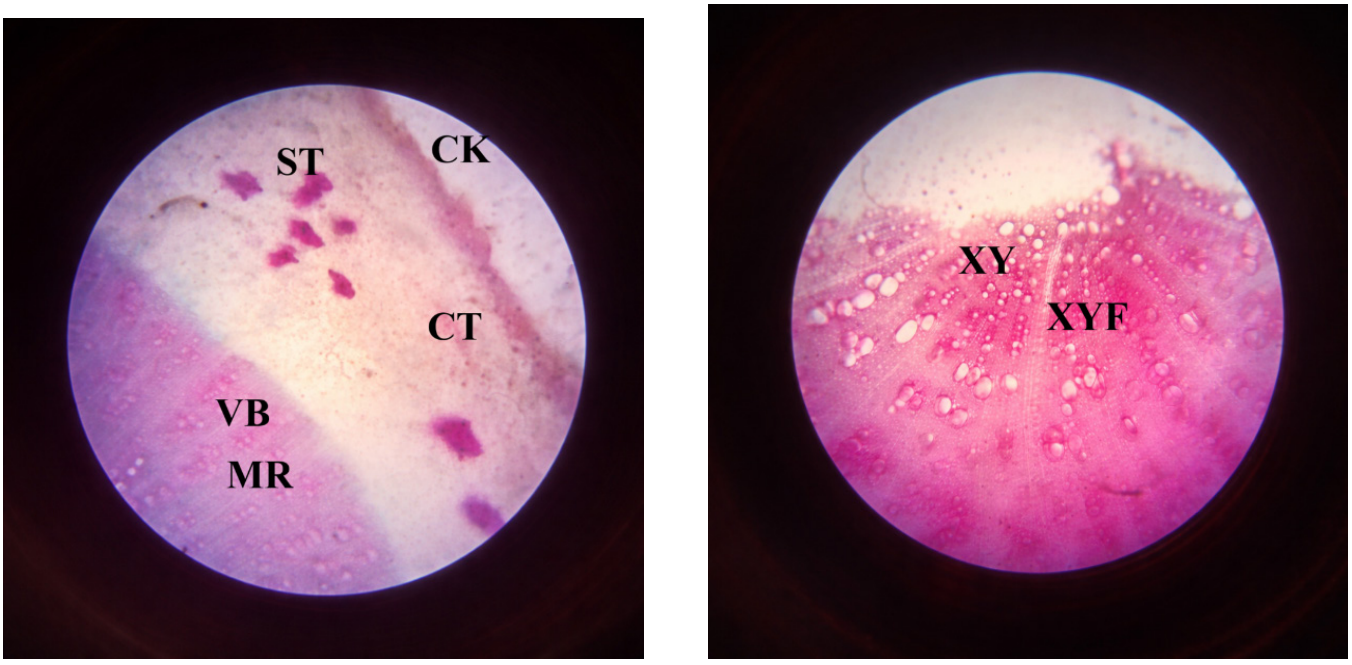
2.7.5 Phytochemical Screening

Phytochemical screening of aqueous extract of *P. echetrosis* showed the presence of flavonoid, steroid, glycoside, Proteins, carbohydrates and triterpenoid. The triterpenoid was mainly responsible for pesticidal and herbicidal activity, which was present in the aqueous extract of the plant (Table 2).

3. Evaluation of the Developed Polyherbal Formulation

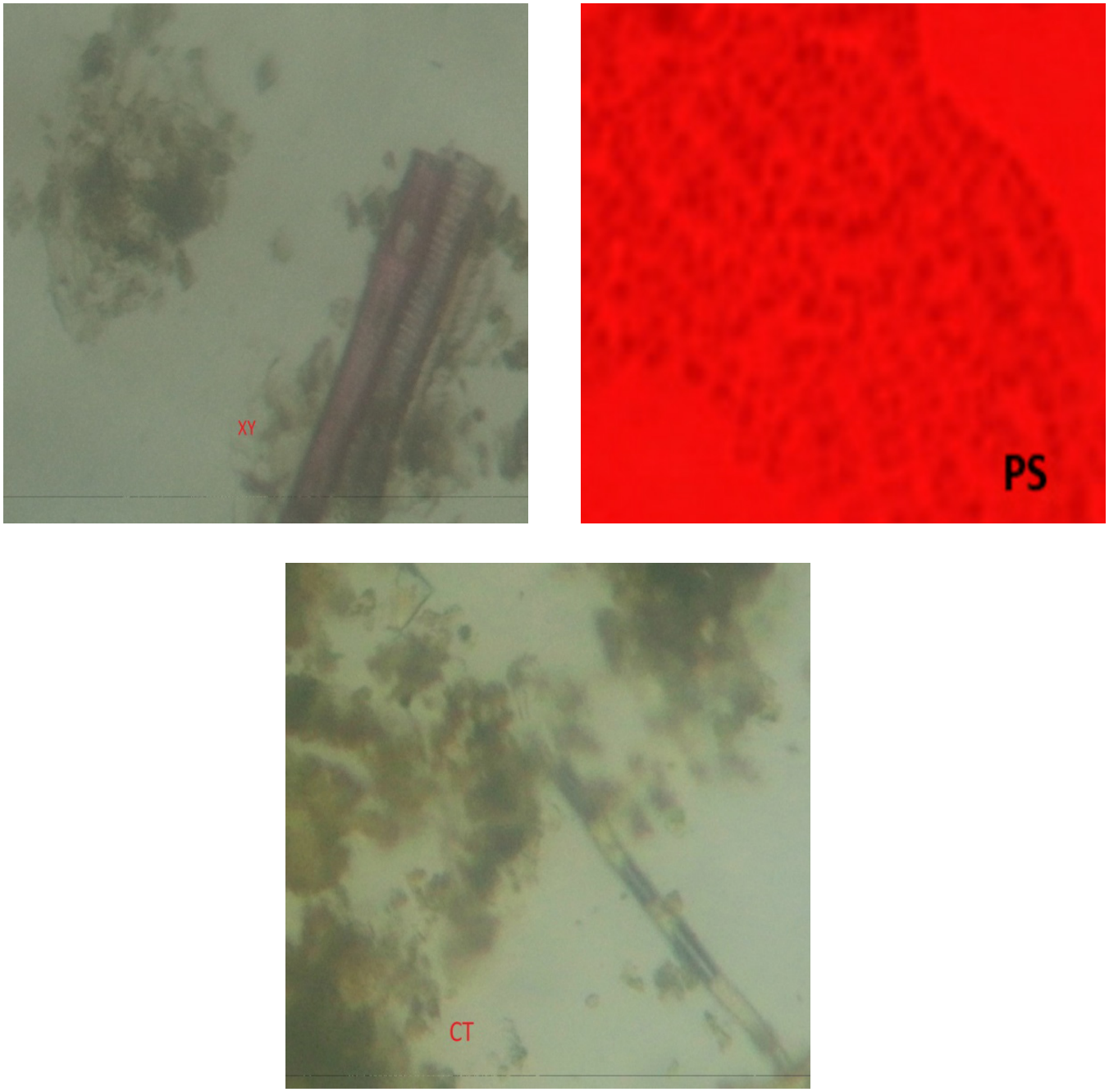
3.1 Physicochemical Evaluation of Emulsion

