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RESEARCH ARTICLE

Potential of organic seed priming for improved crop productivity and sustainable agricultural development

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Abstract

Climate change is a major global concern that adversely affects seedling emergence and crop development during critical growth stages. Thus, as a preventive measure and short-term strategy, seed priming is performed to boost germination and early growth of plants. Chemical seed priming has drawbacks, including high cost, selectivity and impact on target species, soil contamination and environmental pollution. Although plant genetic engineering, has advanced significantly developing resistant varieties remains a slow and unpredictable process. Technological advancements have created a path for future research on the improvement of current environment friendly seed enhancement methods with assured enhancement in seed vigour and crop productivity. Hence, organic seed priming serves as substitute due to their socioeconomic benefits and environmental safety. It represents an agro-ecological approach grounded in the principles of self-sufficiency, biodiversity, recycling and reduced dependency on chemical inputs. Soon, the organic seed priming is expected to exhibit fastest growth in the seed industry, partly due to its ease of registration with the environment regulatory agencies. Therefore, this reviews a few highlights preferred organic seed priming techniques, recent advancements and their significance in sustainable agriculture.

Keywords: biofertilizers; botanical leaf extract; organic liquid manures; priming; seed quality enhancement

Introduction

Sustainable agriculture can be promoted through organic farming techniques that incorporate biologically derived processes. These practices have gained significance in recent times due to increasing ecological degradation and pollution. Over the recent decades, the global area under organic farming has consistently expanded. Reducing the use of chemical pesticides and fertilizers in horticulture and agriculture is imperative due to environmental concerns and alternative solutions are being developed to enhance crop growth and establishment (1).

Fertilizers are used to enhance soil fertility and boost the yield of food crops (2). Utilizing commercial inorganic fertilizers is a simple, quick and reliable approach for improving crop yields (3). Over the past five to six decades, the haphazard application of inorganic fertilizers has a negative impact on the environment, natural products, crop productivity, soil fertility and agricultural quality (4).

Since only required quantity of applied fertilizers is absorbed by plants, the excessive use of inorganic fertilizers has led to serious health concerns and irreversible environmental degradation (3). Continuous use has also caused micronutrient deficiencies, altered the physicochemical properties of soil and contributed to unsustainable crop yields. In addition, the high cost of these fertilizers further discourages their use. Together with the expense of fertilizers, these limitations deter farmers from using inorganic fertilizers, encouraging them to explore more effective, low-cost and environment friendly alternative plant nutrition sources, including compost, green manure and biological inoculums (5). Thus, adding organic nutrients or growth regulators to seeds is one way to encourage plant growth and pest and disease management which will become an unavoidable practice for sustainable agriculture.

Fertilizers are essential for providing the crop with the nutrients it demands. A significant threat to sustainable agriculture is persistent nutrient deficiency. Consequently, it is imperative to reduce the use of chemical fertilizers and promote the utilization of organic fertilizers to raise yield and seed quality (6). One of the vital agricultural inputs is the use of organic manures and bio fertilizers. These inputs improve crop yield and soil fertility by facilitating the plant to absorb available nutrients (7). Moreover, the potential harm that synthetic chemicals can cause to the environment is reduced by organic inputs.

Sustainable agriculture aims to address evolving human needs while also safeguarding natural resources and improving environmental quality (8). Therefore, organic crop management techniques, which are initiated from seed treatment with organic nutrients, are a promising method of seed enhancement. Organic seed treatment is an easy, affordable and efficient method for synchronizing germination and seedling growth by enhancing seed germination and seedling vigour. It can also help plants to develop biotic and abiotic stress tolerance, which decreases their reliance on toxic chemicals such as fungicides and pesticides.

Despite the growing interest in organic nutrient sources, scientific information on their application remains limited. Considering the environmental drawbacks of inorganic fertilizers and the demonstrated benefits of organic alternatives, this review aims to highlight the key components and applications of organic fertilizers that enhance soil quality and increase crop yield.

Seed treatment

In the agricultural industry, especially in developing countries, seeds are important for long-term increases in agricultural output (9). The physical and physiological health of seeds is important for successful crop establishment and lack of quality seeds is one of the major hindrances that contribute to bridge the yield gap. Vigorous, healthy seeds emerge quickly and evenly, with quick-growing root systems and shoot systems that absorb nutrients and light respectively (10). As a result, the seedlings will be better able to withstand biotic and abiotic challenges in the field and outcompete weeds. Since all agricultural operations begin with the quality of seeds, seed treatment is a basic need in agriculture for robust plant growth and establishment. Over the past few decades, a range of seed treatment methods, both basic and advanced have been developed and tested under various conditions. Seed treatment involves applying physical, chemical, or biological compounds to improve germination, vigour, seedling growth and control pests and diseases. This includes basic dressing, coating, pelleting, hardening, seed conditioning and priming (11) (Fig. 1). Seed treatment promotes early germination and protects emerging plants from pests and disease spread through the seed (12).

Seed priming

Seed priming is one of the most significant physiological seed improvement techniques in seed production. It enhances seedling growth by initiating pre-germination metabolic processes before radicle emergence, thereby accelerating germination and improving overall plant performance (13, 14). Seed priming is the controlled hydration, which allows seeds to imbibe water but prevents radicle protrusion (15). It involves soaking the seeds in water and before the seed loses its ability to withstand desiccation, the hydration treatment is stopped and then the seeds are dried to safe moisture content (10, 16-18). It is well established that seed priming improves germination, seedling establishment, crop production and reprieve from phytochrome-induced dormancy in some crops. Although a variety of priming agents of different kinds are employed to prime seeds, the optimization and suitability of the priming agents determine the priming efficiency, which varies from crop to crop (Fig. 2).

