PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.4385

eISSN 2348-1900

REVIEW ARTICLE

Exploring the potential of organic seed treatment and foliar nutrition to achieve sustainability in pulses production

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Received: 19 July 2024; Accepted: 12 January 2025; Available online: Version 1.0: 06 May 2025

Cite this article: Shafiq MH, Sundareswaran S, Suganthy M, Somasundaram E, Raja K, Janaki P. Exploring the potential of organic seed treatment and foliar nutrition to achieve sustainability in pulses production. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.4385

Abstract

Low productivity is a major challenge in organic farming and needs to be addressed to achieve sustainability. Due to their capacity to fix nitrogen, pulses require less organic fertilizer, which makes organic farming feasible. However, a 20% loss in pulse productivity under organic cultivation has been reported. Conventional farming boosts yields with energy-intensive chemical inputs but causes long-term issues like pollution, greenhouse gas emissions, reduced soil fertility and land degradation. The yield loss can be minimised by alternative inputs like bio-formulations preferably derived from farm waste and other sustainable sources. These bio-formulations often include a mixture of beneficial microorganisms, organic nutrients and natural growth-promoting substances which are cost-effective when compared to conventional inputs and help in improved nutrient absorption, enhanced plant growth and yield, disease and pest resistance, stress tolerance and enhanced soil health. There are several approaches for applying bio-formulations to plants such as foliar spray, seed treatment, soil application, drenching, mulch integration and fertigation, all of which are designed to guarantee maximum absorption and efficacy. This review explores the various organic seed treatments and foliar fertilisation using bio-formulations such as panchagavya, jeevamrutha, beejamrutha, fish fermented waste extract, seaweed extract, vermiwash and biofertilizers to improve the productivity of pulses under organic cultivation.

Keywords: bio-formulations; foliar fertilisation; organic farming; pulses; seed treatment; seed priming

Introduction

Organic farming is an approach to farming that places a strong emphasis on environmental responsibility, sustainability and producing food without the use of artificial chemicals or genetically modified organisms (GMOs). Maintaining an adequate supply of nutrient-rich food to serve the world's expanding population does not require synthetic fertilisers or pesticides (1). Worse, their usage may induce activities that harm the ecosystem in general and soil quality in particular. Integrated pest management and organic farming methods aim to minimize the use of synthetic chemicals, promote ecological balance and reduce environmental impact. In recent times, organic farming has gained significant prominence as more people become aware of the benefits it offers in terms of preserving agricultural productivity, dynamic soil nutrient status and a safe environment. Organic farming encourages the use of natural resources and organic waste, most of which is generated on-site, as well as beneficial bacteria to release nutrients into crops (2).

Among 187 nations worldwide, 72.3 million ha of land are used for organic farming. Of all farmers worldwide engaged in organic farming, 43.8% are from India (3). In India, pulses are a crucial part of organic agricultural practices. It is well known that fixing atmospheric nitrogen raises the proportion of nitrogen in the soil and contributes significantly to preserving soil fertility (4). Organic cultivation practices in pulses are feasible because nitrogen fixation demands less bulky organic nutrition sources and reduces the nitrogen requirement. Critics counter that the environmental advantages of organic farming may be undermined by the possibility that organic agriculture produces less food than conventional farming, requiring more area to produce the same amount of food. This might lead to increased deforestation and biodiversity loss (5). Understanding the variables limiting organic yields is necessary to establish organic agriculture as a crucial instrument in sustainable food supply.

The average productivity of pulses is substantially below average, with a projected yield loss of 20% when crops are cultivated organically compared to conventional farming (6). This loss can be reduced through proper seed invigoration and foliar fertilisation practices. Improving seed performance is essential for agricultural production since it has a direct impact on crop yield, crop stand establishment and overall productivity. Seed treatments and foliar fertilisation using bioactive components like Panchagavya, Jeevamrutha, Beejamrutha, fish fermented waste extract, seaweed extract, vermiwash and biofertilizers which are derived from on-farm resources or of other biological origin can be used to promote the productivity of pulse crops under organic approach (Fig. 1). These bioformulations have positive impact on growth and yield of pulse crop like greengram, blackgram (7), cowpea (8), chickpea (9) and soyabean (10) through seed treatments and foliar fertilisation.

This review aims at sustainable alternatives, including organic seed treatments and foliar nutrition in an effort to solve the problem of poor productivity in organic pulse farming. Sustainable alternatives are essential because, over time, conventional farming's dependency on chemical inputs has deteriorated the ecosystem. Bio-formulations based on natural and agricultural waste can potentially enhance soil fertility and plant health as well as increase production in organic systems. By synthesizing knowledge on formulations like Panchagavya, Jeevamrutha and Vermiwash, the article here shows ways to achieve sustainability in pulse production. In order to find relevant research for this review, we carried out an extensive literature search utilizing electronic databases such as Web of Science and Scopus. Keywords like "organic farming practices," "bio-formulations," "Panchagavya," "Jeevamrutha" and their combinations were utilized. Only peer-reviewed journal publications published between 2000 and 2024 were included in the search. Studies examining the impact of bio-formulations on plant growth and yield were among the inclusion criteria.

