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REVIEW ARTICLE

Organic compounds as biostimulants: Cow derivatives, botanicals and biofertilizers enhancing seed germination, vigour and yield in paddy

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Abstract

Organic agriculture employs various natural techniques to cultivate crops, emphasizing crop rotation, composting and biological pest control. In modern intensive agriculture, chemical fertilizer plays a major role. Continuous application of these chemicals leads to the accumulation of residues, resulting in soil hardening and degradation of soil structure. Although chemically treated seeds and inorganic inputs can enhance crop yield initially, their excessive use may negatively affect productivity and result in the accumulation of toxins, rendering the produce unfit for human consumption. Organic farming addresses many of the challenges faced by modern agriculture and food production. The idea behind organic farming is to use affordable, easily accessible inputs. Organic farmers pay significantly more for labour and feed also spend less on inputs. Organic farming utilizes farmyard manure, compost, green manures, farm waste, vermicompost and crop residues that increases the crop yield and restore soil fertility. In this paper, the reasons for using organic compounds are reviewed and their roles are analysed, particularly focusing on their effects as seed treatments and foliar applications on seed germination, growth and yield in paddy. In future, new research pathways emerge, offering the chance to improve organicpractices and ensure healthy environment.

Keywords: foliar application; germination; organic compounds; organic farming; seed treatment

Introduction

Rice serves as a staple food for more than half of the global population and is cultivated in more than 100 countries, with Asia accounting for 90 % of the total production (1). The Indian subcontinent consumes more than 40 % of its calories from rice (2). According to USDA, global rice output and yield are projected to increase by 3.8, 7.2 and 11.3 % by 2025-2026. China produces the most rice among the top ten rice-producing nations (3). In the year 2023-24, the area under rice cultivation in India was 47.82 million hectares, with a total production of 137.83 million tonnes and a productivity of 2882 kilograms per hectare (Department of Agriculture and Farmers Welfare). In India, West Bengal is the top rice-producing state, with an acreage of 5.80 million ha and the highest production of 15.5 million tons, yielding a productivity of 2.79 million tons (4). In conventional farming, the farming community have identified major issues such as quality seed insecurity, declining soil health, productivity stagnation and environmental risks. The use of easily accessible organic materials, such as FYM, compost, biogas slurry, etc., led to a significant increase in interest in organic agriculture (Fig. 1) (5). The basic principles of organic agriculture are the ecology, fairness and environment (6-8). One of the main limitations of organic farming is lower yield compared to conventional farming. To meet the growing food demand of the increasing population, more land must be brought under organic cultivation to achieve comparable yields (9). The incorporation of augmented sludge, biochar in combination with organic fertilizers, biofertilizers, organo-minerals and advanced digital technologies is essential to mitigate the constraints and obstacles associated with organic agriculture (7). As organic farming employs a systems approach to control fertility, weeds and pests rather than depending on off -farm inputs, it also requires a high level of experience (7). To protect future generation, we need transition to organic farming and restore soil fertility.

Reason for using organic compounds in seed treatment

The use of chemical seed treatment products has a negative impact on the environment and human health. Before planting, the seeds should be treated with organic products to ensure high yield and good quality of seeds and thereby