The dilution test confirmed that the emulsion was of the oil-in-water (O/W) type, as it was easily miscible with water, while added oil formed separate droplets. The conductivity test demonstrated electrical conduction,



VB: Vascular Bundle; ST: Stone Cells; CK: Cork Cell; CT: Cortex; MR: Medullary Rays, XY: Xylem, XYF: Xylem Vessel Fibre

Figure 3. Microscopy of *P. echetrosis* root.



Xy: Xylem Vessels; CT: Covering Trichome; PS: Pollen Sac

Figure 4. Powder microscopy.

indicating a continuous aqueous phase. In the dye test, the water-soluble dye amaranth uniformly colored the emulsion, further supporting its O/W nature. These results collectively confirmed the emulsion's oil-in-water classification (Table 3).

The formulated emulsion exhibited a greyish-brown colour, sweet odour, and opaque appearance. The particle size range of 4-4.5 µm was within the normal range for emulsions. Centrifugation showed phase separation, but no serious deterioration occurred after shaking. The emulsion remained stable under agitation, and its viscosity was measured at 21.56 cps. These physicochemical characteristics confirmed the emulsion's stability for one month (Table 4).

Table 1. Proximate analysis of *P. echetrosis*

Parameter	Result Observed (% w/w)
Loss on Drying	3.95±0.25
Ash Values	
Total Ash	15.67 ± 0.66
Acid Insoluble Ash	5.56 ± 0.39
Water Soluble Ash	8.23 ± 0.15
Extractive Values	
Alcohol Soluble Extractive	35 ± 3.5
Water Soluble Extractive	14 ± 0.86

Table 2. Phytochemical screening for the aqueous extract of *P. echetrosis* plant

Phytochemical Test	Result
Alkaloid	-ve
Glycoside	+ve
Flavonoid	+ve
Carbohydrate	+ve
Tannin	-ve
Proteins	+ve
Steroid	+ve
Volatile Oil	-ve
Triterpenoid	+ve
Saponin	-ve

Note : -ve: Negative, +ve: Positive

Table 3. Detection of the type of Emulsion

Test	Observation
Dilution	Water-miscible
Conductivity	carries electricity
Dye Test	The emulsion is coloured by a water-soluble dye.

Table 4. Physicochemical evaluation of emulsion

Parameter	Observation
Colour	Greyish brown
Odour	Sweet
Appearance	Turbid
Particle Size Range	4-4.5µm
Phase Separation by Centrifugation	No serious deterioration
Agitation	Not adversely affected
Viscosity	21.56 cps

3.2 Evaluation of the Herbicidal Activity of the Developed Formulation

3.2.1 Effect of formulation on different weeds

The 12 ml/litre dose of the aqueous extract (15.95% w/v) exhibited the highest herbicidal activity against *Avena fatua* and *Bidens pilosa*. The herbicidal effect was primarily observed in monocot species, including *Avena fatua* and *Cyperus rotundus*. The formulation demonstrated a decreasing effect on the growth of monocot weeds, suggesting its selectivity towards monocot species (Figures 5 and 6).

3.3 Evaluation of the Pesticidal Activity of the Developed Formulation

3.3.3 Effect of Formulation on Different Plants

The pesticidal evaluation showed that formulations with lower concentrations (3.45% and 6.24% w/v) were



Before treatment After treatment

Figure 5. Effect on *Avena fatua* weed.