Organic seed treatment

Organic seed treatment involves using natural and organic methods to enhance the quality, germination and other physiological qualities of seeds without relying on synthetic chemicals or genetically modified organisms. An easy way to provide seeds with the necessary inputs for improved germination, vigour and crop growth is to prime them. Seed priming is a technique used to enhance seed germination and early seedling growth through the controlled hydration and drying of seeds. Seed biopriming involves plant growth promotion, defence-related enzymes, systemic resistance, production of biochemicals, phytoalexins and soil nutrient mobilisation (Fig. 2). Biopriming treatments in rice reduce the proline content by 2.5 fold and increase the relative water content by 89% compared to 11% in control indicating improved drought stress tolerance (11). Organic seed priming with bacterial strains makes the wheat seed resistant to high temperatures (reduced reactive oxygen species) (12) and little moisture, particularly in arid tropical climates and enhances the germination (13) and seedling vigour, which ultimately increases the yield and productivity (14). A study shows

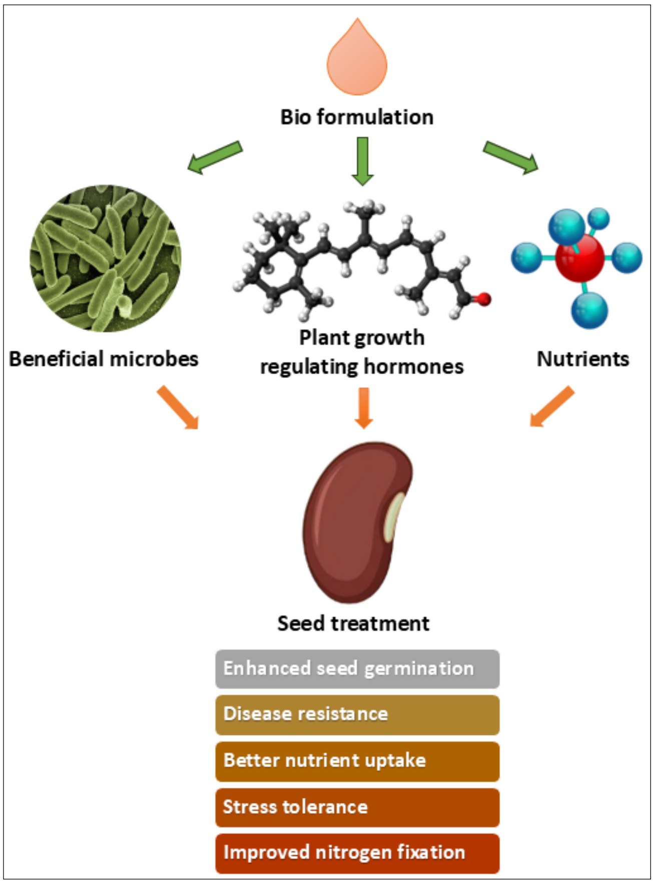

Fig. 2. Bio-formulations seed treatment and its benefits.

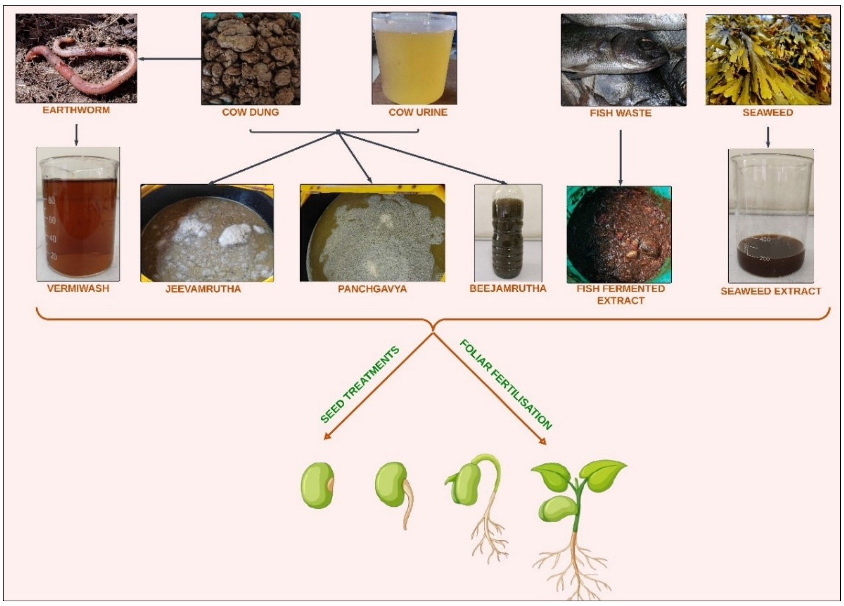

Fig. 1. Bio-formulations from waste materials and marine resources.

greengram seed bioprimed with *Rhizobium leguminosarum* atp9 20% exhibited a 16% increase in germination over control (13). Organic seed priming differs from conventional seed priming by choice of materials used, avoiding synthetic chemicals is the primary requirement in organic seed priming.

