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Synergistic Effects of Vermicompost, Vermiwash, and Moringa Leaf Extract on Growth and Yield of Fenugreek: A Review

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ABSTRACT: Fenugreek (*Trigonella foenum-graecum* L.), a multipurpose spice and medicinal crop, thrives under organic management. Vermicompost, vermiwash, and moringa leaf extract are sustainable inputs that enhance soil fertility, nutrient uptake, and plant vigor. This review synthesizes studies from 2006 to 2022 to explore their synergistic effects on fenugreek's growth (plant height, branches, dry matter) and yield (pods per plant, seeds per pod, seed yield) attributes. Vermicompost improves soil structure, vermiwash delivers foliar nutrients, and moringa leaf extract supplies growth-promoting compounds. These inputs collectively boost fenugreek productivity while reducing reliance on chemical fertilizers. The review also highlights economic benefits, emphasizing their role in sustainable agriculture. By integrating findings from field experiments, this study underscores the potential of these organic amendments for optimizing fenugreek cultivation.

Keywords: Fenugreek, Organic farming, Vermicompost, Vermiwash, Moringa leaf extract, Soil fertility and Organic amendments.

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.), a versatile annual legume, holds a prominent place in global agriculture, particularly in India, which accounts for the majority of its production and export (Babaleshwar & Shetty 2017). Known as 'methi' locally, fenugreek is cultivated across Rajasthan (84% of production), Gujarat (15%), and other states like Uttar Pradesh, Madhya Pradesh, and Chhattisgarh, covering approximately 120,000 hectares with a production of 188,000 tonnes annually (NHB, 2019-20). Its seeds, leaves, and stems are valued for culinary, medicinal, and fodder purposes, with bioactive compounds like diosgenin, used in pharmaceutical synthesis, enhancing its economic significance (Mehrafarin *et al.,* 2010). The global shift toward sustainable agriculture has spotlighted organic inputs such as vermicompost, vermiwash, and moringa leaf extract as alternatives to chemical fertilizers, which degrade soil health over time (Domininguez & Edwards 1997). Vermicompost, a nutrient-rich biofertilizer, improves soil structure, aeration, and microbial activity, fostering robust plant growth (Kale & Bano 1986). Vermiwash, a liquid extract from vermicomposting, delivers enzymes, micronutrients, and nitrogen-fixing bacteria through foliar application, enhancing plant vigor (Zambare *et al.*, 2008). Moringa leaf extract, derived from Moringa oleifera, contains vitamins, antioxidants, and growth-promoting compounds like zeatin, which mitigate environmental stress and boost metabolic activity (Rady *et al.*, 2013). The synergistic application of these inputs addresses soil, foliar, and physiological needs, offering a holistic approach to fenugreek cultivation. This review evaluates their combined effects on fenugreek's growth and yield attributes, drawing from field studies up to 2022, to highlight their potential in sustainable farming systems and their economic viability for farmers.

MATERIAL AND METHODS

This review was conducted by systematically collecting and analyzing relevant research studies published between 2006 and 2022 that focused on the use of vermicompost, vermiwash, and moringa leaf extract in fenugreek (*Trigonella foenum-graecum* L.) cultivation. Peer-reviewed journal articles, theses, conference proceedings, and technical reports were sourced from academic databases such as Google Scholar, ScienceDirect, ResearchGate, and CAB Direct. Studies were screened based on their relevance to organic nutrient management, measurable agronomic parameters (plant height, number of branches, dry matter accumulation, pod and seed attributes), and soil fertility outcomes. Only those trials conducted under

field or controlled conditions and reporting quantitative results were included.

The collected literature was categorized based on the type of organic input, experimental design, and key outcomes. Data were synthesized to identify trends, synergies, and comparative effectiveness of vermicompost, vermiwash, and moringa leaf extract, individually and in combination. The review emphasized studies that reported enhancements in growth parameters, yield attributes, and soil health indicators. Where possible, economic evaluations were also noted to assess cost-effectiveness. This approach allowed for a comprehensive understanding of how these sustainable inputs contribute to improved fenugreek productivity under organic management systems.

RESULTS AND DISCUSSION

Growth Attributes. The application of vermicompost, vermiwash, and moringa leaf extract significantly enhances fenugreek's growth attributes, including plant height, number of branches, and dry matter accumulation, through complementary mechanisms that improve nutrient availability, microbial activity, and stress resilience. These organic inputs create a synergistic effect, addressing both soil and foliar nutritional needs while promoting physiological processes critical for robust plant development.