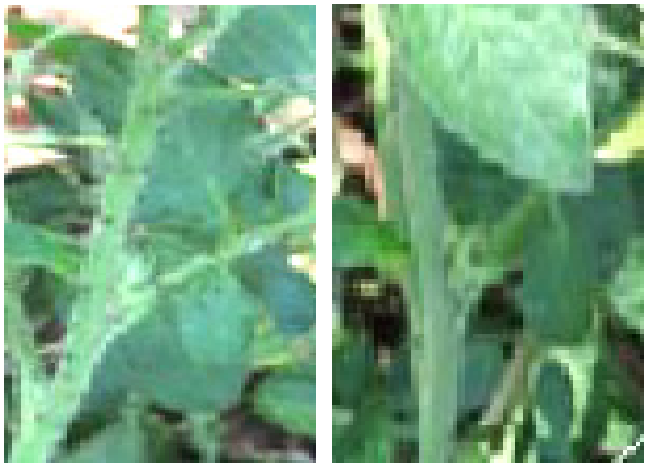
Before treatment After treatment

Figure 6. Effect on *Cyperus rotundus* weed.



Before treatment After treatment

Figure 7. Effect on *Trigonella foenum-graecum*'s plants (Fenugreek).



Before treatment After treatment

Figure 8. Effect on *Solanum lycopersicum's* plants (Tomato).

ineffective, while 9.00% w/v had a slight effect. The formulation with 11.54% w/v was effective, whereas 14.24% w/v exhibited the highest pesticidal activity. The 15.95% w/v formulation showed similar efficacy. Thus, the 10 ml/litre dose (14.24% w/v) was considered the most effective for pesticidal activity. The results suggest that increasing the concentration enhances effectiveness, with 10 ml/litre being the optimal dose (Figures 7-9).

The produced formulation's dose-response relationship at escalating concentrations (3.45–15.95% w/v) is depicted in the figure. Both herbicidal and pesticidal activities show a distinct linear pattern, with efficacy ratings increasing in direct proportion to concentration. The steeper slope of the pesticidal curve indicates a greater sensitivity to concentration increases and an earlier shift from "slightly effective"



Before treatment After treatment

Figure 9. Effect on perennial *Solanum* plants (Potato).

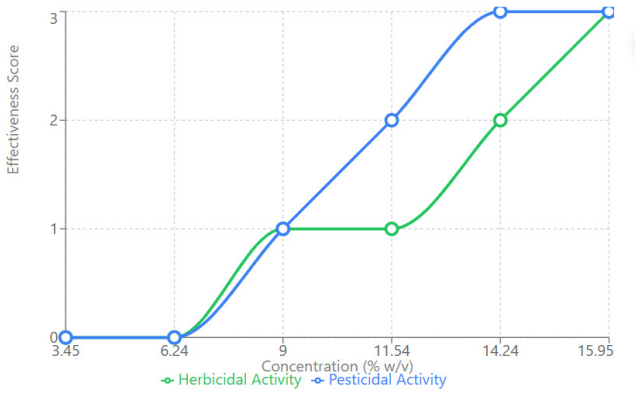


Figure 10. Dose-response curves: Concentration *vs.* Effectiveness (herbicidal and pesticidal activities).

to "effective". The herbicidal curve, on the other hand, shows a delayed response, necessitating a larger dose to have the same degree of biological impact. These trends verify that both activities have a robust, statistically supported dose-dependent relationship (Figure 10).

The effectiveness of pesticides and herbicides at each tested concentration is contrasted in this graphic. In contrast to herbicidal activity, which needs 15.95% w/v to produce the same reaction, pesticidal activity continuously exhibits better scores at equal doses, achieving maximal efficiency at 14.24% w/v. The formulation's superior effectiveness against insect/pest targets compared to weed targets is highlighted by the visual comparison, which may indicate variations in biological susceptibility or mechanisms of action (Figure 11).

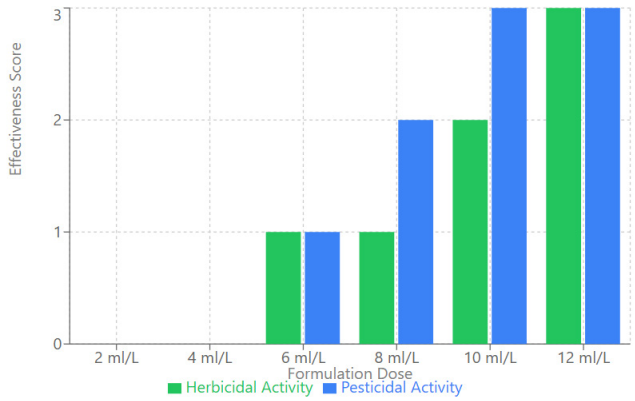


Figure 11. Concentration *vs.* Effectiveness.

Table 5. Statistical summary of dose–response analysis

Parameter	Herbicidal Activity	Pesticidal Activity
Pearson's correlation coefficient (r)	0.9745	0.9798
Coefficient of determination (R^2)	0.9496	0.9600
Regression slope (β_1)	0.3129	0.3295
Regression intercept (β_0)	−2.0588	−1.9706
t-Statistic	8.9772	10.2247
Degrees of freedom (df)	4	4
p-Value	< 0.001*	< 0.001*
Minimum effective concentration (% w/v)	14.24	11.54
Optimal effective range (% w/v)	14.24–15.95	11.54–14.24
Dose for 'Effective' classification (ml/L)	10	8
Maximum effectiveness score	3 ('More effective')	3 ('More effective')

*$p < 0.001$ indicates statistically highly significant relationships.

3.4 Comparison of the Pesticidal Activity of the Developed Formulation with the Marketed Formulation

A comparison between the developed and marketed formulations showed that the developed emulsion (14.24% w/v) took 7 days for effectiveness, whereas the marketed solution (17.8% w/v) acted within 4 days. Despite having a lower concentration, the developed formulation required more time to exhibit its effect, indicating a difference in formulation type and release profile (Figure 12).