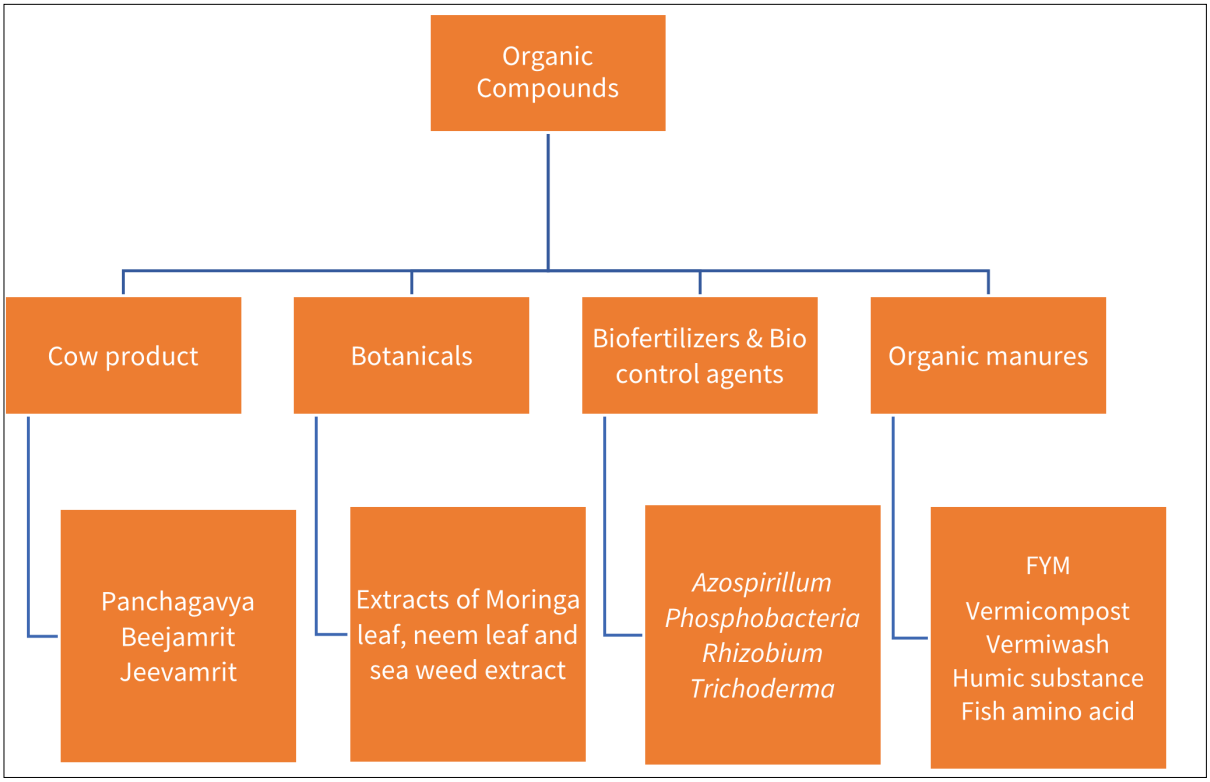

Fig. 1. Types of organic compounds.

reducing the losses due to diseases. Organic seed treatment is currently being used in place of chemical seed treatment (10). For the conventional production of seeds, chemical fertilizers, insecticides, fungicides and herbicides are needed. The main reason in favour of utilizing organic materials for cultivating organic crops is that they are naturally occurring and has lower environmental impacts. In the process of producing organic seeds, various methods such as cropping pattern, organic manures, biofertilizers, cultural practices and biopesticides made from plant materials were used to maintain soil fertility, crop yield and pest control (Fig. 2) (11). Organic products have higher nutrient content and are often free of additives and pesticide residues (6). The use of organic products can improve soil pH, increase soil organic matter and enrich the soil with nutrients (12-14).

Cow products as organic compounds

Cow products include panchagavya, jeevamritta and beejamrita. In organic fertilizer, nitrogen percentage is increased due to the use of cow dung and cow urine as it contains rich source of amino acids. Cow urine, comprises of 95 % water, 25 % urea and 25 % essential minerals, hormones and enzymes (15). Other cow products serve as a rich source of nitrogen, phosphorus, potassium, calcium, magnesium, chloride and sulfate, contributing significantly to soil fertility and plant growth. It also enhances the total phenolic content, control pathogenic infection, improve soil health and plant growth (16). The cow based formulation contain majority of microbial sources like rhizobacteria that promote plant growth in paddy (Table 1) (17).

