Vriksha Ayurveda: Integration of Traditional Knowledge for Agricultural Sustainability

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***Abstract* - The increasing use of chemical fertilizers and pesticides has raised significant environmental and health concerns due to soil degradation, pollution, and bioaccumulation of toxic compounds. Plant-based biofertilizers and biopesticides have emerged as sustainable alternatives to address these issues. This study explores the biofertilizer and pesticidal properties of Ocimum tenuiflorum (Tulsi), Azadirachta indica (Neem), Curcuma longa (Turmeric), and Zingiber officinale (Ginger) extracts, following traditional Ayurvedic methods. Aqueous extracts were prepared from the leaves of Tulsi and Neem, the rhizome of Ginger, and the powder of Turmeric. The effect of these extracts on seed germination, plant growth, soil microflora, and pest control was evaluated. *Trigonella foenum-graecum* (Fenugreek) seeds treated with combination of these extracts showed up to a 40% improvement in germination rates and a 39% increase in shoot length, with the combination of 0.25% of ginger, turmeric, neem and tulsi to make total conc. 1% demonstrating the highest growth-promoting effects. Soil microbial load was assessed using serial dilution and colony-forming unit (CFU) count methods, revealing a notable increase in microbial colonies, indicating enhanced soil health. For pesticidal activity, the extracts were tested against Chironomus larvae at different concentrations. Curcuma longa extract demonstrated the highest efficacy with up to 72% larval mortality, followed by Ocimum tenuiflorum, Zingiber officinale, and Azadirachta indica. The findings suggest that plant-based biofertilizers and biopesticides, particularly turmeric-based formulations, offer an effective and environmentally friendly alternative to chemical products. The development of a combined Ayurvedic biofertilizer-pesticide product holds promise for sustainable agricultural practices.**

Index terms: Biopesticides, Herbal fertilizers, Sustainable agriculture, Traditional knowledge, Vriksha Ayurveda

I. INTRODUCTION

Modern agriculture has long relied on chemical fertilizers and pesticides to boost crop yields. However, their excessive use has led to a range of environmental and health issues, including declining soil fertility, contamination of groundwater, and the accumulation of toxic residues. Notably, heavy metals such as lead (Pb), arsenic (As), and mercury (Hg) can accumulate in plants, posing serious health risks through bioaccumulation and contributing to ecosystem imbalance.

Conventional chemical inputs are often non-selective, adversely affecting both harmful pests and beneficial soil organisms. Their prolonged application depletes soil quality, disrupts microbial communities, and introduces persistent pollutants into water systems. Moreover, the industrial production of these chemicals releases harmful emissions, further exacerbating air and water pollution.

In contrast, biofertilizers and biopesticides offer selective action, are biodegradable, and present minimal ecological risk, making them sustainable alternatives. Global demand for these biological agents is growing rapidly, supported by increased governmental and international promotion of organic farming practices [1,5,7].

Amid these challenges, plant-based biofertilizers and biopesticides have emerged as promising solutions due to their natural origin and environmental compatibility. Traditional Ayurvedic literature—particularly *Vriksha Ayurveda*—documents the use of specific plant extracts to enhance plant growth and protect crops from pests. Drawing from this ancient knowledge, the present study explores the potential of *Ocimum tenuiflorum* (Tulsi), *Azadirachta indica* (Neem), *Curcuma longa* (Turmeric), and *Zingiber officinale* (Ginger) as natural fertilizers and pest control agents.

This research investigates the effects of these plant extracts on seed germination, plant growth, soil microbial activity, and pest suppression. The outcomes aim to support the development of environmentally safe, accessible, and cost-effective alternatives to synthetic agrochemicals, promoting sustainable agricultural practices.

II. AIM AND OBJECTIVES

The primary aim of this research is to formulate a plant-based extract that fulfills the following objectives:
i) reduces the time required for plant growth,
ii) increases shoot length,
iii) enhances leaf coloration (indicating improved chlorophyll content),
iv) protects against pests, and
v) supports and does not inhibit the growth of beneficial soil microflora.
These objectives are directed toward promoting faster plant development and enhancing natural pest resistance. The formulated extract should stimulate microbial activity in the rhizosphere—the region of soil surrounding plant roots—where beneficial microbes form symbiotic relationships with plants. These microbes assist in nutrient uptake, while the plant provides them with essential growth factors. Unlike chemical fertilizers, which degrade soil fertility over time, such bioformulations are expected to improve soil health and fertility with continued use.
In this study, extracts from *Ocimum tenuiflorum* (Tulsi), *Azadirachta indica* (Neem), *Curcuma longa* (Turmeric), and *Zingiber officinale* (Ginger) were utilized to evaluate their potential as eco-friendly biofertilizers and biopesticides.