Numerous attempts have been made to achieve ecosystem stability because intensive modern agricultural practices (heavy tillage, synthetic agrochemicals and mono-cropping) have the potential to worsen already degraded lands by accelerating the loss of organic matter, soil degradation and environmental damage. Altering seed metabolism, which is affected by the seed priming process, is an important step in improving crop growth while maintaining sustainability (19). Consequently, there is a growing need to develop advanced and environmentally friendly priming agents and technologies that can further improve germination and seedling growth across diverse crop species.

Priming memory

Primed seeds retain a 'memory' of the stress responses triggered during priming, which can be reactivated when the plant faces stress during germination or early seedling establishment (20). The stress memory, which persists even after the seeds are dried, facilitates the reprogramming of protein expression profiles upon re-imbibition. Priming is considered a pre-germination stress exposure that can leave plants with stress memory (21).

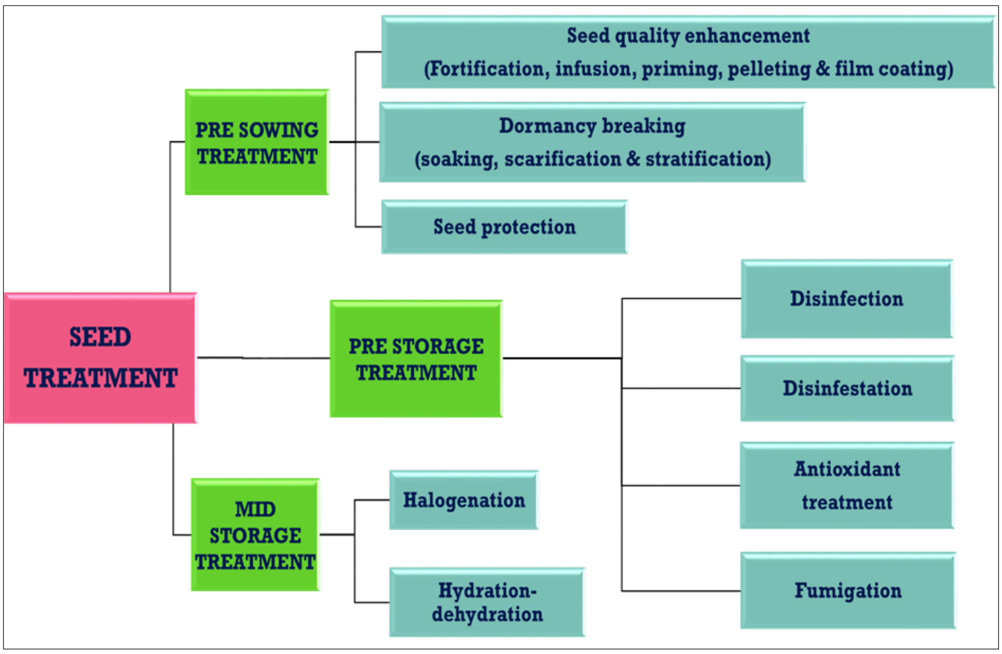

Fig. 1. Types of seed treatments.

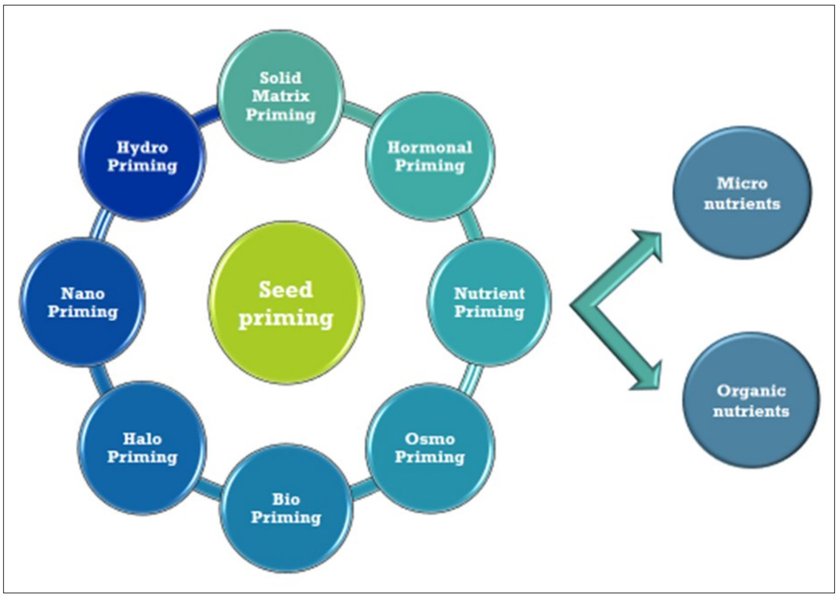

Fig. 2. Types of seed priming.

Thus, the improved stress tolerance during post priming germination may be a manifestation of 'cross-tolerance' induced by priming (22).

Prosperity of seed priming

Reduced imbibition time, metabolic reparation during imbibition, accumulation of germination-promoting metabolites, osmotic adjustment and enzyme activation all contribute to higher, faster and synchronized germination of primed seeds. The reduced lag time of imbibition is the main factor contributing to uniformity, higher rate of germination and improved seedling vigour (23).

The beneficial effects of priming are largely attributed to the metabolic changes initiated during seed imbibition. Similarly, primed seeds are rehydrated after being sown through numerous biological processes, including the synthesis of proteins and nucleic acids, the generation of ATP, the buildup of phospholipids and sterols, the activation of the antioxidant system and DNA repair (11). These processes collectively enhance germination efficiency and seedling establishment.