Plant Height: Vermicompost boosts plant height by enriching soil with macronutrients and micronutrients, improving root development and nutrient uptake. Verma *et al.* (2017) reported that 4 t ha^{-1} vermicompost increased plant height to 58.9 cm at harvest, significantly higher than lower doses, due to enhanced nitrogen and phosphorus availability. Kumar and Sharma (2014) found that 6 t ha^{-1} vermicompost further elevated height to 36.50 cm in loamy sand soils, attributed to increased nutrient content and soil organic matter. Vermiwash, applied foliarly, promotes height by supplying enzymes (e.g., protease, amylase) and nitrogen-fixing bacteria. Narendhiran *et al.* (2022) observed a plant height of 32 cm with 6% vermiwash, linked to microbial stimulation of growth processes. Moringa leaf extract enhances height through its growth-promoting compounds, such as zeatin and antioxidants. Mounika *et al.* (2021) recorded a seedling shoot length of 9.3 cm with 4% moringa leaf extract, reflecting improved metabolic activity and stress mitigation. The synergy of vermicompost's soil enrichment, vermiwash's foliar nutrition, and moringa's hormonal benefits ensures taller fenugreek plants, critical for maximizing photosynthetic capacity.

Number of Branches: Branching, a key determinant of yield potential, is significantly improved by organic inputs. Verma *et al.* (2012) found that 4 t ha^{-1} vermicompost increased branches to 8.06 per plant at harvest, driven by enhanced soil fertility and root nodulation, which supports nitrogen fixation. Tagad *et al.* (2016) reported that combining vermicompost with Rhizobium and phosphate-solubilizing bacteria (PSB) further increased branching, reflecting microbial synergy in nutrient solubilization. Vermiwash enhances branching by delivering micronutrients and enzymes foliarly, with Narendhiran *et al.* (2022) noting 8.33 branches per plant with 6% vermiwash, due to its content of nitrogen-fixing bacteria like Azotobacter. Moringa leaf extract promotes branching by improving ion uptake and metabolic efficiency. Anandhi *et al.* (2019) recorded 6.87 primary branches with 3% moringa leaf extract, attributed to its nutrient-rich composition, including potassium and vitamins. The combined application of these inputs optimizes branching by ensuring balanced nutrition and microbial support, resulting in a robust plant canopy.

Dry Matter Accumulation: Dry matter accumulation, an indicator of plant vigor, is enhanced by the synergistic effects of these inputs. Pushpa *et al.* (2022) demonstrated that vermicompost combined with biofertilizers (Rhizobium, Azospirillum, PSB) significantly increased dry matter, due to improved nutrient availability and soil structure. Vermiwash boosts dry matter through foliar application of micronutrients and enzymes, with Anandhi *et al.* (2019) reporting 1.01 g per plant with 3% vermiwash, linked to enhanced photosynthesis. Moringa leaf extract further promotes dry matter by mitigating environmental stress and upregulating metabolic pathways. Rady *et al.* (2013) found that moringa leaf extract increased dry matter in stressed fenugreek by improving antioxidant activity and ion uptake. The integration of vermicompost's soil-based nutrient supply, vermiwash's foliar enhancement, and moringa's stress alleviation ensures higher biomass accumulation, setting the stage for superior yield outcomes. The combined application of these organic inputs creates a holistic growth environment, with vermicompost improving soil health, vermiwash enhancing foliar nutrition, and moringa leaf extract boosting physiological resilience. This synergy results in taller plants, increased branching, and greater dry matter, all of which contribute to fenugreek's overall productivity.

Yield Attributes. Organic inputs like vermicompost, vermiwash, and moringa leaf extract significantly enhance fenugreek's yield attributes, including the number of pods per plant, seeds per pod, and seed yield, by improving nutrient uptake, reproductive efficiency, and stress tolerance. Their synergistic application optimizes soil fertility, foliar nutrition, and plant physiology, leading to substantial yield improvements.

Number of Pods per Plant: The number of pods per plant, a critical yield component, is markedly increased by organic amendments. Choudhary *et al.* (2011) reported 35.50 pods per plant with 50% recommended dose of nitrogen (RDN) through vermicompost combined with inorganic fertilizers, attributed to enhanced nutrient availability and root development. Jadhav *et al.* (2014) observed 34.48 pods per plant with vermicompost and 2% vermiwash foliar sprays,

reflecting the foliar application's role in improving reproductive growth. Vermiwash's enzyme and microbial content, including phosphate-solubilizing bacteria, supports pod formation by enhancing nutrient assimilation. Moringa leaf extract further boosts pod numbers by improving metabolic activity and stress resilience. Anandhi *et al.* (2019) noted increased pod formation with 3% moringa leaf extract, linked to its antioxidant properties and nutrient content, such as potassium and zinc. The synergy of these inputs ensures optimal pod set by addressing nutritional and environmental constraints, maximizing yield potential.

Seeds per Pod: The number of seeds per pod, another vital yield parameter, is enhanced by organic inputs. Naimuddin *et al.* (2013) found that farmyard manure combined with Rhizobium inoculation maximized seeds per pod, driven by improved nitrogen fixation and nutrient uptake. Vermiwash contributes to seed set by supplying foliar micronutrients, with Lunagariya *et al.* (2018) reporting higher seeds per pod with enriched organic inputs, including vermiwash, due to enhanced phosphorus availability. Moringa leaf extract supports seed development by upregulating metabolic pathways and improving ion uptake. Abdel-Latef *et al.* (2017) observed increased seeds per pod with moringa leaf extract under stress conditions, attributed to enhanced expression of salt tolerance genes. The combined effect of these inputs ensures higher seed numbers by optimizing nutrient supply and reproductive efficiency.