Organic foliar nutrition

Foliar spray provides supplementary nutrients, plant hormones, stimulants and other useful compounds. Foliar nutrition is crucial as it enables nutrients to quickly reach cells through the stomata or leaf cuticle (15). Foliar fertilisation has been shown to boost productivity, resistance to diseases and insect pests, drought tolerance and crop quality. Foliar fertilisation can be 8 to 20 times more effective than ground application in terms of nutrient uptake (16). Foliar feeding can boost yield by 15 - 25% compared to traditional fertilisation methods and allows plants to absorb over 90% of the applied fertiliser (17).

Foliar fertilisation allows for fast nutrient absorption, making it an effective way to give nutrients during peak demand periods and under stress when soil treatments are difficult. It provides a method of micronutrient and macronutrient intake (18), as well as flexibility in giving nutrients to increase harvest quality while reducing application costs. Spraying chelated fertiliser on leaves can minimise the quantity of fertiliser used while increasing fertiliser efficiency. Chelating compounds such as humic acid and amino acids can improve crop stress tolerance, root development and nutrient absorption (19). These humic acids and amino acids of biological origin such as vermiwash, peat and fish amino acids can be used as organic foliar sprays. Foliar fertilisation of bio inputs is an environmentally friendly and effective way to improve the yield of crops.

Bio-formulations used for organic seed treatment and foliar nutrition and its effect on pulses

Panchagavya

Panchagavya is a primary cow product when it comes to sustainable organic farming. Five items that are obtained from cows are used in the ancient organic farming approach known as "Panchagavya" in India. The word "Panchagavya" comes from the Sanskrit word "pancha," which means five and the word "gavya," which describes everything linked to cows. It consists of cow dung, cow urine, cow's milk, curd and ghee. Panchagavya is considered a holistic and sustainable approach to agriculture. Panchagavya not only enhances soil fertility but also helps in controlling pests and diseases, promoting plant growth and improving the overall health of crops. It is often used in organic farming and is gaining attention for its potential benefits in environmentally friendly and sustainable agriculture practices. Panchagavya contributes to the preservation of the ecosystem, soil and crop quality. It has also been shown that Panchagavya has no negative effects and is more affordable and environmentally friendly than chemical fertilisers (20).

Properties of Panchagavya

Panchagavya showed great potential as an organic insecticide (21) and fertiliser. Panchagavya is home to both bacteria that have biological deterrent properties (22) and bacteria that produce compounds that promote plant growth and development. Metabolomic analysis of Panchagavya indicated that they possess practically all the essential macro (N, P, K), secondary (Ca, Mg, S, Na) and micronutrients (Cu, Zn, Fe, Mn) and presence of various amino acids, vitamins, terpenoids, growth- regulators like Indole-3-acetic acid (IAA) and Gibberellic acid (GA) produced by microbes in them (23, 24). Microorganisms found in Panchagavya, including *Rhizobium, Azotobacter, Azospirillum*, Phosphorous Solubilizing Bacteria, *Trichoderma* and *Pseudomonas*, function as liquid fertilisers and biopesticides (25).

The prevalence of *Lactobacillus* and yeast, 2 types of fermentative bacteria, may result from a combination of low pH, milk products and the inclusion of jaggery or sugarcane juice as a growth substrate. The population dynamics and organic detection in the GC analysis demonstrated that the fermentative microorganism's synthesis of organic acids is the reason for the medium's low pH (26). Beyond its own growth, *Lactobacillus* generates several advantageous metabolites, including organic acids, hydrogen peroxide and antibiotics. These metabolites are efficient against other harmful microbes. The presence of compounds of fatty acids, alkanes and alcohol was found by GCMS analysis (26). In Panchagavya, cow dung serves as a growing substrate for the growth of beneficial microbes, while cow urine supplies nitrogen, which is necessary for crop growth. Isolates from Panchagavya show production of critical growth hormones such as GA_3, (27) leading to higher enzymatic activity such as dehydrogenase and alpha-amylase. GA_3 increases enzyme production for the mobilisation of reserve food in seeds.

Effect of Panchagavya on crop growth

Panchagavya is believed to increase the protoplasmic constituents and enhance the cell division and elongation process (28). Panchagavya has superior leaf nitrogen utilisation and effective photosynthetic activity, leading to increased productivity (29). Enhanced nitrate reductase and glutamate synthase enzymatic activity due to the presence of growth-promoting substance like kinetin and GA in Panchagavya contribute to greater protein content percentage in greengram (30). Panchagavya is used as a foliar spray to boost the production and quality indices of various crops. This might be because nutrients in Panchagavya are absorbed quickly through cuticles present in the leaves (31). Panchagavya spray resulted in increased soluble protein content and nitrate reductase activity leading to a higher yield (32). Applying Panchagavya foliar spray at various phases of crop growth improved photosynthetic activity and a better root system, allowing for greater nutrient uptake from soil and increased yield attributes. Table 1 summarizes the effect of Panchagavya on the growth and yield of pulses.