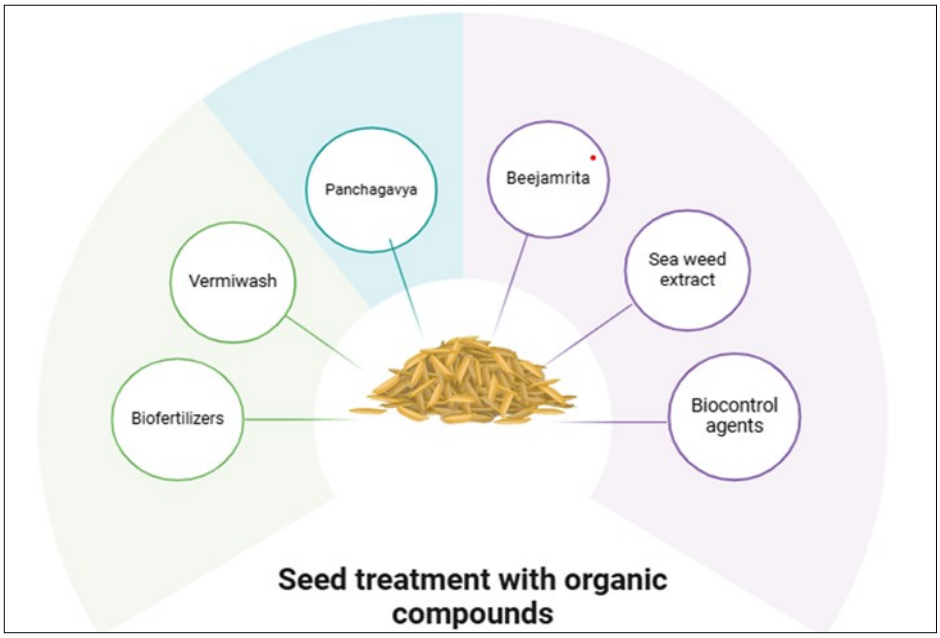

Fig. 2. Seed treatment with organic compounds.

Table 1. Effect of cow-based organic treatments on paddy seeds

S. No	Crop	Method of treatment	Result	Reference
1.	Rice CO 43	Seeds soaked in 4 % panchagavya for 16 hr	Significant rise in seedling growth parameters	(19)
2.	Rice ADT 43	Seeds treated with neem cake + panchagavya	Increased in seed quality and plant growth parameters	(67)
3.	Rice	Seeds treated with 10 % concentration of panchagavya	Germination decreases with increase in panchagavya Recorded maximum seedling length, fresh and dry weight	(20)
4.	Rice DRR Dhan 39	Seeds treated with 50 % vermicompost + jeevamrith 5 % + panchagavya 3 %	Significant increase in grain and straw yield	(79)

Panchagavya is a mixture of five by products of cow include cow dung, cow urine, milk, curd and ghee. These compounds aid in plant growth and have antimicrobial and nutritional quality (18). In Panchagavya, significant amount of nutrients, minerals and growth hormones are present, which enhances plant metabolic activity and promotes seed germination. In addition, panchagavya contains beneficial bacteria that possess biocontrol properties and produce substance essential for plant growth (19). Compared to vermicompost and farmyard manure, panchagavya contains higher levels of organic carbon and total nitrogen. Application of panchagavya significantly increase the chlorophyll content in plants. Wide range of organic C, N, P and K present in Panchagavya may be the cause for higher root and shoot growth (20). Biochemical properties of panchagavya showed that it contains almost all of the major nutrients, including N, P and K, as well as micronutrients and growth hormones, like gibberellic acid (GA) and indole acetic acid (IAA), which are essential for crop growth. It also contains a high concentration of fermentative microorganisms, such as *Lactobacillus*, *Azotobacter*, *Phoshobacteria* and yeast (21). The ammonia uptake and overall N supply are enhanced by the chemolithotrophs and autotrophic nitrifiers (ammonifers and nitrifers) found in panchagavya which proliferate on leaves (22).