Seed priming with organic nutrients

Organic seed priming is a pre-sowing technique in which seeds are treated with organic amendments that increase the resistance and tolerance of seeds to environmental stress (24-27). Organic priming induces accumulation of certain organic molecules (sugars, proline and polyamines) and secondary metabolites (polyphenols and flavonoids) as a defence mechanism in plants under stress condition. It also helps to increase phosphate level, nitrogen fixation, root development, growth enhancement and disease control with increased yield. Compared to conventional fertilizer application, organic seed priming improves the benefit-to-cost (B:C) ratio, making it a more economical and sustainable approach the regular recommended dose of fertilizer, organic priming of seeds helps to improve the B:C ratio (28).

Organic seed priming emerges as a feasible and efficient strategy for enhancing nutrient management in sustainable agriculture (19, 25). An increase in the abundance of organic compounds in seeds leads to a number of photochemical changes that modify the protoplasm and increase the physiological activity of the embryo and its associated structure. Hence, seed quality enhancement in sustainable agriculture is carried out by seed treatment with organic compounds such as cow urine, cow dung, *panchagavya*, *amirthakaraisal*, vermicompost, vermiwash, biofertilizers, biocontrol agents and botanical leaf extracts (Fig. 3).

Positive aspects of organic seed priming

Seed priming with naturally occurring plant growth promoters is one of the most accessible and effective method for enhancing plant stress tolerance. It boosts germination capacity, seedling establishments and strengthens the anti-oxidant defense system to protect against oxidative damage (29) (Fig. 4). Additionally, organic seed priming increases organic matter in the soil which in turn releases plant food in the available form. It also improves physio-chemical and biological property of the soil along with increased water holding capacity and drainage.

Seed priming with liquid organic manures

The increasing recognition of the benefits of organic farming such as enhanced agricultural productivity, improved soil nutrient status and reduced environmental impact has contributed to its growing popularity in recent years. Organic liquid manure is vital for stimulating plant development and providing plant system immunity since it increases yields while using less fertilizer (30). These manures are typically prepared through the active fermentation of plant and animal waste over a period of two to three weeks (31, 32).

The purpose of seed treatment with organic liquid manures is to activate uniform emergence and establishment of vigorous plants. Eco-friendly liquid organic preparations such as *Panchagavya*, *Jeevamrutham*, *Amirthakaraisal* and *Sanjivak* are made from cow products such as urine, dung, milk, curd and ghee in addition with jaggary and legume flour. These preparations are abundant in helpful microorganisms and a variety of plant growth hormones that improve crop development, yield and quality. They also contain many macronutrients, micronutrients, vitamins and essential amino acids (33). Their application in seed priming has shown promise in enhancing early seedling vigour, disease resistance and overall crop performance in a sustainable manner.

Panchagavya: The Vedas, which specify the application of "*Panchgavya*" and "*Jeevamrutham*" in agriculture, are

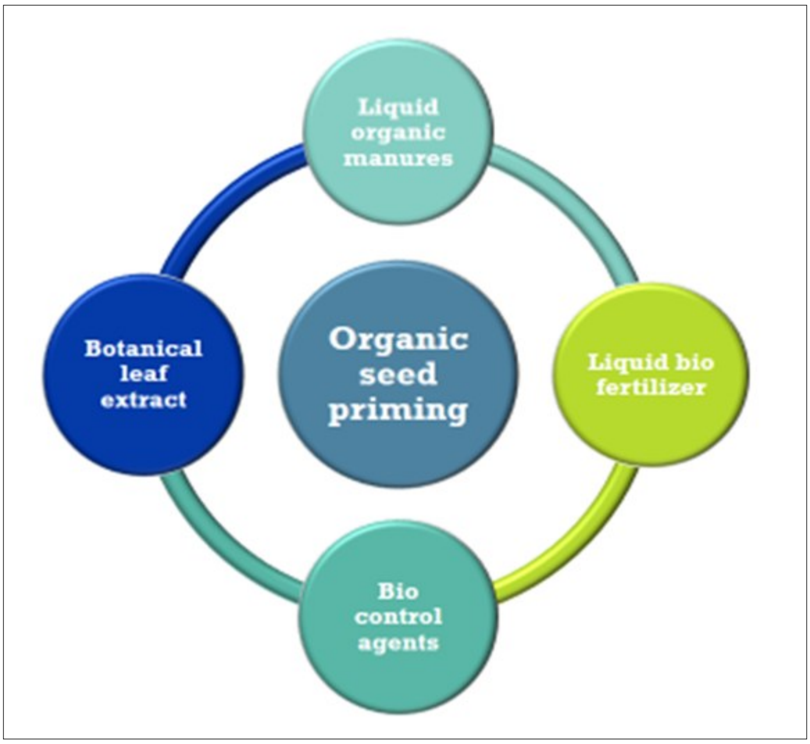

Fig. 3. Types of organic seed priming.

Fig. 4. Benefits of seed priming with organic nutrients.

examples of how organic farming was well established in India in ancient times. *Panchgavya*, as known in Sanskrit, is a combination of five products made from desi cows. Each product is called a "*Gavya*" and all together, the product is called "*Panchagavya*" (34). These components include cow dung, cow urine, milk, ghee and curd in the varied proportions 5:3:2:2:1, respectively. Additional ingredients like banana, jaggery and coconut water are incorporated to enhance the formulation, resulting in a mixture rich in moisture (~85 %) and solids (~15 %). It has qualities similar to those of a biopesticide and fertilizer (35).