Beejamrutha (Seed Elixir)

Beejamrutha is made from cow dung, urine, water and lime. Cow dung (5 kg) wrapped in a cloth is immersed in a bucket with 50 L of water overnight. The final product is created by adding 5 L of cow urine, a handful of soil and 50 g of calcium chloride to the liquid. Beejamrutha provides the finest results when used on the day of preparation due to the presence of higher colony forming units (CFU) in that stage. Beejamrutha contains a variety of helpful microorganisms such nitrogen

Table 1. Effect of panchagavya on growth and yield of pulses

Crop	Mode of application	Benefits	Reference
Greengram (*Vigna radiata*)	Foliar spray (3%) at branching, pre-flowering and pod-setting stages.	Improved dry matter accumulation, physiological growth and yield attributes	(83)
		Higher protein content Percentage	(30)
Cowpea (*Vigna unguiculata* L.)	Foliar spray (7.5%) at 20, 40 and 60 days after sowing.	17% increased grain yield over control	(84)
Chickpea (*Cicer arietinum* L.)	Foliar spray (3%)	Higher seed yield, number of nodules/plants, stover yield and harvest index	(85)
Cowpea (*Vigna unguiculata* L.)	Seed priming (6%)	Higher Field emergence and yield attributes such as number of pods per plant, number of seeds per pod, seed yield per plant, biological yield per plot, Harvest index, Seed index	(14) (86)
Blackgram (*Vigna mungo*)	Seed priming (7%)	Early maturity and higher seed yield per plant and harvest index.	(87)

fixers, actinomycetes and phosphorus solubilizers (33). Beneficial microorganisms present in liquid formulations due to their constituents, including cow dung and urine, which contain essential nutrients, vitamins, amino acids, growth promoters like indole acetic acid (IAA) and gibberellic acid (GA) and beneficial microorganisms. These microorganisms not only improve the environment but also work as a catalyst to increase beneficial microbes. Soil microbes convert organic materials into energy by secreting proteins, organic acids and antioxidants. This process transforms disease-inducing soil into disease-suppressive soil (34).

Microbial isolates from Beejamrutha exhibit N2-fixation, P-solubilization, IAA, GA generation and Sclerotium suppression. These isolates produced the greatest concentrations of IAA (11.36 µg/25 mL) and GA (3.13 µg/25 mL). The Beejamrutha has various nutrients such as 0.14% nitrogen, 0.02% P_2O_5, 0.140% potassium, 355 ppm sulphur, 7550 ppm calcium, 25 ppm magnesium, 9 ppm iron, 2 ppm manganese and 15 ppm zinc which aids in better germinability of seeds (35). The beneficial effect of treating seeds with Beejamrutha has been reported in various pulse crops (Table 2).

Jeevamrutha

Jeevamrutha is also known as a biodynamic microbial consortium. Jeevamrutham consists of 2 words: Jeeva and Amrutham. Both originate from Sanskrit. "Jeeva" refers to a living entity, whereas "Amrutham" refers to a treatment for extending life. Jeevamrutha is made by mixing 10 kg of cow dung, 10 L of cow urine, 2 kg of jaggery, 2 kg of pigeon pea flour and a handful of farm soil. Mix all ingredients thoroughly in a 200 L plastic drum, then add water to get the desired amount. The mixture is mixed in a clockwise direction 3 times each day and stored in a shaded plastic drum with a wet jute bag. The 10-day fermented liquid is used to treat the seeds (36). This is a standard composition proposed by Subhash Palekar and there are various region-specific methods with modified ingredients based on their availability and needs such as enriched jeevamrutha and concentrated jeevamrutha.

Jeevamrutha provides the finest results when used on the 9th to 12th days after preparation due to the presence of higher CFU in that stage. The presence of more bacteria, fungi and N-fixers suggests that the Jeevamrutha has a diverse range of soil microorganisms. To prepare Jeevamrutha, a small amount of soil from the field is taken and added to the mixture. This would serve as the initial inoculum for bacteria, fungi, actinomycetes, N-fixers and P-solubilizers (34). The microbiological makeup of Jeevamrutha is dominated by the *phylum Firmicutes*, Bacteroidetes and Proteobacteria, as well as the genera *Lactobacillus, Streptococcus* and *Clostridium*. This shows the richness of microbial diversity in Jeevamrutha. The Jeevamrutha contains several compounds that aid in plant metabolism and growth, including isoenanthic acid, Columbianetin and Lomatin, 1, 6-Hexanediol, Mevastatin and Gitoxigenin, Dibutoxy anthracine, Erioflorin and nagilactone, Trimegestonea, Rofe Coxib and clupanodonic acid, as identified by GC-MS analysis (37). A wide range of Jeevamrutha metabolites (lactic acid, ascorbic acid, caproic acid, succinic acid, betaine, choline, stachydrine, trehalose, etc.), proteins (chaperone proteins, heat shock proteins, etc.) and exopolysaccharides have the potential to promote microbial survival and proliferation in Jeevamrutha and soil (38). Enhanced growth and yield of several pulse crops by application of Jeevamrutha (Table 2) proves its efficacy as a natural liquid fertilizer. Compared to utilizing them separately, the combined usage of Jeevamrutha and Beejamrutha in natural farming practices produced better yields (39).

