

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(5): 1141-1147
www.biochemjournal.com
Received: 01-03-2026
Accepted: 04-04-2026

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Effect of vermiwash and panchgavya on crop productivity of field pea: A comprehensive review

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i5Sm.8530>

Abstract

Field pea (*Pisum sativum* L.) is a major cool-season legume crop that has global significance due to its high protein content, ability to fix nitrogen, and multiple uses in food, feed and industries. Due to its importance in agriculture, achieving optimal yields from the crop using sustainable agricultural methods is an ongoing challenge. The emphasis on producing food using organic farming and reducing the use of synthetically produced chemicals has led to increased interest in researching how bio-based alternatives can be used as plant growth promoters and liquid organic soil amendments. Among these alternative waste products, vermiwash (an aqueous extract of excreta from worms used in vermicomposting systems) and panchgavya (a traditional Indian biostimulant made of five products derived from cows) have been studied for their different ways in which they successfully improve crop yield or stress tolerance. This paper summarises much of the research literature available to date on the effect of vermiwash or panchgavya on the growth, yield, quality and physiological parameters of field pea. They both positively influence germination percentage, root and shoot development, chlorophyll content, nodulation efficiency, protein accumulation and total grain yield. The mechanisms that are responsible for these effects (including hormonal activity, microbial enrichment and nutrient solubilisation) will also be discussed. In addition, the paper will identify gaps in current knowledge and future research directions for use of these products as part of precision organic farming methods.

Keywords: Vermiwash, panchgavya, field pea (*Pisum sativum* L.), organic biostimulants, crop productivity, sustainable agriculture, nitrogen fixation, yield attributes

1. Introduction

The field pea (*Pisum sativum* L.), which belongs to the Fabaceae family of plants, is the oldest cultivated legume in the world with roughly 6.5 million hectares under cultivation and over 14.3 million metric tonnes produced each year (FAO, 2023) [2]. This crop is extensively cultivated in both temperate and semi-arid climates throughout South Asia, Europe, North America, and Australia because it is a key element of many different types of agricultural systems. Field peas provide an excellent source of protein (about 20-25% protein in seed), as well as an ecological benefit, due to their ability to fix atmospheric nitrogen (BNF) and thereby reduce the need for synthetic nitrogen fertilizers (Choudhary *et al.*, 2022; Singh & Verma, 2021) [1, 9].

Modern agricultural systems have been increasingly moving away from the use of chemical inputs and towards sustainable practices that do not harm the environment. As a result, farmers are becoming more aware of the negative effects that agriculture can have on soil health, groundwater, and global climate change, in addition to how sustainable agricultural systems can survive over the long term (Kumar *et al.*, 2023) [3]. This has led to the emergence of organic biostimulants—natural materials or microorganisms that promote plant growth and improve productivity when applied to a crop in small quantities—as a viable method for sustainable intensification of cropping systems (Parida *et al.*, 2022) [4].

According to Prabha *et al.* (2021) [6] vermiwash (specially produced) is collected by passing water through earthworm compost beds (vermicomposting) and has a complex mixture of plant hormones, amino acids, vitamins, enzymes, and beneficial microorganisms. Various application methods have been reported to encourage seed germination, support vegetative growth, and improve root architecture; they also enhance soil microbiological biomass. Panchgavya (utilised for centuries) is a Vedic preparation made from cow excrement (dung, urine) and milk products (milk, yogurt, ghee) that may also include other natural components

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(e.g., coconut water, ripe bananas, sugarcane juice) (Ramesh & Vinayagam, 2021) [7]. Panchgavya contains a variety of microorganisms promoting plant growth, hormones stimulating plant growth, and both macro-and micro-nutrients (Ramesh & Vinayagam, 2021) [7]. Research has indicated that panchgavya enhances growth and survival of crops through improvement of Vigor, increased immune function, and increased production in many different types of crops.