Panchagavya contains nearly all its major nutrients, as well as micronutrients, microorganisms and growth hormones (IAA and GA_3), which improve plant metabolism and seed invigouration (36). A component of *panchagavya*, cow's urine contains urea, which stimulates the growth of crops. It also contains other minerals, such as sodium chloride, potassium hippurate, magnesium sulfate, uric acid and hippuric acid. Milk, another component, offers protein, fats, glucose, calcium, nitrogen, ammonia, lactic acid and *Lactobacillus*, aiding in plant nutrition and microbial activity. Furthermore, it has antibacterial properties and beneficial bacteria. Cow ghee contributes essential fatty acids, calcium and vitamins A and B, further promoting growth. Curd introduces fermentative bacteria that play a critical role in the natural fermentation process, supporting the formation of bioavailable compounds and microbial metabolites essential for plant health. *Panchagavya* also exhibits antibacterial properties and fosters beneficial microbial populations in the soil.

Panchagavya also contains saprophytic yeasts and *Pseudomonas*, which induce pathogenesis-related proteins, siderophores, antibiotics and hydrogen cyanide (HCN). These properties enable its use as a biocontrol agent, improving soil health, plant growth and overall crop yield (37). *Panchagavya* not only produces plant growth promoting substances but also produces biological deterrent activities that help to increase field emergence due to the presence of beneficial bacteria (38). It also helps in the accumulation of transcription factors or signalling proteins in an inactive state or the development of epigenetic modifications that are regulated by stress and quickly leads to the development of a more effective defence mechanism (39). Thus, *Panchagavya* acts as a multifunctional organic input offering nutritional, microbial and protective benefits, making it highly suitable for seed priming in sustainable agriculture.

Jeevamrutham: *Jeevamrutham* is a type of liquid organic manure that is rich in biomass and natural carbon. It is also a great source of macro- and micronutrients, which include calcium, phosphorus, potassium and nitrogen, needed by plants for growth and development. It also acts as a rich source of microorganisms that fix nitrogen and solubilize phosphorus. *Jeevamrutham* has been shown to be more effective than other manures and can be used in conjunction with other organic manures (40).

Typically, it appears moderately green and emits a mild foul odour that becomes stronger and darker with extended storage. The term *Jeevamrutham* derives from Sanskrit: "*Jeeva*" meaning "life" or "living organisms," and "*Amrutham*" meaning "elixir," signifying its role as a life-enhancing bio-input in organic agriculture. The individual components and their specific roles in *Panchagavya* and *Jeevamrutham* are summarized in Table 1.

Cow urine: Cow urine has historically been believed to be a notably effective biopesticide and biofertilizer in agricultural systems (48). It contains 95 % water, 2.5 % urea and 2.5 % minerals, salts, hormones and enzymes. In addition, it contains vital minerals, including potassium, uric acid, ammonia, manganese, sulphur, carbonic acid, iron, calcium, phosphorus, enzymes, cytokinin, lactose and physiologically active substances, such as growth regulators, nutrients and trace elements, which have beneficial effects on seed germination and crop growth (49, 50). Cow urine improves soil fertility and purifies the air due to its abundant supply of vital plant nutrients and its preventive and disinfecting qualities (51). Since most soils have several nutrient deficits, cow urine may be a useful tool for solving such problems. Because of its low cost of nutritional assistance, it can be used as a substitute for other techniques for plant nutrition, metabolic activation and disease and pest management (52).

Vermiwash: One possible way to reduce the negative impacts of chemical fertilizers is to replace them with organic alternatives. Vermicompost and vermiwash can be used in this manner to improve crop yield by influencing the chemical qualities of the soil, such as pH, temperature, moisture content and soil organic matter. Vermiwash shields the ecosystem from several types of chemical fertilizers. Vermiwash is a liquid extract obtained from vermiculture units that is obtained by passing water through various layers of earthworm culture units (53). It contains several enzymes; plant growth hormones, such as auxin, cytokinin and vitamins; and micro- and macronutrients, such as phosphorus, potassium and calcium, which aid in the growth of all types of plants. The enzymes and earthworm secretions (mucus of earthworms and microbes) included in vermiwash can promote crop development and yield while also helping crops sprayed with it to become resistant to pests and diseases (54, 55).

Vermiwash, a liquid biofertilizer, is used in organic farming as a supplement or alternative for solids because of its exceptional ability to supply nutrients rapidly and efficiently (56). Therefore, vermiwash can be used as a potent biofertilizer to improve the germination and seedling survival rates of crop plants growing in nutrient-depleted soils, thus paving the way for sustainable agriculture using organic farming practices.

Vermiwash represents cost-effective, environmentally friendly bioinoculants with strong potential to enhance agricultural productivity sustainably It can lessen the overuse of chemical fertilizers in the soil, which lowers the soil's fertility. Hence, liquid organic manures can be utilized in organic agriculture as an alternative to chemical-based farming. The effects of seed priming using various liquid organic manures across different crops are summarized in Table 2.

Seed priming with liquid biofertilizer and biocontrol agents

The excessive use of synthetic phosphate and nitrogen fertilizers has led to the accumulation of toxic compounds in soil and water bodies, contributing significantly to environmental degradation. Phosphorus and nitrate eutrophication is a common process that results in animal death and dense plant growth due to oxygen deprivation. Alarmingly, only 10-40 % of the applied fertilizers are absorbed by plants, with the remainder being lost to the environment. Microbial inoculation is required to control integrated nutrients for a green environment and sustainable agricultural production to address the current scenario (73).