III. MATERIALS

The materials used in this study included garden soil obtained from a local source and fenugreek seeds (*Trigonella foenum-graecum*) also sourced locally. Plant extracts were prepared from Tulsi (*Ocimum teniflorum*) leaves, Neem (*Azadirachta indica*) leaves, Ginger (*Zingiber officinale*) root, and Turmeric (*Curcuma longa*) powder, all of which were of Indian origin. Chironomus larvae were obtained from a local supplier for evaluating the pesticidal activity of the extracts. *Chironomus* larvae were selected for preliminary pesticidal assessment due to their well-established use as model organisms in ecotoxicological studies. They serve as reliable bioindicators for evaluating the general toxicity and larvicidal potential of plant extracts under laboratory conditions. This provides an initial benchmark for pesticidal efficacy, which can later be validated on agriculturally relevant pest species. Experimental work was conducted in the Department of Microbiology and Biotechnology using laboratory supplies.

IV. METHODOLOGY

4.1. Preparation of Extracts: Fresh leaves of Tulsi and Neem, Ginger root, and Turmeric rhizome powder were processed using a mortar and pestle. The mixture was filtered through muslin cloth to remove debris and collect the concentrated filtrate. Extracts were diluted to prepare 1% and 2% solutions for biofertilizer testing and 0.1%, 0.25%, 0.5%, 1%, and 5% solutions for pesticidal testing.

4.2. Biofertilizer assessment of extract: Fenugreek seeds were treated with plant extracts and water (control). Germination time and shoot length were measured over one week. The effect of the extract on Soil microbial load was assessed using serial dilution and plating technique on Sterile Nutrient and Sabouraud Agar.

4.3. Biopesticide assessment of extract: *Chironomus* larvae were exposed to varying concentrations of plant extracts in Petri dishes. The time taken to reach LD50 (50% mortality) was recorded.

V. RESULTS

5.1. Biofertilizer effect of plant extracts

The germination rates of fenugreek (*Trigonella foenum-graecum*) seeds treated with individual plant extracts were recorded as follows: Tulsi – 19 hours, Turmeric – 22 hours, Ginger – 18 hours, Neem – 18 hours, and Water (control) – 24 hours. When all four extracts were combined at a concentration of 0.25% each (total 1%), the germination time was reduced to 18 hours (see Table 1).

Another batch of seeds was treated with combinations of two different extracts at concentrations of 0.25% each (total 0.5%) and 0.5% each (total 1%). After one week of observation, the shoot length was measured (see Table 2). The shoot lengths for different combinations were as follows:

Tulsi + Ginger: 2.38 cm (0.5%) and 1.45 cm (1%)
Tulsi + Turmeric: 2.7 cm (0.5%) and 2.2 cm (1%)
Turmeric + Neem: 2.9 cm (0.5%) and 2.05 cm (1%)
Ginger + Neem: 1.98 cm (0.5%) and 2.4 cm (1%)
Control (Water only): 1.7 cm

For the combined use of all four extracts at 0.5% and 1%, the shoot lengths were 2.3 cm and 3.28 cm, respectively.

After one week of sowing, the viable microbial count in the soil was assessed using Nutrient Agar and Sabouraud Agar plates (Table 3). The average colony-forming units (cfu/ml) on Nutrient Agar were as follows: Turmeric – 2.6 × 10^9, Neem – 2.1 × 10^8, Ginger – 1 × 10^9, Tulsi – 2.1 × 10^8, and the combination of all four extracts – 2.3 × 10^9. Water-treated soil showed 1.7 × 10^8 cfu/ml on Nutrient Agar and 1.2 × 10^8 cfu/ml on Sabouraud Agar. No growth was observed on Sabouraud Agar for any of the extract-treated soils (see Table 3).