To enhance crop nutrition, on-site produced Jeevamrit is essential, as it boosts soil microbial activity and improves soil fertility (23). Jeevamrit promotes enormous biological activity in the soil, thereby making nutrients more readily available to crops. Jeevamrit is a nutritious liquid bio-enhancer that improves soil productivity, growth and yield of plants (24). The soil microflora and soil enzymes are increased due to the use of beejamrit and jeevamrit which have microbial properties. Jeevamrit enhances the development of N fixing bacteria on the substrate like FYM and compost (25).

Beejamrit is a type of organic liquid manure that is used to treat crop seeds. It is a powerful organic mixture that protects the seed from various kinds of bacterial and fungal pathogens. Bijamrit or Beejamrita is a pre-sowing treatment for plants, seedlings or any other planting material. In addition to protecting against soil-borne and seed-borne diseases that commonly affect crops after the monsoon season, it effectively protects young roots from fungal infection. Beejamrita is prepared using a variety of microorganisms, such as bacteria, fungi and nitrogen-fixing organisms, which improves seed protection. Beejamrita, enriched with diverse microorganisms like bacteria, fungi and nitrogen-fixers, enhances seed protection by fostering beneficial microbial activity. Its rich microbial composition safeguards seeds against various pests and insect infestations (26).

Botanicals - plant extracts

Botanicals have antioxidant properties and they are rich in cytokinin and zeatin, which increases plant growth (27). Alkaloids, protein, quinine, cytokinin, antioxidants and macro- and micronutrients are all present in *Moringa oleifera* leaves. These biochemicals support the growth, defence and metabolic processes of plants (Table 2) (28). Neem leaf extracts has antifungal properties and is used as a tool for controlling infection caused by seeds and promotes seed germination and seedling growth (27). In seed treatment, botanical agents are utilized to treat several phytopathological diseases and common insect pests that threaten seed storage, which improves the overall storability of seeds (29).

Seaweed extract contains antibiotics, vitamins, macro and micronutrients. This product when sprayed on the vegetative system, plays a vital role in controlling cell components and enhances the plant's resistance to environmental stresses like salt stress and drought stress. It also enhances leaf efficiency and speeds up carbon metabolism (30). In addition, the auxin and cytokinin present in seaweed extract promote elongation and enlargement of internodes and accelerate internal cell division, resulting in taller plants (31). When applied exogenously, seaweed extracts provide a range of plant growth hormones, polyamines, growth promoters, trace elements, vitamins, amino acids, antibiotics and micronutrients (32). Seaweed extract promotes tolerance against environmental challenges and increases

Table 2. Effect of plant-based extracts on paddy seed germination and growth

S. No	Crop	Method of treatment	Result	Reference
1.	Rice	Seeds treated with 5 % solution of *Moringa oleifera* extract Seeds treated with 5 and 15 % solution of vermiwash	Increase germination, seedling vigour and biochemical content in seed	(18)
2.	Rice	Foliar spray of 3 % horse gram sprout extract and 2 % cowpea sprout extract	Observed higher seed germination, number of productive tillers/hill and seed yield	(74)
3.	ADT 43	Application of seaweed sap *Kappaphycus alvarezii* and *Gracilaria* sp. at 15 % + 100 % recommended dose of fertilizer	Increase in chlorophyll content, quality and yield	(80)
4.	ADT 53	Soil application of seaweed extract @ 12.5 kg/ha along with the foliar spray of seaweed extract liquid @ 0.5 % twice at tillering and panicle initiation stage	Recorded the highest value of growth and yield parameters	(81)

plant nutrient uptake from soil (33).