Biofertilizers, derived from organic sources, are increasingly viewed as sustainable alternatives to conventional agrochemicals. Biofertilizer is a term used to describe biological products containing living organisms that promote plant growth and enhance the inherent fertility of soil (74). Through the release of plant growth hormones, mineralization or solubilization; the fixation of nitrogen, phosphorous and potassium; the synthesis of

Table 1. Components and their roles in *Panchagavya* and *Jeevamrutham*

S. No	Components	Role	References
1.	Cow dung*	High in organic matter, beneficial microorganisms and contains antiseptic and prophylactic properties and improves availability of nutrient and helps in disease management	(41)
2.	Cow urine*	Contains iron, urea, uric acid, oestrogen and progesterone that effect the inhibitory response to seed germination, shoot growth and seedling vigour	(42)
3.	Milk*	Promote plant growth, increases tolerance for abiotic stresses and solubilize phosphate under abiotic stress conditions	(43)
4.	Ghee*	Provides necessary nutrients for plant growth and development	(44)
5.	Curd*	Promote fermentation and help in development of beneficial bacteria	(43)
6.	Banana*	Promote fermentation and increase macro and micronutrients	(45)
7.	Jaggary*	Substrate for the growth of fermentative microorganisms	(45)
8.	Coconut water*	Promote fermentation and minimize bad odour	(45)
9.	Pulse flour**	Rich in amino acid and help in mineralization of nutrients	(46)
10.	Soil**	Contains different species of microbes and allows diversity of microbes	(47)

*Components in *Panchagavya* and *Jeevamrutham.*

**Components in *Jeevamrutham.*

Table 2. Effect of seed priming with liquid organic manures for different crops

S. No	Liquid organic manure	Crop	Effects	References
1.	*Panchagavya* @ 1 % and humic acid @ 1 %	*Glycine max*	Produced higher protein and ascorbic acid content	(57)
2.	*Panchagavya* @ 2 and 5 %	*Jatropha curcas*, *Pongamia pinnata*	Improved seed germination and seedling vigour	(58)
3.	*Panchagavya* @ 3 %	*Zea mays* L.	Higher rhizosphere microbial population with higher yield	(59)
4.	Vermiwash @ 10 %	*Phaseolus aureus*, *Hibiscus sabdariffa*	Improved germination and vigour	(56)
5.	Cow urine @ 6 %	*Gossypium* sp.	Enhanced germinability and vigour	(1)
6.	Vermiwash @ 6 %	*Cicer arietinum* L.	Improved germination and seedling vigour	(50)
7.	*Panchagavya* @ 5 %	*Daucus carota* L.	Improved seed quality due to increased beneficial microbial biomass	(38)
8.	*Panchagavya* @ 1 %	*Amaranthus* sp.	Higher concentration of biochemical constituents resulting in improved germination and seedling growth	(60)
9.	*Panchagavya* @ 3 %	*Triticum* sp., *Brassica* sp.	Better emergence and establishment	(61)
10.	*Panchagavya* @ 10 %	*Solanum lycopersicum*	Performed better with highest seedling parameters	(62)
11.	*Panchagavya* @ 3 %	*Cicer arietinum* L.	Enhances the seed performance with improved germination and vigour	(63)
12.	*Panchagavya* @ 8 %	*Capsicum annuum* L.	Higher germination due to inducement of biochemical, physiological, molecular and subcellular changes	(39)
13.	*Panchagavya* @ 4 %	*Lens culinaris*	Superior performance with respect to growth and yield	(64)
14.	*Panchagavya* @ 8 %	*Sorghum bicolor* L.	Performed better with highest seedling parameters	(65)
15.	*Panchagavya* @ 10 %	*Vigna radiate*	Increased germination and seedling growth	(66)
16.	*Panchagavya* @ 2 %	*Vigna unguiculata*	Improved field emergence and crop growth characteristics	(67)
17.	Cow urine @ 6 %	*Gossypium herbaceum*	Higher germination, maximum seedling length with increased no. of lateral roots and seedling vigor.	(68)
18.	*Jeevamrutha* @ 9 %	*Cicer arietinum* L.	Improved field emergence, crop growth and yield	(69)
19.	*Panchagavya* @ 10 %	*Cyamopsis tetragonoloba*	Improved seedling characters and yield	(70)
20.	Cow urine @ 5 %	*Daucus carota* L.	Increased germination and seedling emergence	(71)
21.	Vermiwash @ 1 %	*Abelmoschus esculentus* L.	Improved germination and vigour due to growth promoting hormones	(72)

antibiotics; and the biodegradation of organic materials in the soil, biofertilizers preserve an environment in the soil that is rich in a variety of macro- and micronutrients (75). Biofertilizers can reduce the need for chemical fertilizers by 25-50 %, making them a cost-effective and environmentally friendly input in modern agriculture (76).

Seed priming with biocontrol agents occupies growing root surfaces by forming biofilms around roots. It protects plants from soil-borne plant pathogens throughout crop growth stages through the continuous multiplication of microbes (77). Liquid biofertilizer inoculants are prepared in nutrient-rich media that maintain microbial viability and ensure long-term shelf stability. Additionally, it shields microbial cells from harsh soil conditions, including desiccation and high temperatures. Compared to that of carrier-based biofertilizers, the dose of liquid biofertilizers is ten times lower and the microorganism population can reach 109 cells per milliliter for a period of 12 to 24 months (78). When applied correctly, liquid biofertilizers improve crop yield and soil quality more than do carrier-based biofertilizers (79). Furthermore, liquid formulations eliminate the need for costly sterilization and carrier preparation steps, reducing overall production costs.