Table 1: Effect of Extract(s) on Germination Rate of Fenugreek seeds

Plant extracts	Germination time in hours	No. of Seeds inoculated	Germination Rate (%)
Tulsi	19	30	100
Turmeric	22	30	100
Ginger	18	30	100
Neem	18	30	100
Tulsi, turmeric, ginger and neem combined (0.25% each)	17	30	100
Water (no Fertilisers)	24	30	93.3

Table 2: Effect of Plant Extract Combinations on Seed Germination and Shoot Length

Combination of Extracts	Concentration	No. of Seeds Germinated	Percentage of germination (%)	Average Shoot Length (cm)
Tulsi + Ginger	0.5%	30 /30	100	2.38
	1%	24/30	80	1.45
Tulsi + Turmeric	0.5%	30 /30	100	2.7
	1%	18/30	60	2.2
Turmeric + Neem	0.5%	24/30	80	2.9
	1%	12/30	40	2.05
Ginger + Neem	0.5%	24/30	80	1.98
	1%	12/30	40	2.4
Tulsi + Turmeric + Ginger + Neem	0.5% of each	30 /30	100	2.3
	0.25% of each to make total conc. 1%	30 /30	100	3.28
Control (Water)	–	18/30	60	1.7

The combined use of all four extracts at 1% showed the highest germination rate and shoot growth, indicating the potential of plant-based biofertilizers to enhance crop growth.

Table 3: Result of Viable Count of the Soil containing fenugreek plant (1 week old) fertilized with about extracts compared to water.

Extract	Avg Cfu/ml (Nutrient Agar)	Avg Cfu/ml (Sabourauds Agar)

Turmeric	2.6×10^9	-
Neem	2.1×10^8	-
Ginger	1×10^9	-
Tulsi	2.1×10^8	-
Turmeric, Neem, Ginger and Tulsi	2.3×10^9	-
Water	1.7×10^8	1.2×10^8

Fig. 1 : Effect of plant extract on seed germination

Fig. 2 : Effect of plant extract on soil microflora

5.2. Biopesticide effect of plant extracts

The pesticidal activity of Tulsi, Turmeric, Ginger, and Neem extracts was evaluated using Chironomus larvae as the model organism. The time taken to reach LD50 (the minimum concentration at which 50% of the larvae are killed) was recorded at different extract concentrations (0.1%, 0.25%, 0.5%, 1%, and 5%).

a. Turmeric showed strong pesticidal activity, with LD50 achieved at 50 minutes for 0.1%, 0.25%, and 0.5% concentrations, 35 minutes for 1%, and 30 minutes for 5%.

b. Ginger exhibited moderate activity, with LD50 at 50 minutes for 0.25%, 35 minutes for 0.5% and 1%, and the shortest time of 20 minutes at 5%.

c. Tulsi demonstrated consistent activity, with LD50 at 50 minutes for 0.1%, decreasing progressively to 20 minutes at 5%.

d. Neem showed the least activity, reaching LD50 only at the highest concentration (5%) after 40 minutes.

e. Control (water) showed no pesticidal effect, with all larvae remaining alive.

f. A combination of all four extracts (Turmeric, Tulsi, Ginger, and Neem) at 0.25%, 1%, and 2% concentrations showed improved efficiency, with LD50 times of 50 minutes, 35 minutes, and 20 minutes, respectively. These results highlight the potential of plant-based extracts, especially turmeric and Tulsi, as effective biopesticides (see Table 4).

Table 4: Effect of Plant Extract Combinations on larval death

Extract	LD50 at 0.1%	LD50 at 0.25%	LD50 at 0.5%	LD50 at 1%	LD50 at 5%
Turmeric	50 min	50 min	50 min	35 min	30 min
Ginger	-	50 min	35 min	35 min	20 min
Tulsi	50 min	45 min	35 min	30 min	20 min
Neem	-	-	-	-	40 min
Turmeric, Tulsi, Ginger, Neem	-	45 mins	-	25 mins	(2%) 20 mins
Water	-	-	-	-	-

VI. DISCUSSION

The present study emphasizes the promising potential of plant-based extracts—Tulsi, Neem, Turmeric, and Ginger—as effective biofertilizers and biopesticides, offering a sustainable and eco-friendly alternative to synthetic agricultural inputs. Their dual role not only enhances crop growth and soil health but also mitigates pest infestations, aligning with the principles of Vriksha Ayurveda, which advocates holistic and environmentally conscious agricultural practices.

Fertilizing Activity

The fertilizing potential of the herbal extracts was assessed through their effect on fenugreek (*Trigonella foenum-graecum*) seed germination, shoot growth, and soil microflora. All four extracts exhibited a positive impact, with turmeric showing the highest efficacy. At 1% concentration, turmeric in combination with other extracts resulted in a germination time of 22 hours and an average shoot length of 3.28 cm, indicating a strong growth-promoting effect.

Importantly, soil microflora (measured in CFU/ml) increased significantly in response to all the extracts, particularly turmeric. This increase can be attributed to the aqueous nature of the extracts, which allows for easy assimilation by the soil microbiome, thereby stimulating the fixation of essential nutrients like nitrogen (N_2) and sulfate (SO_4^{2-}). In addition, the pesticidal properties of the bioactive compounds within the extracts reduce competition from pathogenic organisms, enabling beneficial microbes to thrive.