Bio-fertilizers and bio-control agents

Biofertilizers enhance soil fertility by supplying essential nutrients through nitrogen fixation, phosphate and potassium solubilization, mineralization and organic matter decomposition. They also promote plant growth by releasing phytohormones, synthesizing antibiotics and improving soil microbiota (34). Application of biofertilizers to seeds, seedlings, plants or soil helps mobilize plant nutrients for crop growth through biological nitrogen fixation, phosphorus solubilization or mobilization of any other plant nutrient required for crop growth. Biofertilizers are enriched with beneficial live microorganisms and formulated using sterilized carriers like lignite or talc, enhancing soil fertility and plant growth. To control a variety of root-borne infections, several biofertilizers also function as efficient biocontrol agents. They increase the fertility of the soil and make plants resistant to diseases (35). Bio-fertilizers establishes symbiotic relationship with plants and they are inoculated with live microorganisms that enhances major nutritional supply to plants and maintain soil fertility (36). They include *Azospirillum*, *Phosphobacteria*, *Rhizobium*, *Pseudomonas* and *Trichoderma* species. The use of biofertilizers increases plant height, boosts nitrogen use efficiency and increases the chlorophyll content in rice leaf tissue (Table 3) (37). Predominant PGPRs thriving in minimally or non-tilled soils include *Azotobacter, Azospirillum, Rhizobium*, cyanobacteria, phosphate solubilizers, potassium mobilizers and mycorrhizae, all of which contribute to improved soil fertility and plant growth (38). Productivity in rice is increased due to the application of *Azospirillum* (36). Benefits of applying biofertilizer include increased nutrient and water uptake from roots and also involve in biological nitrogen fixation (39).

Trichoderma is well known for its ability to promote growth and actively control plant diseases (40). It alters physiological processes in plants, enhancing the efficient use of water, light and nutrients (41). Rhizobium seed inoculation enhances nodulation, boosts seed yield, lowers fertilizer costs and helps mitigates soil degradation and environmental pollution caused by excessive chemical fertilizer use (35).

In many crop species, including rice, soil bacteria like *Pseudomonas* and *Azospirillum* are known to reduce abiotic stressors. One type of free-living fungi that interacts extensively with roots, soil and leaves is *Trichoderma* (42). It enhances nutrient absorption, stimulates seed germination even under adverse soil conditions and strengthens tolerance to abiotic stress. It secretes phosphate-solubilizing enzymes and phytohormones, inhibits harmful root microflora and promotes root growth, seedling vigour, plant development and overall yield improvement (43). By improving the availability of minerals, particularly P and Zn to plants, *Trichoderma* stimulates growth and improves rice grain and vegetable yield even with minimal mineral fertilizer use (44). *Trichoderma* combined with 70 % NPK and burnt rice straw increased soil fertility, benefit-cost ratio and crop yield while lowering the cost of inorganic fertilizer (45). *Trichoderma* species that stimulate the production of auxins and gibberellins improve the performance of rice seedlings during seed germination (46). Increased nutrient uptake by *Trichoderma*-treated plants led to improved root and shoot growth as well as increased plant vigour, which ensured quick growth and increased plant greenness because of higher photosynthetic rates, which in turn raised the production of biomass and carbohydrates (47).

Azotobacter fixes atmospheric nitrogen in the rhizosphere, making it available to plants. In addition to nitrogen fixation, *Azotobacter* produces gibberellin, thiamine, riboflavin, nicotine and indole acetic acid. These compounds enhance seed germination and help reduce plant diseases. Seeds with low germination rates can be inoculated with *Azotobacter* to increase germination by 20-30 % (48). *Azospirillum* enhances plant growth by promoting development, enhancing nutrient absorption, improving biomass accumulation, increasing water uptake and ultimately boosting yield (49).

Organic manures

The integrated use of organic manures such as FYM, vermicompost, poultry manures and castor cake contain macro and micronutrients. They enhance the crop productivity and soil fertility (Table 4) (50). The application of organic manures improves soil health by enhancing its physical, chemical and biological properties (51). The main forms of organic matter that enhance soil fertility and help plants make better use of fertilizers are farmyard manure, press mud (a sugar waste product), green manure (*Sesbania aculeata*) and wheat residue. Farmyard manure boosts microbial activity, root penetration, water and nutrient retention and nutrient exchange capacity, thereby significantly improving soil fertility (52). The seeds treated with organic manure showed higher percentage of nitrogen in rice (53). Organic carriers, such as FYM, cow and poultry manures, improve plant development by changing the biological and physico-chemical properties of the soil (54). Due to its excellent capacity to store water, nutrients and buffers, peat has been utilized effectively as an organic carrier (55). Due to the presence of major nutrients and other essential elements like P and K, vermicompost promotes the growth of plants (56). Vermicompost, a potent organic fertilizer, enhances soil fertility and promotes sustainable crop