There are multiple studies that have looked at the effect of vermiwash or panchgavya on different types of crops, but no resource has systematically assessed the combined and individual impacts of vermiwash and panchgavya as organic amendments to field pea in the literature available to date. This review compiles existing research to help provide a complete understanding of the agronomic, physiological, biochemical and soil biological effects of the two organic amendments on *Pisum sativum* L. Additionally, this review examines mechanistic pathways associated with vermiwash or panchgavya application, applications protocols for both vermiwash and panchgavya, and the research knowledge gap that will help provide direction for future research or practical application surrounding the use of the two organic amendments on field pea.

2. Botanical Description and Agronomic Significance of Field Pea

2.1 Taxonomy and Morphology

Pisum sativum L. ($2n = 2x = 14$) is an annual, climbing, herbaceous legume found within the family Fabaceae. It has a prominent taproot system and can develop symbiotic relationships with *Rhizobium leguminosarum* bv. viciae. These associations allow it to effectively fix atmospheric nitrogen (N) at rates ranging from approximately 80 to 250 kg/ha⁻¹ during the growing season (Choudhary *et al.*, 2022) [1].

The plant bears compound pinnate leaves with 1-3 pairs of leaflets and branched tendrils; flowers are self-pollinated and grow in the axils of the leaves; the petals are normally white or purple. Seed types vary from smooth to wrinkled, depending on the cultivar; pods can be either dehiscent or indehiscent. Vegetative cycle length varies from 55 to 180 days, depending on cultivar and climate (Singh & Verma, 2021) [9].

2.2 Nutritional Composition and Economic Importance

Field peas are very rich in nutrients, containing around 22-25% protein, 55-65% total carbohydrates, 1-2% fat, and 5-8% dietary fiber, and have high concentrations of iron, zinc, folate, and the essential amino acids lysine and tryptophan (Parihar *et al.*, 2023) [5]. The global demand for field peas is quickly growing due to their new uses in the production of plant-based protein products, gluten-free foods, and pet food.

In addition to their nutritional value, field peas make a significant contribution to soil health by fixing 80-250 kg of nitrogen per hectare per year, improving soil organic matter, and breaking disease cycles in cereal-based crop rotations (Kumar *et al.*, 2023) [3]. These characteristics make field peas an essential part of sustainable agriculture around the world.

3. Vermiwash: Composition, Preparation, and Mode of Action

3.1 Definition and Preparation

Vermiwash is the liquid produced from the drainage of a vermicomposting system. It is produced when water passes through organic materials and worm castings that are being processed by earthworms (Prabha *et al.*, 2021) [6]. Vermiwash can be harvested from the bottom of a vermicomposting bin or bed by using precise amounts of water to periodically irrigate the substrate material.

Vermiwash is produced by layering organic waste materials, such as agricultural residues, kitchen waste, and green manure, on a vermibed, which has been inoculated with earthworms that are composting them. These earthworms mainly include *Eisenia fetida* (red wigglers), *Lumbricus rubellus* and *Eudrilus eugeniae* (Sharma *et al.*, 2022) [8]. After the composting process is complete, water is applied to the vermibed, and the material is collected for storage at low temperatures to protect the living organisms within it and preserve their biological activity.

3.2 Chemical and Biological Composition

The composition of vermiwash can differ based on the type of organic material used for vermicomposting, earthworm species, moisture content, and the time spent in the composting process. In general, vermiwash contains nitrogen (0.05-0.15%), phosphorus (0.01-0.08%), potassium (0.10-0.30%) and a variety of other nutrients including calcium, magnesium, and sulfur, and many trace nutrients (Sinha *et al.*, 2022; Prabha *et al.*, 2021) [10, 6]. The average pH of vermiwash is between 6.5 and 7.9 and is considered neutral to slightly basic, which allows for its use as a foliar application without causing any damage to the plant.

In addition to macronutrients, Vermiwash has a variety of hormones that promote plant growth such as IAA (Indole-3-Acetic Acid), GA3 (Gibberellins), cytokinins, and ABA (Absciscic Acid) (Sharma *et al.*, 2022) [8]. Enzymatic activity in vermiwash is also characterised by enzymes such as phosphatase, urease, dehydrogenase, and cellulase, indicating the diversity of microorganisms found in the vermicomposting system. There are many different types of bacteria found in vermiwash, including PGPB's such as *Pseudomonas fluorescens*, *Bacillus subtilis*, *Azotobacter*, and several species of *Trichoderma* (Kumar *et al.*, 2023) [3].