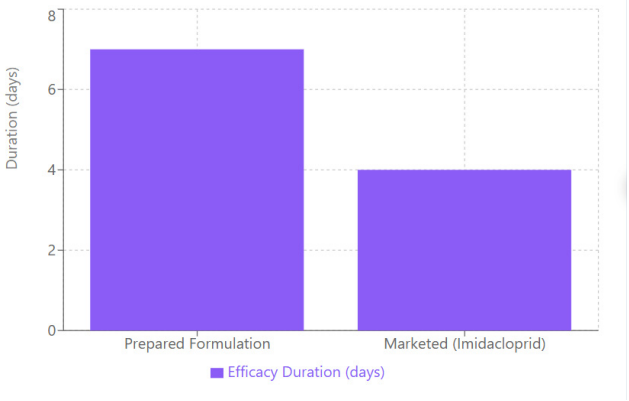


Figure 12. Efficacy duration comparison between prepared and marketed formulations.

Table 6. Comparative efficacy duration

Parameter	Prepared Formulation	Marketed Formulation (Imidacloprid)
Concentration (% w/v)	14.24	17.8
Applied dose (ml/L)	10	3
Efficacy duration (days)	7	4
Duration advantage (%)	+75%	—
Applications needed for 7-day protection	1	2
Total volume for equal duration (ml)	10	6
Effectiveness classification	More effective	More effective
Pest/weed spectrum	Aphids, thrips, whiteflies, hoppers, weeds	Aphids, thrips, whiteflies, hoppers, termites

4. Discussion

The homemade formulation (10 ml/L, 14.24% w/v) and the commercial imidacloprid formulation's duration of action are compared in this figure. Compared to the marketed formulation (4 days), the manufactured product offers a noticeably extended protection time

(7 days). The produced formulation shows a 75% improvement in residual activity despite the larger dose requirement, suggesting a longer persistence and slower degradation profile. This prolonged effect may offer useful benefits in field settings and is consistent with the high dose-response characteristics that have been reported. Strong correlations ($r > 0.97$) and good predictability ($R^2 > 0.94$) confirmed this study's clear dose-dependent and highly linear increase in the synthesised botanical formulation's herbicidal and pesticidal efficacy. Greater target sensitivity was shown by pesticidal activity responding at lower doses than herbicidal activity. The formulation had a greater durability (7 *vs.* 4 days) than the commercial imidacloprid product, indicating slower degradation and less frequent reapplication. Overall, the statistically significant results ($p < 0.001$) demonstrate the formulation's potential for successful and long-term agricultural usage and validate dependable dose-response behaviour.

The prepared formulation (14.24% w/v) required a higher dose and longer duration for effectiveness compared to the marketed formulation (17.8% w/v) (Tables 5 and 6). However, as a natural emulsion, it was biodegradable and left no toxic residues on plants. In contrast, the synthetic marketed formulation contained toxic ingredients that could persist on plants and pose health risks if consumed. Thus, the developed formulation offers a safer, eco-friendly alternative for pest control.

5. Conclusion

The developed formulation effectively utilised the beneficial aspects of *P. echetrosis* while minimising its adverse effects. The herbicidal and pesticidal activities were demonstrated against selective monocot and dicot species, with significant effectiveness at optimal doses. The emulsion was confirmed to be stable, biodegradable, and free from toxic residues, making it a safer alternative to synthetic pesticides. Although the time required for action was longer compared to marketed formulations, the natural composition ensured environmental safety and reduced human health risks. The study confirms that the developed formulation shows strong, dose-dependent herbicidal and pesticidal activities, with highly linear response patterns and earlier maximum efficacy in pesticidal action. It also outperforms a marketed imidacloprid product by providing 75% longer protection.

Overall, the formulation demonstrates reliable efficacy, predictable dose–response behaviour, and extended residual activity, supporting its potential for commercial use. Recommended doses of 10–12 ml/L appear suitable for practical application. Further field trials and stability studies are needed to fully support large-scale deployment. This study highlights the potential of *P. echetrosis*-based formulations in sustainable agriculture and integrated pest management.

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8. References

1. Van Ast A, Bastiaans L, Kropff MJ. A comparative study on Striga hermonthica interaction with a sensitive and a tolerant Sorghum cultivar. Weed Res. 2000; 40(6):479–493. https://doi.org/10.1046/j.1365-3180.2000.00204.x
2. Melese D, Woldu Z, Asfaw Z, Warkineh B. Predicting the invasion potential of two alien plant species (Parthenium hysterophorus L., Asteraceae and Salvia tiliifolia Vahl, Lamiaceae) under the current and future climate change scenarios in Ethiopia. Ecol Process. 2025; 14(1):123-135. https://doi.org/10.1186/s13717-025-00626-9
3. Bashar HMK, Juraimi AS, Ahmad-Hamdani MS, Uddin MK, Asib N, Anwar MdP, et al. A mystic weed, Parthenium hysterophorus: threats, potentials and management. Agron J. 2021; 11(8):1514. https://doi.org/10.3390/agronomy11081514
4. McElroy JS. Vavilovian Mimicry: Nikolai Vavilov and his little-known impact on weed science. Weed Sci. 2014; 62(2):207–216. https://doi.org/10.1614/WS-D-13-00122.1
5. Reddy BS, Mariaselvam CM, Reni Micheal BN, Vallayyachari K, Bulusu SN, Thabah MM, Anand MP, Madhavan T, Negi VS. Functional characterization of complete and immunodominant epitopes of a novel pollen allergen from Parthenium hysterophorus. Eur Ann Allergy Clin Immunol. 2025; 57(6):260–269. https://doi.org/10.23822/EurAnnACI.1764-1489.355 PMid: 39082874.
6. Ramos A, Rivero R, Visozo A, Piloto J, García A. Parthenin, a sesquiterpene lactone of *Parthenium hysterophorus* L., is a high toxicity clastogen.Mutat Res.2002; 514(1–2):19–27. https://doi.org/10.1016/S1383-5718(01)00321-7
7. Picman AK, Towers GHN. Sesquiterpene lactones in various populations of Parthenium hysterophorus. Biochem Syst Ecol. 1982; 10(2):145–153. https://doi.