Table 3. Effect of biofertilizers and biocontrol agents on paddy seed treatment

S. No	Crop	Method of treatment	Result	Reference
1.	Rice	Seeds treated with *Azospirillum brasilense* + *Bacillus megaterium* @ 4 kg/ha	Recorded higher seedling growth parameters	(82)
2.	Rice	Seeds treated with *Azospirillum* + *Phosphobacteria* + VAM at 600g/ha	Recorded higher values in growth and yield parameters	(76)
3.	Organic rice	*Azotobacter* (12.5 g/kg) + *Azospirillum* (12.5 g/kg) + FYM (12 t/ha)	Increased the yield and yield components of organic rice	(49)
4.	Rice	Foliar spray of *P. fluorescens* + butter milk (0.5 %) or *P. fluorescens* (0.5 %)	Reduced the incidence of sheath rot, false smut and grain discolouration in rice	(27)

Table 4. Impact of organic manure on paddy growth and yield

S. No	Crop	Method of treatment	Result	Reference
1.	Rice	Foliar application of vermiwash at 6 % twice during the active tillering and 50 % flowering stage	Increases productivity and achieves greater yield	(71)
2.	Rice	Foliar spray of egg amino acid 1 % + recommended dose of fertilizer	Recorded high leaf area index, soluble protein and yield	(65)
3.	Rice	Application of fish amino acid with a dose of 1mL	Increases the plant height, number of tillers and N uptake in plant leaves	(83)
4.	Bali red rice	Application of 2.5 % fish waste fertilizer	Increases the growth parameters in rice	(84)
5.	Rice	FYM + goat manure + compost manure @ 16.5 t/ha	Improves the grain quality	(85)
6.	Rice	Foliar application of vermiwash @ 5 %	Increases the growth parameters and nutrient uptake	(86)

growth. Its rich microbiota and bioactive compounds aid in suppressing pests and diseases, improving overall plant resilience (57).

Vermicompost, derived from earthworms and its liquid extract, vermiwash, enhance soil properties by increasing electrical conductivity, water retention and moisture content. It promotes superior plant growth and productivity (58). The physical, chemical and biological qualities of soil are enhanced by vermicompost (59). Vermiwash contains plant growth hormones such as auxins and cytokinins (58). The application of vermiwash may increase the level of chlorophyll and cytokinin, which prevent leaf senescence and extend the retention of effective photo assimilatory surface (60).

Humic substances, key sources of organic nitrogen and carbon, are naturally derived compounds formed through the decomposition of plant matter from terrestrial or marine origins (61). Their structure contains several phytohormones and exogenous auxins that induce plant growth (62). The stimulating effect observed in the humic substance extract is attributed to the presence of humic acid and fulvic acid. Due to their multifunctionality and diverse structure, humic substances include components that promote the activity of certain enzymes, as well as minerals, amino acids, phytohormones and beneficial microbes (63). Humic substances enhance plasma membrane H^+-H-ATPase activity, facilitating H^+ release into the soil, thereby reducing soil and root surface pH. This process optimizes nutrient solubility and absorption, improving overall plant nutrition (64).

Liquid organic manure generated from fish waste is known as fish amino acid. Fish contain various minerals and amino acids that are valuable to plants and microbes for their growth. Foliar and soil application of fish amino acid enhances nutrient uptake, providing the plant with adequate nitrogen and chlorophyll to support its growth and health (65). Fish waste typically contains a variety of nutrients, including potassium (K), phosphorus (P) and nitrogen (N), making it a valuable component of organic fertilizers (66).