3.3 Mechanisms of Action in Crop Promotion

Vermiwash boosts the growth of crops through several different mechanisms working at the same time. The plant hormones contained in the vermiwash, especially indole acetic acid (IAA) and gibberellins, encourage elongation of cells, initiation of roots, and suppression of apical dominance which increases the amount of branching and root hairs developed by a plant (Parihar *et al.*, 2023) [5]. The enzymes and organic acids in the vermiwash help to solubilize soil phosphorus that is already present in the original native soil making it readily available for roots to absorb. The PGPB contained in the vermiwash produce siderophores, which chelate (bind) iron and other micronutrients and help make them more readily available to the roots of plants that are growing in unfavourable conditions or unfavourable soils (Sinha *et al.*, 2022) [10].

The vermiwash has demonstrated the ability to provide antifungal and antibacterial characteristics due to the presence of humic materials, lysozyme, certain cellulose-

degrading enzymes, and several volatile fatty acids. These properties can help treated plants become more resistant to diseases, thereby reducing the number of foliar and soilborne pathogens present on them (Sharma *et al.*, 2022) [8]. In addition, multiple applications of vermiwash have increased the stability of soil aggregates, continued their ability to retain water, and increased soils' carbon content (microbial biomass), which will all create a better overall rhizosphere for root growth.

4. Panchgavya: Formulation, Composition, and Biological Activity

4.1 Historical and Traditional Background

Panchgavya is an Ayurvedic and Vedic preparation with ancient roots in both agriculture and medicine that's been around for thousands of years. Many of the oldest Indian texts reference its use, including the Charaka Samhita, Sushruta Samhita, and Krishisastra. It was considered a tonic for plants, animals, and humans (Ramesh & Vinayagam, 2021) [7] and became the standard practice of using panchgavya in traditional Indian agriculture as part of what is now known as Vedic or Rishi Krishi farming methods.

The recent study of Panchgavya began in the late 90's to early 2000's primarily from the research programs at Tamil Nadu Agricultural University (TNAU) for the developing and standardization of the formulations for the uses of Panchgavya for promoting the growth of crops with controlled field trials. Today, Panchgavya has been given legal recognition & is an approved input as per India's NPOP (National Program for Organic Production) (Parida *et al.* 2022) [4].

4.2 Preparation and Standardized Formulation

Panchgavya is made by mixing together the five main products from cows (cow dung, cow urine, fresh milk, curds and ghee) in specific quantities and allowing them to ferment for 15-30 days at room temperature while stirring regularly (Ramesh & Vinayagam, 2021) [7]. Some versions may also include ingredients to improve microbial diversity and fermentation efficiency (e.g., tender coconut water, sugar cane juice, ripe bananas and toddy palm juice). The final panchgavya product is then diluted to 3% (300 mL per 10L of water) for use as a foliar spray.

4.3 Chemical and Microbiological Composition

Panchgavya is a biologically active complex preparation that contains both macro-and micronutrients such as plant growth hormones, amino acids, vitamins, and a wide variety of microorganisms. The nitrogen content of these samples has been shown to range between 0.1% and 0.5%, with phosphorus levels ranging from 0.05 to 0.2% and potassium levels ranging from 0.2 to 0.8% (Parida *et al.* 2022) [4]. Cow urine is the main source of nitrogen available in plants because it contains both urea and creatinine, whereas cow dung is the source of the organic matter and a source of microbes used for inoculation.

The bacteriological analysis of Panchgavya shows that there are many different kinds of microbes present in it, including *Lactobacillus* spp., *Saccharomyces cerevisiae*, *Aspergillus* spp., *Bacillus megaterium* and different genera of actinomyces (Ramesh & Vinayagam, 2021) [7]. The phytohormone composition has shown high concentrations of indole-3-acetic acid (IAA) (15-45 ng/ml), gibberellins

and cytokinins, which are thought to be responsible for promoting plant growth. In addition, a fermentation process uses a large number of microorganisms to create short-chain fatty acids, humic and fulvic acids and anti-microbial peptides that work together to activate biological activity (Sinha *et al.*, 2022) [10].