org/10.1016/0305-1978(82)90021-7
8. Patel S. Harmful and beneficial aspects of Parthenium hysterophorus: an update. 3 Biotech. 2011; 1(1):1–9. https://doi.org/10.1007/s13205-011-0007-7 PMid: 22558530 PMCid: PMC3339593.
9. Nawaz H, Ishaq MW, Qadeer S, Mahmood MH, Adeel M, Anwar I, et al. Assessing the threat: Parthenium adverse effects on biodiversity, human communities, and environmental integrity. Scholars Bull. 2025; 11(03):21–41. https://doi.org/10.36348/sb.2025.v11i03.001
10. Kaur M, Aggarwal NK, Kumar V, Dhiman R. Effects and management of Parthenium hysterophorus : a weed of global significance. Int Sch Res Not. 2014; 2014:1–12. https://doi.org/10.1155/2014/368647 PMid: 27355059 PMCid: PMC4897546.
11. Kaur A, Kaur S, Jandrotia R, Singh H, Batish D, Kohli R, et al. Parthenin—a sesquiterpene lactone with multifaceted biological activities: insights and prospects. Molecules. 2021; 26(17):5347. https://doi.org/10.3390/molecules26175347 PMid: 34500778 PMCid: PMC8434391.
12. Belz RG, Reinhardt CF, Foxcroft LC, Hurle K. Residue allelopathy in Parthenium hysterophorus L. Crop Prot. 2007; 26(3):237–245. https://doi.org/10.1016/j.cropro.2005.06.009
13. Hériché M, Arnould C, Wipf D, Courty PE. Imaging plant tissues: advances and promising clearing practices. Crop Prot. 2022; 27(6):601–615. https://doi.org/10.1016/j.tplants.2021.12.006 PMid: 35339361.
14. Villani TS, Koroch AR, Simon JE. An improved clearing and mounting solution to replace chloral hydrate in microscopic applications. Appl Plant Sci. 2013; 1(5):1300016. https://doi.org/10.3732/apps.1300016 PMid: 25202549 PMCid: PMC4105042.
15. Raja KS, Taip FS, Azmi MMZ, Shishir MRI. Effect of pre-treatment and different drying methods on the physicochemical properties of Carica papaya L. leaf powder. J Saudi Soc Agric Sci. 2019; 18(2):150–156. https://doi.org/10.1016/j.jssas.2017.04.001
16. Quirino DF, Lima NSA, Palma MNN, Franco MO, Detmann E. Evaluation of heating times for loss on drying at 105°C for estimation of laboratory dry matter in animal feeds. J AOAC Int. 2023; 106(2):261–266. https://doi.org/10.1093/jaoacint/qsad004 PMid: 36610993.
17. Mohapatra P, Ray A, Jena S, Nayak S, Mohanty S. Influence of various drying methods on physicochemical characteristics, antioxidant activity, and bioactive compounds in Centella asiatica L. leaves: a comparative study. BioTechnologia. 2022; 103(3):235–247. https://doi.org/10.5114/bta.2022.118666 PMid: 36605822 PMCid: PMC9642956.
18. Khaled BM, Das AK, Alam SMS, Saqib N, Rana MdS, Sweet SR, et al. Effect of different drying techniques on the physicochemical and nutritional properties of Moringa oleifera leaves powder and their application in bakery product. Appl Food Res. 2024; 4(2):100599. https://doi.org/10.1016/j.afres.2024.100599
19. Rao Y, Xiang B. Determination of total ash and acid-insoluble ash of Chinese herbal medicine Prunellae spica by near infrared spectroscopy. Yakugaku Zasshi. 2009; 129(7):881–886. https://doi.org/10.1248/yakushi.129.881 PMid: 19571524.
20. Mahima, Singh B, Kumar A, Vaishali, Kumar SP. Botanical identification to assess the standards through the comprehensive pharmacognostical study of Acorus calamus Linn. leaves. Biomedicine. 2024; 43(6):1864–1869. https://doi.org/10.51248/.v43i6.3246
21. Kc Y, Bhattarai S, Shiwakoti LD, Paudel S, Subedi M, Pant BR, et al. Sensorial and chemical analysis of biscuits prepared by incorporating Moringa flower powder and leaf powder. Int J Food Prop. 2022; 25(1):894–906. https://doi.org/10.1080/10942912.2022.2069807
22. Bello Abdullahi Abdu, Uzairu Adamu, Sallau Muhammad Sani, Okunola Oluwole Joshua. Physical and phytochemicals study of some local herbal remedies.
IOSR Journals. 2015; https://figshare.com/articles/Physical_And_Phytochemicals_Study_Of_Some_Local_Herbal_Remedies/1518515/1
23. Hait M, Kashyap NK, Chandel SS, Vaishnav MM. Proximate analysis of herbal drugs: methods, relevance, and quality control aspects. In: Izah SC, Ogwu MC, Akram M, editors. Herbal Med Phytochem. Springer International Publishing; 2023. https://doi.org/10.1007/978-3-031-21973-3_42-1
24. Bukunmi AA. Phytochemical and proximate analysis of some medicinal leaves. Clin Med Res. 2017; 6(6):209. https://doi.org/10.11648/j.cmr.20170606.16
25. Yadav VK, Irchhiaya R, Ghosh AK. Phytochemical and pharmacognostical studies of Anogeissus acuminata. J Drug Delivery Ther. 2019; 9(4-A):450–457. https://doi.org/10.22270/jddt.v9i4-A.3507
26. Liu K. New and improved methods for measuring acid insoluble ash. Anim Feed Sci Technol. 2022; 288:115282. https://doi.org/10.1016/j.anifeedsci.2022.115282
27. Gul, Rauf A, Khan IA, Alnasser SM, Shah SUA, Rahman MdM. Phytochemical Analysis and in vitro and in vivo pharmacological evaluation of Parthenium hysterophorus Linn. Evid Based Complement Altern Med. 2022; 2022:1–7. https://doi.org/10.1155/2022/6088585 PMid: 35754691 PMCid: PMC9232325.
28. Patil VN, Pande SS, Dhote AD, More KA, Kongre NC, Gandhare NV. Phytochemical screening of some important medicinal plants used for kidney stone. Int J Pharm Sci Rev Res. 2023; 79(1). https://doi.org/10.47583/ijpsrr.2023.v79i01.008
29. Elvis NI, Rich J, Chizoba O, Robinson N. Phytochemical screening of the herbal formulation of Morinda citrifolia and Costus afer leaf extracts. Sch Int J Tradit Complement Med. 2023; 6(04):63–66. https://doi.org/10.36348/sijtcm.2023.v06i04.003
30. Nigam R, Arnold R. Qualitative and quantitative phytochemical screening and chemical fingerprint analysis of herbal plant Phyllanthus niruri using HPTLC. J Sci Res. 2021; 13(2):623–633. https://doi.org/10.3329/jsr.v13i2.50391
31. Ribeiro S, Almeida R, Batista L, Lima J, Sarinho A, Nascimento A, et al. Investigation of guar gum and xanthan gum influence on essential thyme oil emulsion properties and encapsulation release using modeling tools. Foods. 2024; 13(6):816. https://doi.org/10.3390/foods13060816 PMid: 38540806 PMCid: PMC10969728.