In chickpeas, the foliar application of jeevamrutha at a rate of 25% prior to flowering and throughout the pod initiation phases improved growth and yield characteristics,

Table 2. Effect of Jeevamrutha and Beejamrutha on growth and yield of pulses

Crop	Product / Mode of application	Benefits	Reference
Blackgram (*Vigna mungo*)	Beejamrutha - Seed soaking (100%)	Higher seed germination and seedling vigour and increased amylase enzyme activity	(88)
Cowpea (*Vigna unguiculata* L.)	Beejamrutha - Seed soaking (100%)	Increased grain yield	(8)
Chickpea (*Cicer arietinum* L.)	Jeevamrutha - Foliar spray (25%) at pre-flowering, pod initiation stages	Higher grain and haulm yield	(9)
Blackgram (*V. mungo*)	Jeevamrutha - Foliar spray (3%) at every 10 days	Early emergence, increased total number of nodules per plant and dry matter accumulation	(40)
pigeon pea (*Cajanus cajan*)	Beejamrutha - Seed soaking (100%)	Enhanced growth parameters and higher grain yield	(89)

seed yield, maximum net returns and benefit-cost ratio. This study suggests that jeevamrutha foliar spray improved the photosynthetic ability of plants, which in turn enhanced photosynthate transfer to sinks (9). In comparison to other organics, a study conducted in blackgram reveals that Jeevamrutha foliar spray (3%) every 10 days has increased plant height and dry matter accumulation (35.41 cm and 13.51 g plant^{-1}) because it contains more nitrogen and micronutrients like Fe, Zn and Mn (40).

Fermented fish waste extract (Gunapaselam)

Fermented fish waste extract is a material obtained from the fermentation of fish waste, usually using microorganisms such as bacteria or yeast. This method breaks down the organic matter in fish waste, resulting in a liquid extract high in nutrients and bioactive substances. The goal is to utilize the enormous amount of waste generated in fish processing like stunning, grading, slime removal, deheading, washing, scaling, gutting, fin cutting, flesh bone separation and steaks and fillets (41). These waste materials should be fermented or broken down as it cannot be used as raw in agricultural activities. Fermented fish waste extract is prepared by using fish waste and jaggery. The fish guts are removed and coarsely mashed (1 kg) and 1 kg of powdered jaggery is added. Mix the 2 ingredients in a plastic bucket with a cover. Keep the lid closed and keep it aside for 15 to 20 days. This mixture is stirred often for at least 15 to 20 days to prevent undesirable smells. The fermented liquid will be obtained by filtration and used as liquid manure (36).

Fermented fish waste extract has low BOD and COD levels and is devoid of harmful bacteria. It contains proteins, amino acids like arginine, threonine, valine, isoleucine, methionine, leucine, lysine and tryptophan and essential plant elements such as nitrogen (1.49%), phosphorus (0.52%), potassium (0.48%), calcium (0.4%) and magnesium (0.28%) that can be utilised by plants for vegetative growth, fruit, flower production and disease resistance (42). Fermented fish waste extract provides nutrients which promote plant development by stimulating rhizobacteria, fixing atmospheric nitrogen and improving nutrient intake. Fermented fish waste extract enhances flavonoid release from *V. radiata* root and promotes nod D gene expression and nif H transcript levels. This leads to elevated leghaemoglobin content and enhances the nitrogen-fixing activity in legumes (43). All these properties make it suitable for use as liquid manure (Table 3). Spraying fermented fish waste extract at crucial stages of crop growth such as the flowering stage and pod formation stages improves plant height and leaf chlorophyll due to higher nutrition availability and promotes cell division and metabolic activity. Improved yield attributes might be due to the rapid absorption and assimilation of macro and micronutrients during crucial stages of mung bean crop growth (7).

Seaweed extract

Seaweed extract is a bio stimulant derived from various types of seaweed or Macroalgae and often used as a biofertilizer or plant growth stimulant and can boost crop growth, quality, stress resistance and soil health. Seaweed may be utilised in several forms, including fresh, dried, powder, granular and liquid fertiliser. Seaweeds contain minerals, organic components, plant hormones and polysaccharides like laminarin, fucoidan and alginates (44). The protein content of *Ulva lactuca* seaweed species is 11 ± 2.12% on dry weight basis. Isoleucine is the most abundant amino acid with 16.51%, followed by histidine, arginine, tyrosine, serine, aspartic acid, threonine, phenylalanine, leucine, alanine, lysine, glycine and glutamic acid (45) that are not often present in plants. Seaweed extracts function as chelates, improving soil mineral elements, nutrient absorption, soil structure and aeration leading to enhanced root development. Seaweeds can benefit plant and soil health by providing nutritional benefits (nitrogen, phosphorous, potassium, trace elements), imparting disease resistance (sulphated polysaccharides), hormonal effects (cytokinins, auxins, gibberellins) and soil conditioning (water retention, beneficial soil microbes) (46). A study shows that soaking of cowpea in aqueous extracts of *Sargassum wightii* 20% increased seedling growth parameters and biochemical parameters such as chlorophyll (1.599 mg/g of fresh weight), α-amylase (1.927 g min^{-1}mg^{-1}protein) may be due to the presence of phenylacetic acid (PAA) along with a presence of some growth promoting substances (47). Seaweed extracts can also be applied as a foliar spray to promote plant growth and yield. Foliar spray of 15% *Kappaphycus alvarezii* sprayed at 30 and 60 days after sowing at the rate of 650 L/ha spray volume in each spray recorded highest yield of 21.09 quintal/ha compared to 13.4 quintal/ha in control treatment with no spray in soyabean (10).