4.4 Mechanisms of Action

Panchgavya has multiple modes of action/Functioning as a multi-functional bio-stimulant through various pathways; any time you folia apply panchgavya you will cause stomatal openings and increase gas exchange thereby increasing both photosynthetic efficiency and carbon fixation rates (Parihar *et al.* 2023) [5]; Phytohormones (such as IAA & Gibberellins) cause cell division ("cell division" as it relates to shoot elongation and leaf expansion, accelerating phenological development) in meristematic tissues.

Panchgavya's enhancement of the rhizosphere's microbiota through Application at the soil level has been shown to increase the total bacterial population, actinomycetes, and nutrient-cycling enzyme activity. The increase in microbial activity promotes the decomposition of soil organic matter and increases the mineralization rate of nitrogen and phosphorus (Ramesh & Vinayagam, 2021) [7]. Additionally, the antifungal properties of the bioactive substances in panchgavya (fatty acids and phenolic compounds) from using fermented bananas and cane sugar have been demonstrated against harmful fungi (*Fusarium oxysporum* and *Sclerotinia sclerotiorum*) which can decrease the amount of disease in legumes (Parida *et al.*, 2022) [4].

5. Effects of Vermiwash on Field Pea Growth and Productivity

5.1 Germination and Early Seedling Vigour

The ability of seeds to germinate is crucial for establishing a crop stand and for allowing crops to produce efficiently. Studies have shown that field pea seeds grown in vermiwash have better germination rates, become larger and appear healthier when measured by the vigor index, have a faster average germination time than those grown not in vermiwash (Prabha *et al.*, 2021) [6]. Soaking seeds in a solution of 10-25% vermiwash for 8-12 hours prior to sowing activates the enzymatic hydrolysis of protein and carbohydrate reserves in the seed and provides energy for the embryo axis and cotyledons as they emerge from the seed.

Parihar *et al.* (2023) [5] discovered that field pea seeds treated with 25% vermiwash had a germination rate of 93.5% compared to 84.2% in untreated seeds and had significantly longer root length (23.4cm vs 16.7cm) and shoot length (17.8cm vs 13.1 cm) than untreated seeds 10 days after sowing. The increased seedling vigor index was 38.6% greater than that of the control; this increase is likely due to the IAA content of the vermiwash that promotes elongation of the primary root and initiation of lateral roots. Similarly, Sharma *et al.* (2022) [8] found that the application of foliar application of 5% vermiwash at 20 and 40 DAS produced a significant increase in LAI and CGR of field peas during the vegetative growth period.

5.2 Vegetative Growth Parameters

According to Kumar *et al.* (2023) [3], application of vermiwash on vegetative growth parameters of field pea has

demonstrated consistent improvement in height, stem diameter, number of branches per plant, leaf area and dry matter accumulation. Two years of an experimental trial was conducted by Kumar *et al.* (2023) [3] in the Indo-Gangetic Plains, where it was determined that there were significant increases to its height (+ 18.3%), number of branches per plant (+ 22.7%), and total dry matter (+ 26.4%) with respect to unsprayed controls when using 10% foliar applications of vermiwash at the vegetative, pre-flowering, and pod-filling phases of growth. These positive effects were attributed to the synergistic impact of IAA, gibberellins, and cytokinins in vermiwash on the activity of the apical meristem and internode elongation.

According to Sinha *et al.*, (2022) [10], they looked to see whether vermiwash on the ground (2 L/m² every two weeks) had any effect on the growth of field peas compared to using it as a spray (5%) applied to the plant leaves. The results showed that using the spray method produced better growth than using drenching methods. This indicates that plants may have been able to absorb nutrients directly through their leaves from vermiwash. There was also a 19.4% increase in the chlorophyll SPAD readings in the plant using foliar applied vermiwash, indicating more photosynthetic pigments were synthesized, along with more nitrogen being converted into protein.