Effect of organic compounds on seed germination in paddy

Organic seed treatment in rice will increase germination rates and promote healthy seedling growth (Table 5). In Rice cultivar CO 43, the rate of imbibition was low in organic solutions of panchagavya, vermiwash, starter solution, cow's urine and coconut water when compared to water soaking (30.34 %) (19). On comparing the organic combination of neem cake + panchagavya, the inorganic treated seeds exhibited 5–8 % lower germination. The application of neem cake + panchagavya treatment in rice enhances germination and seed filling. The improvement in seed filling is reflected in a higher seed-to-husk ratio and increased 100-seed weight (67).

The seeds treated with various organic solutions at different levels will have significant rise in the vigour and germination compared to the control (19). Treating the seeds with different extracts of organic emulsion like *Parthenium hysterophorus*, *Moringa oleifera* leaves, vermiwash, panchagavya, *Ascophyllum nodosum* and *Medicago denticulate* at 5, 10, 15 % concentration increases germination of rice seeds (18). Application of organic amendments increases seed germination rate when compared to antibiotic control in plants, as demonstrated by the results of the Tukey's HSD test (68).

Rice seeds imbibed in humic substance derived from bovine manure vermicompost for 24 hr at 2 different dilutions

Table 5. Effect of organic seed treatment and foliar spray on paddy

S. No	Crop	Method of treatment	Result	Reference
1.	Rice	Application of rice husk, FYM and poultry litre mix with soil at 5 g/kg. After 2 weeks, antibiotics applied in aqueous solution form at 10 mg/kg.	Improves physiological growth parameters in rice	(68)
2.	Rice Sukhadhan 3, Tilkidhan	Seeds treated with 20 t FYM/ha. Before transplanting, the seedlings were dipped in bio inoculation of *Trichoderma* for 10-20 min.	Recorded maximum grain yield	(78)
3.	RiceBlackgram sequence	Application of vermicompost at 4 t/ha + foliar spray of panchagavya at 3 % at tillering and panicle initiation stage.	Recorded maximum plant height, number of tillers/ hills. Increases in dry matter production and nutrient uptake.	(86)
4.	Rice ADT 45	Application of neem cake + foliar spray of panchagavya @ 3 %	Increased the growth and seed quality parameters.	(87)
5.	Rice NDR 359	Application of vermicompost 5 t/ha + panchagavya 3 %	Recorded the highest plant growth and yield parameters.	(88)

recorded no effect on germination percentage but increased in seedling growth. This is because of humic substances on increasing the percentage of seeds that successfully germinate. Germination involves complex cellular and metabolic activities, starting from water absorption and culminating in the emergence of the radicle, without encompassing seedling growth (69).

In rice variety (Keteki Joha), the seeds are treated with five organic bioformulations namely organic metajal, organic trichojal, organic beauverijal, *Azospirillum* sp. and BIO phos liquid PSB formulation. Among all bioformulations, organic metajal showed higher seed germination percentage and seedling vigour (70).

Effect of organic compounds on growth and yield in paddy

Foliar application of jeevamrutha @ 10 % or 20 %, panchagavya @ 3 %, vermiwash @ 6 % and cow urine @ 100 % increases the productivity and economical returns in cereals and millets (71). When panchagavya and egg lime mix were applied to crops such rice, wheat, bananas, vegetables, greens and fruit trees, the plants' longevity and productivity increased (72). Foliar spray alone did not provide enough nutrients for crop growth in sodic soil. However, when combined with the required fertilizer dosage, a 1 % foliar spray of fish and egg amino acids increased yield, soluble protein content and leaf area index (65).

In rice plants, foliar spray of horse gram and cowpea sprout extract at critical stages increases seed filling, productive tillers, number of panicles and seed yield (73). Foliar spray of horse gram sprout extract and cowpea sprout extract of different concentration @ 1, 2, 3 and 4 % recorded higher seed germination, number of productive tillers/hill and seed yield (74). In rice-blackgram sequence, the basal incorporation of green manure at 6.25 t ha^{-1} along with vermicompost in four equal splits and foliar spray of panchagavya twice enhance growth and yield parameters (75).