Azotobacter species perform a variety of metabolic activities since they are free-living nitrogen fixing bacteria and plant growth promoting rhizobacteria (PGPRs) (80). These bacteria enhance plant development through multiple mechanisms, including the facilitation of nutrient uptake and the activity of the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which reduces stress-induced ethylene levels in plants (74, 81). It is also able to produce vitamins such as thiamine and riboflavin in addition to plant hormones such as gibberellins (GA), cytokinins (CK) and indole acetic acid (IAA) (82).

Phosphate-solubilizing bacteria (PSB) are beneficial microorganisms that can solubilize organic substances by converting them into inorganic phosphorus compounds through the synthesis of phosphatases such as phytase. Approximately 1-50 % of the entire microbial population in soil is composed of two main phosphate-solubilizing species, *Bacillus* and *Pseudomonas* (83). Compared with untreated plants, plants inoculated with PSB significantly produced higher seed yield and stalk yield over non-inoculated in black gram. PSB form for enrichment of, non-inoculated plants inoculated with PSB had significantly greater seed yields and stalk yields. PSB enriches the rhizosphere region of crops with microbes that helps to fix natural nitrogen and helps in the elicitation of systemic resistance in plants (84).

While agrochemical inputs have contributed to increased crop productivity, their overuse has caused significant harm to ecosystems and human health (85). The excessive use of chemicals has led to serious hazards to the environment and human health and this has increased interest in the use of bioagents as a practical means of lowering the use of agrochemicals. Numerous naturally existing soil biocontrol agents have proven to have superior abilities to repel plant diseases and the use of biocontrol agents are being explored as potential substitutes for chemical pesticides for crop protection (86). Hence, the inoculation of seeds with beneficial microorganisms improves seed germination, seedling vigour, plant growth and subsequent protection against diseases and ultimately enhances crop yield (87). The effects of seed priming using liquid biofertilizers and biocontrol agents on various crops are summarized in Table 3.

Seed priming with the botanical leaf extract

Botanical seed treatment involves the use of a liquid formulation that has a synergistic effect on early and uniform seed germination and enhances tolerance to pests and diseases during the early crop stage. The use of botanicals has recently gained importance because of their considerable benefits in terms of plant growth, productivity and seed quality due to antifungal properties against seed-borne fungi (105). Priming with botanical leaf extract has stimulating effects that are associated with an improved conversion of reserve nutritional material into mobile molecules (106). Neem can be used to create cheaper, safer products that are safe for beneficial organisms because of its active compound azadirachtin, a potent insecticidal alkaloid known for repelling pests. Due to its advantageous properties, neem leaf extract is now used more often in agriculture. Other botanicals used for seed treatment include *Calotropis procera*, *Carica papaya*, *Pongamia pinnata*, *Ricinus communis*, *Moringa oleifera*, *Vitex negundo* and *Ocimum sanctum*. These extracts not only protect seedlings but also improve early plant vigour by enhancing photosynthetic efficiency, promoting nodulation in legumes and increasing water retention and nutrient availability in the root zone (107). The effects of seed priming with various botanical leaf extracts on different crops are summarized in Table 4.

Impact of organic seed priming on soil quality

The growing need for environmentally sustainable farming practices has been intensified by global economic and ecological challenges (119). The main obstacle faced by organic farmers is increasing crop yields. With the use of technological advances, a solution to this problem can also be found. Therefore, government has established a framework for research to improve the production of many different crops organically (120). It is crucial to keep in mind that any comparison must start with the real agricultural field considering the advantages of organic agricultural systems (121). The soil organic carbon and quality characteristics of the soil can be improved organically, which also mitigates the effect of climate change (122). Soil organic carbon improves soil physical structure, soil chemical properties, soil biological properties, soil organic matter, water holding capacity and cation exchange capacity (123).

Organic manures promote synergistic impact that benefits soil microbes. In the presence of organic matter, microbes secrete proteins, organic acids and antioxidants, which are then converted into energy. This microbial synergy transforms suboptimal soil conditions into an environment conducive to plant growth and development (124).

The humus content of the soil is improved by organic liquid manures, which are crucial for the rapid breakdown of organic wastes and for safeguarding the activity of microbes in the soil (125). Liquid organic manures also aid in boosting the earthworm population that helps the soil become more porous with enhanced aeration and increase its ability to hold water. It also can absorb minerals from deep soil layers (44).

Biopriming with beneficial microbes fosters a dense and active soil microbial population, leading to improved nutrient use efficiency, enhanced crop performance and increased resistance to biotic and abiotic stresses (126). Priming with botanical leaf extract enhances soil microbial activity, soil

Table 3. Effect of seed priming with liquid biofertilizer and bio-control agents for different crops