5.3 Nodulation and Biological Nitrogen Fixation

Field pea agronomy relies heavily on its ability to form symbiotic, nitrogen-fixing relationships with *Rhizobium leguminosarum* bv. *viciae*. The use of vermiwash has been shown to positively affect nodule formation, nodule count, nodule weight, and leghemoglobin levels—all of which serve as important measures for biological nitrogen fixation (Choudhary *et al.*, 2022) [1].

Prabha *et al.* (2021) [6] showed in a pot trial that field pea seeds that were inoculated with *Rhizobium* and received 10% vermiwash by foliar application at 30 and 50 days after sowing produced significantly higher numbers of nodules (28.4 nodules/plant) and nodule dry weight (412 mg/plant) than when field pea seeds received only *Rhizobium* inoculation (19.7 nodules and 298 mg of nodule dry weight). This enhancement has been attributed to IAA in the vermiwash that stimulated root hair curling and formation of infection threads. Also, the PGPR in the vermiwash produced flavonoids that triggered *Rhizobium* nod-gene expression. The estimated amount of total nitrogen fixation, determined using the acetylene reduction assay (ARA), was 34.2 percent greater in plants treated with vermiwash.

5.4 Yield and Yield Attributes

The main agronomic goal of every biostimulant application is to provide an improved harvestable yield. In relation to field peas, the use of vermiwash has resulted in significant increases in the following yield attributes, i.e. pods per plant, seeds per pod, and 100-seed weight, as well as the yield of grain per ha (Singh & Verma, 2021) [9].

According to Parida *et al.* (2022) [4], multi-location field trials in three agro-climatic zones resulted in an average increase in mean grain yield of between 18.6-24.3% from the application of 10% vermiwash via three foliar applications compared to water-sprayed controls in field pea. There was an increase in the number of pods per plant (14.2 to 18.6), the number of seeds per pod (4.8 to 5.9) and 100-seed weights (18.4 g to 21.7 g). This enhanced

performance of plants treated with vermiwash was due to improved partitioning of photosynthates to reproductive organs; increased rates of sucrose loading into developing seeds, and superior nutrient supply during pod development due to continued absorption of nutrients from the vermiwash into the leaves of the plants.

The results of the meta-analysis completed by Kumar *et al.* (2023) [3], which compiled data from 22 separate studies regarding the effect of vermiwash on grain legume crops (eight of these were conducted with only field pea) show an overall weighted average increase in yield of 19.80% (confidence interval 95%: 16.20-23.40). The most positive responses were experienced when applying vermiwash at rates between 3-5% concentration and using two to three foliar sprays on crops at critical periods of growth (during flowering and prior to pod development) due to the increased needs for nutrients that occur during the reproductive period.

5.5 Quality Parameters

In addition to increasing yield quantity, vermiwash applications also enhance the quality of seeds from both a nutritional standpoint and as a commercial product instead of a food source. In Sinha *et al.* (2022) [10], it was shown that, when compared to the control plants, the field pea grains produced in the vermiwash-treated plots contained higher levels of crude protein (23.8% vs. 21.2%), iron (45.6 mg kg⁻¹ vs. 38.2 mg kg⁻¹), and zinc (32.4 mg kg⁻¹ vs. 27.6 mg kg⁻¹). The increase in protein values was due to increased nitrogen fixation and changes in nitrogen use efficiency. The increased levels of the micronutrients were also due to the presence of these micronutrients in vermiwash and because vermiwash provides better pathways for the uptake of micronutrients into plants.

6. Effects of Panchgavya on Field Pea Growth and Productivity

6.1 Seed Germination and Seedling Establishment

Panchagavya has been proven beneficial for priming seeds of several legumes, including field pea. Eight hours of soaking field pea seeds in a 3% panchagavya solution before planting enhances the speed of absorption (imbibition), activates hydrolytic enzymes (α -amylase, protease), and increases the rate of respiration by the embryo, creating uniformity in germination and better emergence of seedlings (Ramesh and Vinayagam, 2021) [7]. Choudhary *et al.* (2020) [1] showed that priming field pea seeds with 3% panchagavya improved the germination percentage from 82.4% to 91.6%, the germination rate index from 18.3 to 24.7, and the seedling vigor index from 1024 to 1436.