When the rice seeds are inoculated with *Azospirillum* + *Phosphobacteria* + VAM, most of the growth and yield parameters are increased (76). The most effective pre-sowing treatment for enhancing seed germination and seedling vigor is to treat rice seeds with 4 % *P. fluorescens* for 12 hrs (77).

In rice variety ADT 45, seeds treated with various organic inputs recorded higher values of growth, yield and seed quality parameters (5). In a pot experiment, soil was amended with organic inputs at 5 g/kg and after two weeks, antibiotics (ciprofloxacin, levofloxacin, ofloxacin, amoxicillin and ampicillin) were applied as an aqueous solution at 10 mg/kg. The study confirmed that the application of rice husk combined with antibiotics significantly improved physiological growth parameters in rice (Fig. 3) (68).

In the organic SRI method of rice cultivation, *Trichoderma* treatment showed greater yield, grain weight, plant height and more panicle per square meter. When *Trichoderma* inoculation and traditional cultivation techniques were used, the average yield increased by 12.5 % than untreated plot (78).

Conclusion

The transition to organic farming is a viable option for enhancing resilience to environmental pressures. Organic farming practices play high priority on biodiversity, soil health and preservation of natural resources. Reduced dependency on external inputs makes the farming system more self-sufficient and economically viable. This not only lowers production costs for farmers but also improves food security and promotes eco-friendly agriculture. Embracing organic farming fosters rural livelihood and community development, benefiting both farmers and society. By investing in research, education and policy support, we can accelerate the shift towards organic farming, fostering sustainable and fair agricultural sector that benefits future generation.

Authors' contributions

MS contributed to writing original draft preparation. NP was responsible for conceptualization. ASA and SE supervised the work and were involved in drafting and reviewing the manuscript. SG participated in sequence alignment, editing

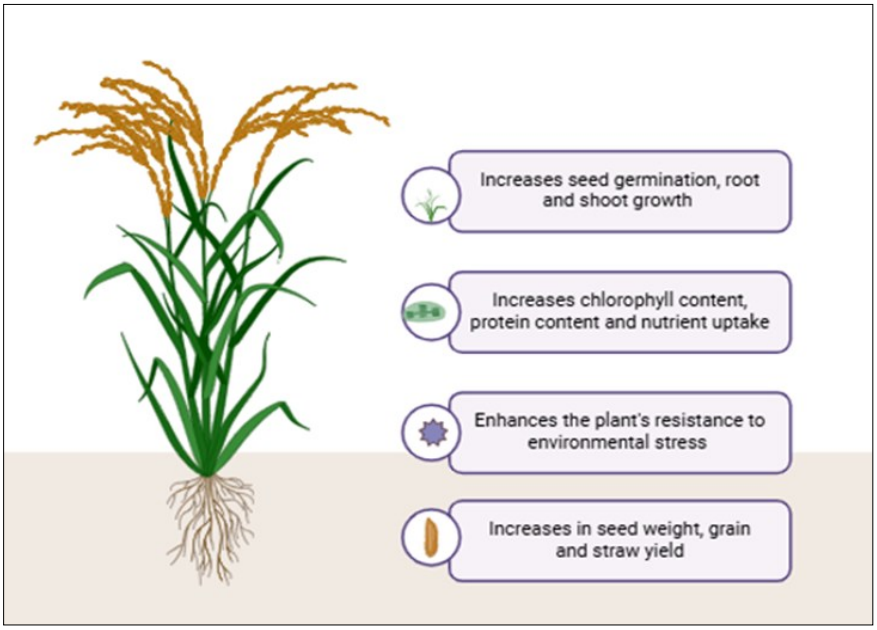

Fig. 3. Effect of organic compounds on growth and yield of paddy.

and visualization. All authors have read and approved the final version of the manuscript for publication.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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