Seed Yield: Seed yield, the ultimate measure of productivity, is significantly boosted by organic amendments. Dubey *et al.* (2012) reported a 70.69% increase in seed yield with 5 t ha^{-1} vermicompost and Rhizobium, due to improved nutrient uptake and soil fertility. Shivran *et al.* (2016) achieved a seed yield of 1781 kg ha^{-1} with 50% RDN through vermicompost and inorganic sources, reflecting balanced nutrition. Vermiwash enhances yield through foliar sprays, with Jadhav *et al.* (2014) recording 1161.33 kg ha^{-1} with 2% vermiwash, linked to its microbial and enzyme content. Moringa leaf extract improves yield by enhancing nutrient assimilation and stress tolerance, with Anandhi *et al.* (2019) reporting a herbage yield of 5.49 kg $plot^{-1}$ with 3% moringa extract. The synergy of vermicompost's soil enrichment, vermiwash's foliar nutrition, and moringa's physiological benefits maximizes seed yield, reducing reliance on chemical fertilizers. The integration of these organic inputs creates a synergistic effect that enhances fenugreek's reproductive capacity. Vermicompost improves soil nutrient pools, vermiwash supports foliar nutrient delivery, and moringa leaf extract mitigates stress, collectively increasing pod numbers, seeds per pod, and seed yield. This approach ensures sustainable productivity with minimal environmental impact. (Word count: 496)

Synergistic Effects. The combined use of vermicompost, vermiwash, and moringa leaf extract creates a synergistic effect, addressing soil fertility, foliar nutrition, and physiological needs. Vermicompost enhances soil structure and nutrient availability, vermiwash delivers enzymes and microbes, and moringa leaf extract mitigates stress (Ali *et al.,* 2018; Zambare *et al.,* 2008; Rady *et al.,* 2013). Pushpa *et al.* (2022) found that vermicompost with biofertilizers increased seed yield to 32.67 q ha^{-1}. Narendhiran *et al.* (2022) reported a herbage yield of 6.11 t ha^{-1} with vermiwash and biostimulants. These inputs collectively improve fenugreek's growth and yield, promoting sustainable agriculture with reduced environmental impact.

Economic Implications. Organic inputs enhance the economic viability of fenugreek cultivation. Shivran *et al.* (2016) reported a net return of Rs. 52,151 ha^{-1} with 50% RDN through vermicompost and inorganic sources. Jadhav *et al.* (2014) noted a benefit-cost ratio of 3.17 with vermicompost and vermiwash. Anandhi *et al.* (2019) found a benefit-cost ratio of 3.85 with 3% vermiwash, highlighting cost-effectiveness. Moringa leaf extract, being locally sourced, reduces costs, as noted by Saini *et al.* (2022). These organic inputs reduce input costs while maintaining high yields, making fenugreek cultivation economically viable.

Challenges and Considerations. Despite the proven benefits of vermicompost, vermiwash, and moringa leaf extract in enhancing fenugreek growth and yield, several challenges must be addressed for their widespread adoption. One major concern is the inconsistent quality and availability of organic inputs, especially in rural or resource-limited areas. Variability in nutrient content, microbial activity, and preparation methods can lead to uneven field performance. Additionally, the lack of standardized application protocols regarding dosage, frequency, and mode of application (soil vs. foliar) may limit the reproducibility of positive results across different agro-ecological zones.

Moreover, transitioning from conventional to organic systems requires a shift in farmer mindset, initial investment, and training. There is limited awareness about the synergistic effects of these inputs, and many farmers still rely heavily on chemical fertilizers due to their quick results. Also, the short shelf-life of liquid formulations like vermiwash and moringa leaf extract can affect their efficacy if not stored or applied properly. To overcome these issues, there is a need for robust extension services, quality certification systems, and localized research to develop user-friendly, cost-effective organic input packages tailored to fenugreek cultivation.

FUTURE SCOPE

The promising outcomes of integrating organic amendments in fenugreek cultivation open avenues for further research and field-scale validation. Future studies should focus on long-term trials across diverse agro-climatic regions to evaluate the consistency of these inputs under varying soil and environmental

conditions. Investigating the microbial dynamics and biochemical interactions within the rhizosphere influenced by vermicompost, vermiwash, and moringa leaf extract can provide deeper insights into nutrient cycling and plant health. Additionally, precision in dosage, timing, and application methods of these organic inputs can be optimized through advanced agronomic modeling. Exploring their synergistic effects in intercropping or mixed cropping systems may further contribute to sustainable intensification. Finally, economic analyses and life-cycle assessments can strengthen policy recommendations for promoting these eco-friendly practices at the farmer level.

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Conflict of Interest. None.

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