Research supports that the improvement of seedling establishment (as compared with no application) has been linked to increases in bioregulators (IAA and Gibberellins) from IGP. There is evidence that amino acids from CG may directly supply N to the developing embryo thereby reducing the developing embryo's reliance on cotyledonary reserves enabling them to establish more quickly under less than optimum soils (Parida *et al.*, 2022) [4].

6.2 Photosynthesis and Chlorophyll Content

The use of 3% panchagavya via foliar application has been research-proven to improve photosynthetic capabilities within field crops. Ramesh and Vinayagam (2021) [7], found that applications of three 3% panchagavya foliar applications

(at 20, 40 and 60 days after sowing), resulted in 28% increase in total chlorophyll (from 2.14 mg/g of fresh weight to 2.75 mg/g of fresh weight), 22.6% increase in the rate of photosynthesis, 18.3% increase in stomatal conductance and 14.7% increase in transpiration efficiency compared to the untreated control crops. Thus, these physiological improvements lead to increased net rates of photosynthesis per unit area and improved crop growth rate during the vegetative phase.

Chlorophyll production and enhancement through panchgavya occurs via three different processes: (i) cytokinin stimulation of chloroplasts' development and delaying leaf aging; (ii) increased iron supply in the root zone contributing to the activity of ferrochelatase; and (iii) promoting the synthesis of delta-aminolevulinic acid that is the rate-limiting step in the production of porphyrins by microbial metabolites found in panchgavya (Parihar *et al.*, 2023) [5]. During periods of environmental stress, panchgavya contains antioxidants that may prevent oxidative damage to the membranes of chloroplasts.

6.3 Flowering and Reproductive Development

Using panchgavya as an application method has been linked to earlier and more synchronised flowering in field peas, which would affect both yield potential and the timing of harvest (Singh & Verma, 2021) [9]. In the research done by Kumar *et al.* (2023) [3], field pea plants treated with panchgavya treatment via foliar application at a concentration of 3% at 25 and 45 days after seeding (DAS) flowered 3.2 days earlier than untreated controls and had a 24.6% increase in flowers per plant. The percentage of flowers retained on the plants increased from 64.3% to 74.8%, suggesting that there was a decrease in flower abortion, which is likely due to the cytokinin in panchgavya helping to prevent premature abscission.

During pod development and seed filling, panchgavya application enhanced sucrose synthase and ADP-glucose pyrophosphorylase activities in developing seeds, promoting starch biosynthesis and carbohydrate accumulation (Ramesh & Vinayagam, 2021) [7]. This was reflected in significantly higher seed filling rates and shorter seed fill duration in panchgavya-treated plants, resulting in superior 100-seed weights.

6.4 Yield and Harvest Index

The use of panchgavya has been shown to improve crop yields through numerous field trials. Three years of experiments performed by Parida *et al.* (2022) [4] in Odisha, India revealed a yield increase from 21.4 to 27.8% with three applications of panchgavya at 3% concentration versus untreated controls (1,842 to 2,104 versus 1,512 to 1,648 kg ha⁻¹). The harvest index was increased from 0.38 to 0.44, thereby demonstrating that the panchgavya treatment improved the partitioning of assimilates to the harvested component of field pea.

The authors conducted an experiment to determine the impact of various panchgavya concentrations and frequencies of application (1, 3, 5, and 7%) on the yield of field pea plants. Their results indicate that the treatment which provided the highest yield (2267 kg/ha) was 3% concentration applied three times over the course of the growing season. The increase in yield from the control was 29.3%. There was no beneficial effect seen with higher

concentrations of panchgavya (5-7%) than 3%, which the authors attribute to either phytotoxic effects from too much hormone concentration or osmotic stress from excessive amounts of organic solutes in the soil, respectively (Choudhary *et al.*, 2022) [1].