32. Wang Y, Li D, Wang L, Li SJ, Adhikari B. Effects of drying methods on the functional properties of flaxseed gum powders. Carbohydr Polym. 2010; 81:128–133. https://doi.org/10.1016/j.carbpol.2010.02.005
33. Türker DA, Saraç MG, Doğan M. Investigating the interfacial and bulk rheological properties of emulsions containing dry bean powder. Eur Food Res Technol. 2024; 250(10):2659–2668. https://doi.org/10.1007/s00217-024-04566-0
34. Turchiuli C, Munguia M, Sanchez M, Ferre H, Dumoulin E. Use of different supports for oil encapsulation in powder by spray drying. Powder Technol. 2014; 255:103–108. https://doi.org/10.1016/j.powtec.2014.01.019
35. Rigane K, Laurichesse E, Chouaibi M, Schmitt V. Encapsulation of polyphenols in double water-in-oil-in-water emulsions stabilized by polyglycerol polyricinoleate and tunisian arabic gum. Langmuir. 2025; 41(14):9335-9347. https://doi.org/10.1021/acs.langmuir.4c05214
36. Özbek Z, Ergönül P. Optimisation of wall material composition of freeze–dried pumpkin seed oil microcapsules: interaction effects of whey protein, maltodextrin, and gum Arabic by D–optimal mixture design approach. Food Hydrocoll. 2020; 107:105909. https://doi.org/10.1016/j.foodhyd.2020.105909
37. McNamee BF, O'Riordan ED, O'Sullivan M. Emulsification and microencapsulation properties of gum arabic. J Agric Food Chem. 1998; 46(11):4551–4555. https://doi.org/10.1021/jf980260p
38. Martins D, Estevinho B, Rocha F, Dourado F, Gama M. A dry and fully dispersible bacterial cellulose formulation as a stabilizer for oil-in-water emulsions. Carbohydr Polym. 2020; 230:115657. https://doi.org/10.1016/j.carbpol.2019.115657 PMid: 31887925.
39. Martins D, Dourado F, Gama M. Effect of ionic strength, pH and temperature on the behaviour of re-dispersed BC:CMC – a comparative study with xanthan gum. Food Hydrocoll. 2022; 125:107396. https://doi.org/10.1016/j.foodhyd.2021.107396
40. Kuevi D, Kuntworbe N, Ayertey E. Effects of pH and electrolytes on castor oil emulsions with various stabilisers using Khaya senegalensis gum as an emulsifier. Adv Pharmacol Pharm Sci. 2021; 2021:6628453. https://doi.org/10.1155/2021/7049332 PMid: 34693291 PMCid: PMC8536427.
41. Khalesi H, Emadzadeh B, Kadkhodaee R, Fang Y. Effect of Persian gum on whey protein concentrate cold-set emulsion gel: structure and rheology study. Int J Biol Macromol. 2019; 125:17–26. https://doi.org/10.1016/j.ijbiomac.2018.12.097 PMid: 30550823.
42. Jeong J, Kwon J, Lee J, Weiss J, Choi MJ. Enhancing the stability of xanthan/locust bean gum-based double emulsions using canola and medium-chain triglyceride oils: examination of physicochemical and thermal properties. Food Chem. 2025; 489:145078. https://doi.org/10.1016/j.foodchem.2024.145078 PMid: 40505333.
43. Feng S, Zhang S, Jiang M, Liu F, Chen K, Zhang Y. Effects of glycation methods on the interfacial behavior and emulsifying performance of soy protein isolate-gum Arabic conjugates. Int J Biol Macromol. 2023; 237:123554. https://doi.org/10.1016/j.ijbiomac.2023.123554 PMid: 36740109.