S. No	Bio fertilizer/ Bio control Agent	Crop	Effects	References
1.	*Trichoderma harzianum*	*Abelmoschus esculentus* L.	Enhanced seed germination	(88)
2.	*Azospirillum*	*Abelmoschus esculentus* L.	Higher organic seed yield	(89)
3.	*Trichoderma harzianum*	*Phaseolus vulgaris* L.	Enhanced seed germination, seedling emergence, reduced seed and soil borne pathogens	(90)
4.	*Pseudomonas fluorescens*	*Oryza sativa*	Improved seed germination and seedling vigour	(91)
5.	*Rhizobium* + *Pseudomanas*	*Cicer arietinum* L.	Synthesis of the hormones which trigger the activity of α-amylase and germination specific enzymes like protease and nuclease	(92)
6.	*Azospirillum + PPFM*	*Oryza sativa*	Increased seed germination and seedling vigour	(93)
7.	*Pseudomonas fluorescens*	*Paspalum scrobiculatum*, *Echinochloa frumentacea*, *Setaria italica*, *Panicum sumatrense* and *Panicum miliaceum* L.	Improved seed germination and vigour	(94)
8.	*Pseudomonas fluorescens*	*Panicum miliaceum* L.	Accumulation of seed constituents like proteins, carbohydrates and enzymes that contain greater metabolites for resumption of embryonic growth during germination with increased seedling vigour	(95)
9.	*Rhizobium* + *Trichoderma viride*	*Phaseolus vulgaris* L.	Improved plant growth and reduced the incidence of major diseases like Rhizoctonia root rot and angular leaf spot	(96)
10.	*Trichoderma viride*	*Abelmoschus esculentus* L.	Enhanced germination, seedling length and vigour	(97)
11.	*PPFM* either as single or co-inoculant with *Rhizobium*	*Cajanus cajan*	Better seed germination and seedling vigour	(98)
12.	*PPFM* either as single or co-inoculant with *Rhizobium*	*Vigna mungo* L.	Better microbial population during storage and showed improved germination and vigour	(99)
13.	*PPFM*	*Sorghum bicolor* L.	Enhanced seed germination and seedling vigour	(100, 101)
		Solanum lycopersicum	Enhanced seed germination, seedling vigour and maintained vigour and viability during storage	
14.	*Pseudomonas fluorecens*	*Oryza sativa*	Stimulatory effect on emergence, seedling growth and yield	(102)
15.	*Azospirillum*	*Gossypium* sp.	Improved morphological, physiological and biochemical parameters	(103)
16.	*Rhizobium*	*Vigna radiata*	High seed of germination with higher vigour and seed quality parameters	(104)

Table 4. Effect of seed priming with botanical leaf extract on different crops

S. No	Botanical Leaf Extract	Crop	Effects	References
1.	Moringa leaf extract @ 3 %	*Zea mays* L.	Chilling tolerance in maize through modulation of vigour due to hydrolytic enzyme activities, chlorophyll and carbohydrate metabolism.	(108)
2.	Moringa leaf extract	*Triticum* sp.	Enhanced seed emergence and seedling vigour	(109)
3.	Moringa leaf extract @ 5 %	*Cyamopsis tetragonoloba*	Improved germination and seedling growth and development	(110)
4.	Chlorophytum, Agel, Azadirachta and Vinca @ 2 %	*Solanum lycopersicum*	Enhanced seedling vigour and reduced mortality rate in presence of *Fusarium oxysporum*	(111)
5.	Prosopis leaf extract @ 1 %	*Vigna mungo* L.	Improved speed of emergence, germination percentage, seedling length, dry matter production and vigour	(112)
6.	Moringa leaf extract @ 3 %	*Raphanus sativus* L.	Improved total phenolic content (TPC) and radical scavenging capacity	(113)
7.	Arrapu leaf Extract @ 3 %	*Abelmoschus esculentus* L.	Improved vigour and induced plant growth promoting hormones	(110)
8.	Moringa leaf extract @ 5 %	*Sesamum indicum*	Higher seed yield and improved seed quality	(114)
9.	Noni leaf extract @ 1 %	*Zea mays* L.	Increased seedling vigour, growth and reduced lipid peroxidation	(115)
10.	Neem leaf extract @ 10 %	*Cicer arietinum* L.	Improved germination, speed of emergence and seedling establishment	(116)
11.	Moringa leaf extract at 3 %	*Oryza sativa*	Improved the speed of emergence and enhanced the growth, photosynthetic pigments and antioxidant activities	(117)
12.	Pungam leaf extract @ 1 %	*Vigna mungo* L.	Higher germination percentage, seedling length, dry matter production and vigour	(118)

nutrient availability and water use efficiency and has become more popular in sustainable agriculture (127). They also have an impact on plants at several stages of development, from enhancing the soil's nutrient accessibility to enhancing the quality of crops after harvest (128). The effects of different organic seed priming techniques on soil quality are summarized in Table 5.

Conclusion

With the growing global trend towards the production of organic food crops, organic manures produced from naturally available plant waste materials, animal products, earthworms, botanicals and biocontrol agents will supply nutrients and other soil stimulants for plant growth and production. The state of the world today clearly highlights the necessity of improving environmentally friendly agricultural techniques to achieve sustainable agriculture. Inorganic management system in agriculture has a negative effect on the health of the soil, as well as on the beneficial microbial communities and plants that grow in it. Hence, organic farming provides the best solution for ecological agriculture, which is synonymous with “sustainable agriculture”. Organic fertilizers are simple to prepare, require less money input and yield high net returns, all of which assist farmers in achieving high B:C ratio. Organic manures are environmentally nontoxic, safe and supportive of sustainability. Seed enhancement with organic manures is an effective and ecofriendly method to promote seedling vigour and establishment due to the presence of beneficial microbial populations, phytohormones and growth factors present in organic formulations. In general, seed treatment is a vital initial phase in crop raising and plays an indispensable role in sustainable crop production that cannot be disregarded. Hence, the availability of high-quality organic seeds developed through organic crop management techniques becomes more crucial for enabling farmers to use complete organic package for crop and seed production.

Authors' contributions

KD and RJ conceptualized the review. KD performed the literature search and drafted the initial manuscript. KD and SM contributed to the writing of the manuscript. JR and STK participated in the critical review and provided feedback. TSD contributed to the editing and refinement of the final manuscript. VV supervised the project and provided critical insights throughout the process. All authors have made a substantial, direct and intellectual contribution to the work and approved the final version of the manuscript.