6.5 Protein Content and Nutritional Quality

According to Sinha *et al.*, (2022) [10], panchgavya application increased the essential amino-acid profile and protein content of field pea seeds. In a study by Ramesh & Vinayagam (2021) [7], panchgavya-treated field peas produced seeds with 24.8% crude protein versus 21.6% in the control treatment; also, treated seeds had greater concentrations of lysine (7.2 vs. 6.1 g/100 g protein), methionine (1.24 vs. 0.98 g/100 g protein), and threonine than the control treatment. The underlying reason for these improvements was the presence of excess nitrogen fixation, greater synthesis of amino acids within the leaf, and improved efficiency of remobilizing nitrogen from vegetative to storage tissue during the grain fill stage.

7. Combined Application of Vermiwash and Panchgavya

7.1 Synergistic Interactions

Vermiwash and panchgavya are both backed by lots of research as separate practices, however, research on how to use them together is less common, but has been encouraging to see additive or synergistic effects. Vermiwash has a lot of microbial inoculants and enzymes, and panchgavya has a lot of hormones and fermentation activity, hence the reason for using these two products together (Sharma *et al.*, 2022) [8].

Kumar *et al.* (2023) [3] conducted a split-plot experiment in field pea examining single and combined applications of vermiwash (10%) and panchgavya (3%) as foliar sprays. The combined treatment produced the highest grain yield (2,394 kg ha⁻¹), which was 34.6% above control, 12.4% above vermiwash alone (2,130 kg ha⁻¹), and 9.8% above panchgavya alone (2,180 kg ha⁻¹). The authors identified complementary mechanisms: panchgavya-derived cytokinins promoting flower retention while vermiwash-derived phosphate-solubilizing bacteria enhanced phosphorus supply during pod development.

7.2 Integrated Organic Management

The combination of vermiwash and panchgavya in integrated organic farming systems such as vermicompost application as basal dose, Rhizobium seed inoculation, biofungicide treatment is emerging as a new paradigm in sustainable field pea production (Parida *et al.*, 2022) [4]. They showed that a total organic treatment package (vermicompost (5 t ha⁻¹), rhizobium (inoculation), foliar application of vermiwash (10%) and panchgavya (3%)) yielded 91.3% of the yield possible with recommended NPK fertilization while also increasing the SOC by 18.4% and the microbial biomass by 26.7% during the treatment trial (Prabha *et al.*, 2021) [6].

The fields cultivated with combined vermiwash and panchgavya application for two successive fields pea seasons exhibited positive legacy effects with significant increase in soil health parameters such as available soil phosphorus (+ 24.3%), soil microbial biomass carbon (+ 31.6%), and aggregate stability (+ 19.2%), which may lead to a decrease in input dependency in future growth seasons.

8. Soil Health Effects and Environmental Implications

8.1 Soil Biological Properties

The vermiwash and panchgavya have been shown to have significant positive effects on soil biological properties. Increased total microbial biomass, densities of certain functional groups such as nitrogen fixers, phosphate solubilizers, cellulose decomposers and soil enzymatic activities (urease, phosphatase, dehydrogenase) in field pea grown soil (Sharma *et al.* 2022) ^[8]. These biological improvements contribute to the long-term fertility of soils and the need for external nutrient inputs is reduced.

8.2 Environmental Safety

Vermiwash and Panchgavya are biodegradable and do not cause major risks of contaminating the soil and water when compared to agro-chemicals which have a synthetic origin. (Ramesh & Vinayagam, 2021) ^[7]. Residue analysis studies have been conducted and the field pea grains from organically managed plots with these biostimulants have been found to be devoid of harmful chemical residues, thus complying with international food safety standards (Parida *et al.*, 2022) ^[4]. They are thus in line with sustainable development goals (SDG 2: Zero Hunger; SDG 15: Life on Land) and contribute to the provision of ecosystem services and better food production.

9. Comparative Mechanism of Action: Vermiwash vs. Panchgavya

Vermiwash and panchgavya have a few mechanisms of action common to both, and also complementary pathways towards plant growth promotion that are common, although different in their context and methods.

9.1 Shared mechanisms involve: phytohormone-mediated growth stimulation (mainly IAA and gibberellins); improving root structure and surface area for nutrient uptake; enhancing soil microbiological diversity and activity; inducing systemic disease resistance; and upregulation of antioxidant enzyme systems under stress (Parihar *et al.*, 2023; Choudhary *et al.*, 2022) ^[5, 1].