44. Estrada-Fernández A, Román-Guerrero A, Jiménez-Alvarado R, Lobato-Calleros C, Álvarez-Ramírez J, Vernon-Carter E. Stabilization of oil-in-water-in-oil (O1/W/O2) pickering double emulsions by soluble and insoluble whey protein concentrate-gum Arabic complexes used as inner and outer interfaces. J Food Eng. 2018; 221:35–44. https://doi.org/10.1016/j.jfoodeng.2017.10.006
45. Didar Z, Hesarinejad M. Preparation of vitamin D3-loaded oil-in-water-in-oil double emulsions using psyllium gum: optimization using response surface methodology. Chem Biol Technol Agric. 2022; 9:1–17. https://doi.org/10.1186/s40538-022-00348-6
46. Diana G, Milanesi A, Candiani A, Sodano A, Rassè P, Bonda AF, et al. Spray drying of an oil-in-water emulsion containing vitamin D3: a synergy between formulation and process conditions to obtain microparticles. Int J Pharm. 2025; 632:125384. https://doi.org/10.1016/j.ijpharm.2024.125384 PMid: 39986492.
47. Daoub R, Misran M, Hassan E, Osman M. Examination of stability of emulsions containing two gums from the Vulgares family and combinations. Int J Sci Res. 2024; 13:1–10. https://doi.org/10.21275/SR24318024018
48. Çetinkaya T, Altay F, Ceylan Z. A new application with characterized oil-in-water-in-oil double emulsions: Gelatin-xanthan gum complexes for the edible oil industry. LWT–Food Sci Technol. 2020; 134:110773. https://doi.org/10.1016/j.lwt.2020.110773
49. Atgié M, Masbernat O, Roger K. Emulsions stabilized by gum arabic: composition and packing within interfacial films. Langmuir. 2018; 35(4):962–972. https://doi.org/10.1021/acs.langmuir.8b02715 PMid: 30507121.
50. Alouk I, Lv W, Chen W, Miao S, Chen C, Wang Y, et al. Encapsulation of Monascus pigments in gel in oil in water (G/O/W) double emulsion system based on sodium caseinate and guar gum. Int J Biol Macromol. 2024; 239:138232. https://doi.org/10.1016/j.ijbiomac.2023.138232 PMid: 39626818.
51. Abdolmaleki K, Mohammadifar M, Mohammadi R, Fadavi G, Meybodi N. The effect of pH and salt on the stability and physicochemical properties of oil-in-water emulsions prepared with gum tragacanth. Carbohydr Polym. 2016; 140:342–348. https://doi.org/10.1016/j.carbpol.2015.12.061 PMid: 26876862.
52. Zhang W, Du T, Xu X, Zhao X.Multi-scale rheology for emulsion stability investigation: bulk-, interfacial-, and micro-perspectives. Adv Colloid Interface Sci. 2025; 345:103627. https://doi.org/10.1016/j.cis.2025.103627
53. Wang X, Li X, Xu D, Zhu Y, Cao Y, Wang J, et al. Comparison of heteroaggregation, layer-by-layer and direct mixing techniques on the physical properties and in vitro digestion of emulsions. Food Hydrocoll. 2019; 96:498–508. https://doi.org/10.1016/j.foodhyd.2019.05.050
54. Wang K, Li G, Zhang B. Opposite results of emulsion stability evaluated by the TSI and the phase separation proportion. Colloids Surf A Physicochem Eng Asp. 2018; 555:33–40. https://doi.org/10.1016/j.colsurfa.2018.07.061
55. Tekin Z, Avcı E, Karasu S, Toker O. Rapid determination of emulsion stability by rheology-based thermal loop test. LWT–Food Sci Technol. 2020; 122:109037. https://doi.org/10.1016/j.lwt.2020.109037