Effect of seaweed extract on crop growth

Seaweed extract of *Spatoglossum asperum* shows antifungal activity against the harmful plant pathogen *Macrophomina phaseolina* (48). *Sargassum wightii*, a brown seaweed, contains the sulphoglycerolipid 1-0-palmitoyl-3-0-glycerol, which is effective against *Xanthomonas oryzae* pv. oryzae, a bacterium responsible for rice bacterial blight (49). *Sargassum* extracts when used as foliar spray act as growth

Table 3. Effect of fermented fish waste extract on growth and yield of pulses

Crop	Mode of application	Benefits	Reference
Cluster bean (*Cyamopsis tetragonoloba* (L).)	Foliar spray (100 µl concentration)	Improved growth, flowering and yield. Reduction of Necrotic Lesions caused by Tobacco Necrotic Virus (TNV)	(90)
Blackgram (*Vigna mungo*)	Foliar spray (2.0%) at the time of flowering and 15 days after first spray	Improved leaf chlorophyll content, grain yield and protein content	(7)
Cowpea (*Vigna unguiculata* L.)	Seed treatment (10%)	Improved seedling growth, number of nodules and elevated proteins, amino acids, total phenolics, flavonoid and chlorophyll content	(41)
Cowpea (*Vigna unguiculata* L.)	Foliar spray (1.25%) at 30 and 48 days after planting	Improved vegetative growth characteristics and yield.	(91)

promoters leading to improved yield (50). Marine bioactive substances in seaweed extract induce water stress tolerance by maintaining a greater leaf water potential and stomatal conductance throughout the stress period resulting in a rapid recovery in rehydrated plants (51). At lower concentrations application of seaweed extract increases germination contributed by the presence of growth-promoting chemicals such as indole-3-acetic acid (IAA) and indole butyric acid (IBA), gibberellins A and B, cytokinins, minerals (Fe, Cu, Zn, Co, Mo, Mn and Ni), vitamins and amino acids (52). Blackgram seeds primed with *Turbinaria conoides* extract exhibited improved protein content, dehydrogenase activity and gibberellic acid leading to a higher vigour index (53).

Due to the presence of halogenated phenolics in the seaweed extract derived from *Durvillaea potatorum* and *Ascophyllum nodosum* effectively inhibits the development of sclerotinia blight (54). Spraying of seaweed extract at crucial stages of pigeon pea crop leads to improved yield attributes resulting from the presence of hormones like cytokinin in seaweed extract. In vegetative parts, cytokinin performs nutrient partitioning and in reproductive parts, it influences nutrient mobilization leading to higher yields (55). *Ascophyllum nodosum* extract enhanced salt tolerance in *Arabidopsis thaliana* by altering the expression of a variety of stress-responsive genes, promoting plant tolerance to salinity stress (56). T. *conoides* seaweed liquid extract contains bioactive compounds that enhance growth and germination at lower concentrations while inhibiting growth at larger concentrations due to nutrient overdose (57). Extracts of *Sargassum latifolium, Turbinaria turbinate* and *Pterocladiella capillacea* exhibit insecticidal properties and the capacity to damage the exoskeleton of insects (58, 59). These extracts can be used as potential biopesticide against destructive crop pests. *Padina durvillei* extract improves the antioxidant status of crops and acts as biostimulant (60). Table 4 summarizes the effect of seaweed extracts on the growth and yield of pulses.

Vermiwash

Vermiwash is a liquid fertiliser produced during the vermicomposting process. Vermicomposting is the utilisation of earthworms to digest organic waste items including kitchen remains, yard waste and farm waste. As the worms eat the organic waste, they generate vermiwash, a nutrient-rich liquid that collects as it drains through the composting material. The composition of vermicompost and vermiwash depends on the materials used in the vermicomposting process. Vermiwash not only provides nutritional benefits but also acts as a pest repellent (61). The use of vermiwash is more efficient than vermicompost as it is easily available to crop to utilise. The Liquid chromatography and mass spectrometry study of vermiwash revealed chemicals having pesticidal, insecticidal, antifungal and plant hormone activities and the presence of Indole-3-acetyl-L-valine, a plant hormone derivative (62) and also consists of several hormones, vitamins, proteins, mucous, enzymes and nutrients.