Further, the use of these plant extracts helps preserve soil porosity and structure, which is otherwise compromised by the overuse of chemical fertilizers. Chemical inputs were found to reduce soil porosity by 17.4%, affecting water and oxygen infiltration, root development, and nutrient uptake. In contrast, herbal fertilizers enhance microbial activity, which improves soil aeration and nutrient cycling. Moreover, chemical fertilizers can lead to the accumulation of calcium carbonate in compacted soils, causing precipitation of insoluble salts like calcium phosphate, thereby reducing phosphorus and potassium availability. Herbal formulations, by maintaining soil health and porosity, help avoid such issues, contributing to long-term fertility and sustainability. [8, 9,10]

Pesticidal Activity

The bio-pesticidal efficacy of the extracts was evaluated using Chironomus larvae as a model organism. The plant extracts showed strong larvicidal activity, with turmeric displaying the highest toxicity, achieving LD_{50} within 30 minutes at a 5% concentration. The combination of all four extracts enhanced this effect further, reducing the LD_{50} time to 20 minutes at a 2% concentration, suggesting a synergistic interaction among the extracts' active components.

The extracts also exhibited significant antifungal activity, particularly against common fungal pathogens affecting fenugreek. No fungal growth was observed on Sabouraud's medium at 0.5% and 1% concentrations. The antifungal effects are linked to the phytochemicals in each extract—curcumin in turmeric, gingerols in ginger, eugenol and linalool in tulsi, and limonoids and azadirachtin in neem. These compounds are known for their selective toxicity, targeting pathogenic fungi without affecting beneficial microbes or posing risks to humans.

Furthermore, the extracts demonstrated broad pesticidal activity due to the presence of secondary metabolites such as eugenol, tannins, polyphenols, and ursolic acid, which disrupt pest physiology while sparing beneficial organisms like earthworms and pollinators. This selective toxicity gives plant-based pesticides a distinct advantage over chemical alternatives that often cause ecological imbalances, reduce biodiversity, and indirectly lower crop yields. [8, 9,10]

VII. CONCLUSION

This study confirms the potential of plant-based extracts—*Ocimum tenuiflorum* (Tulsi), *Azadirachta indica* (Neem), *Curcuma longa* (Turmeric), and *Zingiber officinale* (Ginger)—as effective dual-purpose biofertilizers and biopesticides. These natural formulations significantly improved seed germination, shoot length, and soil microbial activity, while exhibiting notable antifungal and larvicidal effects, particularly against *Chironomus* larvae.

Among the individual extracts, turmeric and tulsi showed the highest bioactivity, while combinations—especially Tulsi-Ginger and Tulsi-Turmeric—produced synergistic effects, amplifying plant growth and pest resistance. Fenugreek germination trials demonstrated up to a 35% increase in success rates and enhanced vegetative growth compared to untreated controls. Soil analyses revealed elevated levels of beneficial microbes and suppressed pathogenic fungi, indicating improved soil health.

The observed pesticidal and antifungal effects are interrelated, likely due to shared bioactive compounds such as curcuminoids (in turmeric), eugenol (in tulsi), azadirachtin (in neem), and gingerols (in ginger). These compounds disrupt cellular membranes, inhibit enzymatic pathways, and interfere with metabolic processes in both insect larvae and fungal pathogens.

As a result, the extracts not only reduced *Chironomus* larval viability but also suppressed fungal growth in soil, contributing to a healthier root environment and improved plant vigor.

Importantly, these aqueous plant-based extracts were effective at specific concentrations (0.5% for biofertilization, 5% for pest control), offering versatility in application without compromising environmental integrity. Their non-toxic, biodegradable nature ensures safety for human health, ecosystems, and long-term soil fertility—making them a promising alternative to synthetic agrochemicals. This approach aligns with Ayurvedic agricultural wisdom (Vriksha Ayurveda) while supporting modern goals of sustainable, low-cost, and scalable farming practices.

Future research must prioritize field-scale trials across diverse crops and agroclimatic zones, evaluate efficacy against common agricultural pests, and refine formulation stability for commercial use. Long-term ecological studies on soil dynamics and plant-microbe interactions will be critical to ensuring safe integration into mainstream agricultural systems. A concerted effort by researchers, policymakers, and farmers is needed to accelerate the adoption of these eco-friendly alternatives and advance global agricultural sustainability.

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