Some of the divergent mechanisms of Vermiwash are its excellent ability of direct microbial inoculation, especially PGPB and Mycorrhizal fungi, its high capacity to solubilize phosphate and its relatively higher enzymatic activity (Sinha *et al.*, 2022) ^[10]. In contrast, Panchgavya showed superior effect for improvement in flowering and fruit set by its cytokinin activity, exhibited significantly higher antifungal property by sharing fermented fatty acid content, and has a higher impact on the synthesis of photosynthetic pigment by having unique fermented bioactive profile (Ramesh & Vinayagam, 2021) ^[7].

10. Research Gaps and Future Directions

Despite considerable progress in understanding the agronomic effects of vermiwash and panchgavya on field pea, several critical research gaps remain that warrant systematic investigation:

10.1 Standardization of quality: The chemical and biological composition of both vermiwash and panchgavya varies considerably depending on preparation methods, parent materials, fermentation conditions, and storage duration. Development of standardized quality parameters

and quality control protocols is essential for reliable and reproducible field-scale application (Kumar *et al.*, 2023) ^[3].

10.2 Dose optimization under diverse agroecological conditions: Most published studies have been conducted in limited geographical areas. Multi-location, multi-season trials across diverse soil types and climatic zones are needed to develop site-specific recommendations for field pea cultivation (Singh & Verma, 2021) ^[9].

10.3 Mechanistic studies using molecular tools: The molecular mechanisms through which vermiwash and panchgavya modulate gene expression in field pea—particularly regarding nitrogen fixation, hormone signalling pathways, and stress response networks—remain poorly characterized. Transcriptomic, proteomic, and metabolomic approaches could yield valuable insights into these interactions (Parihar *et al.*, 2023) ^[5].

10.4 Long-term soil health studies: The cumulative effects of repeated vermiwash and panchgavya application on soil microbiome structure, soil carbon sequestration, and soil physical properties need evaluation over multi-year periods using modern metagenomic and metatranscriptomic tools (Sharma *et al.*, 2022) ^[8].

10.5 Economic analysis and farmer adoption: Comprehensive cost-benefit analyses comparing organic biostimulant-based management with conventional inputs, alongside participatory action research approaches to understand farmer adoption barriers, are needed to facilitate widespread implementation (Parida *et al.*, 2022) ^[4].

10.6 Integration with precision agriculture technologies: The potential to combine vermiwash and panchgavya application with precision agriculture tools—including remote sensing-based crop monitoring, variable-rate application technology, and decision support systems—represents an exciting frontier for research (Choudhary *et al.*, 2022) ^[1].

11. Conclusion

This state-of-the-art review brings together all scientific data on the impact of vermiwash and panchgavya on growth, physiology, yield and quality of field pea (*Pisum sativum* L.). All presented evidence has confirmed that vermiwash and panchgavya are useful biostimulants which could increase the productivity of field pea in the field by several different mechanisms such as phytohormone activity, microbial enrichment, nutrient solubilization and induction of antioxidant enzymes. Vermiwash gives a 18-25% improvement in grain yield consistently, across all critical growth stages, without any foliar sprays, and has been shown to enhance biological nitrogen fixation efficiency, seed protein content and micronutrient density. The application of Panchgavya at 3% concentration 2-3 times during the cropping season has similar or better yield improvement (20-29%) and flower retention, chlorophyll content and other parameters of seed quality. When both biostimulants are applied together with the application of vermicompost basal dose and the Rhizobium seed inoculation, the production level is nearly 90-95% of the conventional NPK application, soil health is enhanced, environmental contamination is minimized, safe and

nutritious food is produced. These findings are highly relevant to both farmers and policy makers as well as agricultural researchers all over the world, as the movement to organic and low-external-input farming systems continues across the globe. The potential of the vermiwash and panchgavya as key components supporting sustainable field pea production systems should be fully realised through future research efforts focusing on standardisation, elucidation of mechanisms with molecular tools, developing networks of trial sites in diverse regions, soil health assessment over the long term, and the integration of these concepts with emerging precision agriculture technologies.

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