Vermiwash improves soil biodiversity by promoting beneficial microbes that produce growth-regulating hormones and enzymes. It also controls pathogens, nematodes and pests, leading to improved plant health and reduced yield loss (63). French bean plants treated with vermiwash during growth turn out to be more productive in terms of nutrition and growth indices. It offered abundant bioavailable macro and micronutrients to support biomass production (64). When it comes to bio-formulations, the optimum dosage is recommended for application, although vermiwash had no negative effect on the crop even at higher dosage (65). The effects of vermiwash on several pulse crops are given in Table 5.

Biofertilizers

Biofertilizers are living microorganisms that improve plant growth and soil fertility by making nutrients available to plants. Unlike chemical fertilisers, which deliver nutrients directly to plants, biofertilizers act in collaboration with the natural processes of the soil-plant system. They encourage sustainable agriculture by minimising the need for synthetic fertilisers (66), which can have severe environmental consequences. The widespread application of synthetic fertilisers has degraded the soil, contaminated water basins (67), killed microorganisms and helpful insects, making crops more susceptible to illnesses and reducing soil fertility. Biofertilizers are used in agriculture as an alternative to traditional fertilisers. Biofertilizers are living microorganisms that colonise the plant's rhizosphere and promote growth by converting nutrients like nitrogen and phosphorus into available forms through biological processes like nitrogen fixation and rock phosphate solubilization. Various kinds of biofertilizers, each with distinct beneficial microorganisms such as nitrogen-fixing bacteria, phosphorus-solubilizing bacteria, potassium-mobilizing bacteria and mycorrhizal fungi. *Rhizobium* symbiotically interacts with legume roots

Table 4. Effect of seaweed extract on growth and yield of pulses

Crop	Product / Mode of application	Benefits	Reference
Cowpea (*Vigna sinensis*)	*S. wightii* - seed soaking (20%)	Increased seedling vigour, elevated chlorophyll, protein and amino acid content	(47)
soybean (*Glycine max*)	*K. alvarezii* - Foliar spray (15%) at the 30 and 60 days after sowing.	Increased growth parameters and yield	(10)
Blackgram (*Vigna mungo*)	*K. alvarezii* - Foliar spray (10%) at 40 and 52 days after sowing *Gracilaria edulis*- Foliar spray (10%) at 40 and 52 days after sowing	Increase in 47.52% seed yield Increase in 42.5% seed yield	(92)
Redgram (*Cajanus cajan*)	*Sargassum myricocystum* - Foliar spray 5% at vegetative and flowering stages	18.3% increase in seed yield	(55)

Table 5. Effect of vermiwash on growth and yield of pulses

Crop	Mode of application	Benefits	Reference
Chickpea (*Cicer arietinum* L.)	Foliar spray (12.5%) at 30 days after sowing	Threefold increased productivity over control	(93)
Greengram (*V. radiata*)	Seed soaking (1:5)	Increased seedling vigour	(94)
Common bean (*Phaseolus vulgaris*)	Foliar spray	Biological control of mite (*T. urticae*)	(95)
Chickpea (*Cicer arietinum* L.)	Seed priming (8 h)	Early emergence, improved yield attributes	(96)
Blackgram (*Vigna mungo*)	Foliar spray (10%) at initiation of flowering and 15 days after the first spray	High yield and protein content	(97)

and fixes the atmospheric nitrogen, reducing the requirement for nitrogenous fertilizers (68). Plants may get insoluble phosphorus through phosphorous solubilising microorganisms, particularly bacteria and fungi.

Priming with biofertilizers is called biopriming, this method combines seed imbibition with biocontrol agents or Plant Growth Promoting Rhizobacteria (PGPR) seed inoculation. Bio-priming, like other priming methods, increases seed germination rates and uniformity while also protecting seeds from pathogens. Nitrogen fixers *Rhizobium*, a member of the Rhizobiaceae family, work symbiotically with legumes to fix nitrogen. It is beneficial for legumes such as chickpeas, redgram, peas, lentils and blackgram, as well as oil-seed legumes like soybean and groundnut and forage legumes like berseem and lucerne. *Rhizobium* colonises the roots of legumes, forming root nodules that produce ammonia (69). *Azospirillum*, a member of the Spirilaceae family, is both heterotrophic and associative. These plants not only fix nitrogen, but also create growth-regulating compounds (70). Phosphate-solubilizing bacteria dissolve insoluble inorganic phosphates such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite and rock phosphate. Bacterial species with potential plant growth-promoting activity include *Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter* and *Agrobacterium* (71).