56. Tadros T. Application of rheology for assessment and prediction of the long-term physical stability of emulsions. Adv Colloid Interface Sci. 2004; 108–109:227–258. https://doi.org/10.1016/j.cis.2003.10.010 PMid: 15072947.
57. Sjöblom J. Emulsions and emulsion stability. Adv Colloid Interface Sci. 1996; 65:1–30. https://doi.org/10.1016/0001-8686(96)00293-X
58. Shi X, Qi D, Lin C, Li J. A technical review on characterization methods for structures and properties of emulsion. APL Mater. 2024; 12:041103. https://doi.org/10.1063/5.0241903
59. Prakash A, Mercer S. Ultrasonic based methods to characterize stability of water-in-crude oil emulsions. Colloids Surf A Physicochem Eng Asp. 2020; 596:125900. https://doi.org/10.1016/j.colsurfa.2020.125900
60. Plassard L, Mouret A, Nieto-Draghi C, Dalmazzone C, Langevin D, Argillier J. Comparison of methods used to investigate coalescence in emulsions. Langmuir. 2024; 40:12345–12357. https://doi.org/10.1021/acs.langmuir.4c01234 PMid: 39013805 PMCid: PMC11295198.
61. Niu H, Wang W, Dou Z, Chen X, Chen X, Chen H, et al. Multiscale combined techniques for evaluating emulsion stability: a critical review. Adv Colloid Interface Sci. 2022; 311:102813. https://doi.org/10.1016/j.cis.2022.102813 PMid: 36403408.
62. Niederquell A, Machado A, Kuentz M. A diffusing wave spectroscopy study of pharmaceutical emulsions for physical stability assessment. Int J Pharm. 2017; 530(1–2):213–223. https://doi.org/10.1016/j.ijpharm.2017.06.061 PMid: 28634140.
63. McClements D. Critical review of techniques and methodologies for characterisation of emulsion stability. Crit Rev Food Sci Nutr. 2007; 47:611–649. https://doi.org/10.1080/10408390701289292 PMid: 17943495.
64. Lorusso V, Orsi D, Salerni F, Liggieri L, Ravera F, McMillin R, et al. Recent developments in emulsion characterisation: diffusing wave spectroscopy beyond average values. Adv Colloid Interface Sci. 2020; 288:102341. https://doi.org/10.1016/j.cis.2020.102341 PMid: 33359963.
65. Li L, Qu J, Liu W, Peng B, Cong S, Yu H, et al. Advancements in characterisation techniques for microemulsions: from molecular insights to macroscopic phenomena. Molecules. 2024; 29:1582. https://doi.org/10.3390/molecules29122901 PMid: 38930964 PMCid: PMC11206267.
66. Leister N, Karbstein H. Evaluating the stability of double emulsions—a review of the measurement techniques for the systematic investigation of instability mechanisms. Colloids Interfaces. 2020; 4:28. https://doi.org/10.3390/colloids4010008
67. Lei Q, Zhang Y, Luo JH, Han R, Geng X, Lü X, et al. Method for evaluating stability of highly concentrated emulsion and its application. Acta Phys-Chim Sin. 2019; 35:1906021. https://doi.org/10.3866/PKU.WHXB201906021
68. Kupikowska-Stobba B, Domagała J, Kasprzak M. Critical review of techniques for food emulsion characterization. Appl Sci. 2024; 14:4125. https://doi.org/10.3390/app14031069
69. Filipas A, Kuchman A, Zarnitsyn AYu, Isaev Y. Determination of surface tension based on thermocapillary motion. Bull Tomsk Polytech Univ Geo Assets Eng. 2025; 356:45–52. https://doi.org/10.17223/19988602/356/5/
70. Aghajanzadeh S, Asghari A, Cordella CBY, Khalloufi S. Using low-field nuclear magnetic resonance to investigate the effect of composition, mechanical treatments, and storage on the stability of emulsions. Food Chem. 2025; 478:143585. https://doi.org/10.1016/j.foodchem.2025.143585 PMid: 40043432.
71. Purkait A, Biswas S, Saha S, Hazra DK, Roy K, Biswas PK, et al. Formulation of plant based insecticides, their bio-efficacy evaluation and chemical characterization. Crop Prot. 2019; 125:104907. https://doi.org/10.1016/j.cropro.2019.104907
72. Rys M, Miastkowska M, Sikora E, Łętocha A, Krajewska A, Synowiec A. Bio-herbicidal potential of nanoemulsions with peppermint oil on barnyard grass and maize. Molecules. 2022; 27(11):3480. https://doi.org/10.3390/molecules27113480 PMid: 35684420 PMCid: PMC9181968.
73. Taban A, Saharkhiz MJ, Khorram M. Formulation and assessment of nano-encapsulated bioherbicides based on biopolymers and essential oil. Ind Crops Prod. 2020; 149:112348. https://doi.org/10.1016/j.indcrop.2020.112348
74. Ding J-wei, Zhou E-min, Wang X, Jiang H, Su H-fen, Gao Q, et al. Cellulose nanocrystals-based Pickering emulsion with enhanced foliar adhesion and pH responsiveness for intelligent delivery of pesticides. Int J Biol Macromol. 2025; 286:138192. https://doi.org/10.1016/j.ijbiomac.2024.138192 PMid: 39638167.
75. Chen L, Huang J, Chen J, Shi Q, Chen T, Qi G, et al. Halloysite nanotube-based pesticide formulations with enhanced rain erosion resistance, foliar adhesion, and insecticidal effect. ACS Appl Mater Interfaces. 2022; 14(36):41605–41617. https://doi.org/10.1021/acsami.2c11234 PMid: 36041169.
76. Wu J, Yang R, Zheng Q, Wei L, Wang B, Yan W, et al. Effect of Brucea javanica oil on the toxicity of β-cypermethrin emulsifiable concentrate formulation. ACS Appl Mater Interfaces. 2024; 16(8):9713–9724. https://doi.org/10.1021/acsami.3c16384 PMid: 38373060.

Author Contribution

Bhatt Mehul: Pharmacognostical work, writing, editing, proofreading, and thorough correspondence. Patel Divyang: Biocidal work, evaluation. Agrawal Smit: Formulation and review of existing literature. Parmar Maneesha: Comparative analysis. Yadav Ankit: Formulation and gathering information. All authors have read and agreed to the published version of the manuscript.