Effect of biofertilizers on crop growth

The effect of *Rhizobium* in increasing crop productivity is mainly caused by improved nutrient availability through biological nitrogen fixation and the production of substances like vitamins and growth-promoting hormones in rhizosphere soil (72). *R. leguminosarum* enhanced the production of hormones like gibberellins, methylotroph mediating cytokinin and IAA in the germinating seed, activating enzymes including amylase that promote early germination and improving starch absorption in greengram and pigeon pea (13, 73). Plant needs essential major nutrients like nitrogen, phosphorous and potassium in ample amount for better growth and development, single beneficial microorganisms cannot provide all these, hence it is always advisable to use diverse organisms in combination to get better productivity. Combined inoculation of *Rhizobium* and PSB in Chickpea resulted in a greater number of nodules which leads to higher yield (74). Blackgram infused with Pink-Pigmented Facultative Methylotrophs shows improved germination and vigour (75). The combinatorial effect of a liquid or carrier-based *Rhizobium* and Phosphate solubilizing bacteria (PSB) boosted the growth and yield components of greengram due to dual inoculation increased the absorption of N and P content in plant and also enhanced the soil physiochemical characteristics, including organic carbon (0.46%), available nitrogen (285 kg/ha) and available phosphorus (46.63 kg/ha) (76). *Rhizobium* and PSB inoculation may stimulate endogenous growth regulators, release ammonia and provide phosphorous nutrients through PSB solubilization, leading to increased productivity in pea (77). *Rhizobium* inoculation in greengram improved protein content, growth and yield under high salinity levels due to improved mineral absorption, reducing the negative effects of salinity stress (78). Effects of various biofertilizers on the growth and yield of pulses are given in Table 6.

Effect of biofertilizers on biotic and abiotic stress

Hydrating pathogen-infected seeds during priming can promote microbial development and reduce plant vigour. Priming with antagonistic microorganisms is a sustainable means to combat the pathogens-infested seeds as they are shown to provide signals, which trigger the defence mechanism. Lipopolysaccharides present in antagonistic bacteria *Pseudomonas fluorescens* strain WCS417r act as an elicitor, developing resistance to certain diseases. *Trichoderma* strains have been shown to produce chitinases which aid in the breakdown of fungal pathogen cell wall and xylanases which induce the production of phytoalexins, ethylene and lipid peroxidation in pathogen. Through the creation of physical barriers at the locations where fungal penetration is attempted, *Pythium oligandrum* causes

Table 6. Effect of biofertilizers on growth and yield of pulses

Crop	Product / Mode of application	Benefits	Reference
Greengram (*Vigna radiata*)	*Rhizobium* and *P. fluorescens* - seed treatment (3%)	Increased seedling vigour and grain yield. Protection against *Macrophomina phaseolina* (damping off).	(98)
Greengram (*Vigna radiata*)	*Rhizobium* @ 4 g, *Bacillus megaterium* at 5mL/1000 mL, *Trichoderma harzianum* at 5mL/1000 mL and *Trichoderma viride* at 5mL/1000 mL - seed priming	Higher seedling vigour, seed yield and nodulation	(99)
Greengram (*Vigna radiata*)	*R. leguminosarum* - seed priming (20%)	Higher seed germination rate, seedling vigour, dehydrogenase enzyme activity and lower electrical conductivity.	(13)
Greengram (*Vigna radiata*)	Liquid based *Rhizobium* and Phosphate solubilizing bacteria - seed treatment (10 mL/kg)	Higher seed yield and protein content	(76)

resistance in plants (79, 80). Bacteria employed as biocontrol agents may persist in the rhizosphere (81) and provide support to plants after germination. Seed priming with biofertilizers and biocontrol agents protects seeds against both abiotic and biotic stress conditions. The combination of seed priming which is a physiological enhancement process and bioagents which offers protection against pathogens and PGPR which make nutrients available to growing seedling became the best substitute for chemical treatments. *Trichoderma* inoculant soaking treatment significantly increased total phenol and free proline and peroxidase enzyme activity in common bean (82).

Conclusion and future perspective

Organic farming has long-term advantages for soil health, biodiversity and ecosystem resilience, but it also has drawbacks, such as increased costs and poor yields than conventional techniques. The potential for increasing pulse crop production is highlighted in this review by bioactive organic formulations such as Panchagavya, Jeevamrutha, Beejamrutha, vermiwash, fermented fish waste extract and seaweed extract. Formulations like Panchagavya, Jeevamrutha, Beejamrutha and vermiwash are best suited for large-scale usage as it relies on farm cattle waste and availability as commercial products. By combining foliar nutrition and seed treatments, these bio-formulations offer benefits such as growth promotion, disease suppression and insecticidal action. Awareness and availability of these bioresources are crucial for their effective adoption. To assess the relative advantages of organic compared to conventional systems and to improve bio-formulation applications for best outcomes, further research is required. Organic pulse farming can be crucial to attain sustainable agriculture, reducing the negative impacts of climate change and ensuring food systems for the future by efficiently utilizing bio-resources and waste management.

Acknowledgements

Authors acknowledge the Department of Seed Science and Technology, Nammazhvar Organic Farming Research Centre and Directorate of Agribusiness Development of Tamil Nadu Agricultural University, Coimbatore for providing valuable insights, support and assistance during the writing of this review paper.

Authors' contributions

SS conceptualized the review article. HMS has written the article under the supervision of SS, with contributions from MS, KR, ES and PJ. SS and HMS edited the article. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors declare no competing or conflict of interest.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process: During the preparation of this work, the authors used QuillBot Paraphrasing Tool in order to refine the language of the contents. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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