Table 5. Effect of organic seed priming on soil quality

S. No	Organic seed priming	Crop	Effects	References
1.	*Trichoderma*	*Zea mays* L.	Antagonists multiply quickly in soil and colonize roots	(125)
2.	*Staphylococcus + Pseudomonas + Bacillus*	*Oryza sativa*, *Vigna unguiculata* ssp. *sesquipedalis*	Higher soil urease, phosphatase and dehydrogenase activity	(129)
3.	*Trichoderma*	*Helianthus annuus*	Root colonization and subsequent nutrient mobilization that increases plant nutrient absorption	(130)
4.	*Enterobacter*	*Abelmoschus esculentus* L.	Colonization of roots, solubilization of P and K and production of organic acids	(27)
5.	*Trichoderma*	*Glycine max*	Root elongation and acid phosphatase activity-mediated soil P solubilization	(131)
6.	Humic acid, vermicompost and chitosan	*Vigna unguiculata*	Increased nitrogen availability and suitable hormonal conditions for the seedling establishment	(132)
7.	Moringa leaf extract @ 30 %	*Triticum* sp.	Prominent activity of antioxidant defence system diminished the toxic-free ROS productions and boosted the seedlings tolerance to drought with suitable growing environment	(29)

Compliance with ethical standards

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

Ethical issues: None

References

1. Kumar J, Chaurasia AK, Bara BM. Effect of organic priming on germination and vigour of cotton (*Gossypium hirsutum* L.) seed. Journal of Pharmacognosy and Phytochemistry. 2017;6(3):815-9.
2. Akbar M, Aslam N, Khalil T, Akhtar S, Siddiqi EH, Iqbal MS. Effects of seed priming with plant growth-promoting rhizobacteria on wheat yield and soil properties under contrasting soils. Journal of Plant Nutrition. 2019;42(17):2080-91. https://doi.org/10.1080/01904167.2019.1655041
3. Gupta S, Kaushal R, Spehia RS, Pathania SS, Sharma V. Productivity of capsicum influenced by conjoint application of isolated indigenous PGPR and chemical fertilizers. Journal of Plant Nutrition. 2017;40(7):921-7. https://doi.org/10.1080/01904167.2015.1093139
4. Chandra MS, Naresh RK, Lavanya N, Varsha N, Chand SW, Chandana P, et al. Production and potential of ancient liquid organics panchagavya and kunapajala to improve soil health and crop productivity: a review. Journal of Pharmacognosy and Phytochemistry. 2019;8(6):702-13.
5. Abbas G, Khattak JZK, Mir A, Ishaque M, Hussain M, Wahedi HM, et al. Effect of organic manures with recommended dose of NPK on the performance of wheat (*Triticum aestivum* L.). Journal of Animal and Plant Sciences. 2012;22(3):683-7.
6. Smriti S, Ram RB. Effect of organic, inorganic and bio fertilizers on growth, seed yield and quality traits of okra [*Abelmoschus esculentus* (L.) Moench]. International Journal of Current Microbiology and Applied Sciences. 2018;7(4):2388-92. https://doi.org/10.20546/ijcmas.2018.704.274
7. Sharma KK, Singh US, Sharma P, Kumar A, Sharma L. Seed treatments for sustainable agriculture: a review. Journal of Applied and Natural Science. 2015;7(1):521-39. https://doi.org/10.31018/jans.v7i1.641
8. Panda D, Pramanik K, Nayak BR. Use of seaweed extracts as plant growth regulators for sustainable agriculture. International Journal of Bioresource and Stress Management. 2012;3(3):404-11.
9. Tyagi V. India's agriculture: challenges for growth and development in present scenario. International Journal of Physical and Social Sciences. 2012;2(5):116-28.
10. Mahakham W, Sarmah AK, Maensir S, Theerakulpisut P. Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles. Scientific Reports. 2017;7(1):8263. https://doi.org/10.1038/s41598-017-08669-5
11. Panda D, Mondal S. Seed enhancement for sustainable agriculture: an overview of recent trends. Plant Archives. 2020;20 (1):2320-32.
12. Pandiyan M, Sivakumar P, Krishnaveni A, Sivakumar C, Radhakrishnan V, Vaithiyalingam M, et al. Adzuki bean. In: The beans and the peas. Cambridge: Woodhead Publishing; 2021. p. 89-103. https://doi.org/10.1016/B978-0-12-821450-3.00006-8
13. Taylor AG, Allen PS, Bennett MA, Bradford KJ, Burris JS, Misra MK. Seed enhancements. Seed Science Research. 1998;8(2):245-56. https://doi.org/10.1017/S0960258500004141
14. Dawood MG. Stimulating plant tolerance against abiotic stress through seed priming. In: Advances in seed priming. Singapore: Springer; 2018. p. 147-83. https://doi.org/10.1007/978-981-13-0032-5_10
15. Heydecker W, Gibbins B. The 'priming' of seeds. Acta Horticulturae. 1978;83:213-5. https://doi.org/10.17660/ActaHortic.1978.83.29
16. Paparella S, Araujo SS, Rossi G, Wijayasinghe M, Carbonera D, Balestrazzi A. Seed priming: state of the art and new perspectives. Plant Cell Reports. 2015;34:1281-93. https://doi.org/10.1007/s00299-015-1784-y
17. Ibrahim EA. Seed priming to alleviate salinity stress in germinating seeds. Journal of Plant Physiology. 2016;192:38-46. https://doi.org/10.1016/j.jplph.2015.12.011
18. Bose B, Kumar M, Singhal RK, Mondal S. Impact of seed priming on the modulation of physico-chemical and molecular processes during germination, growth and development of crops. In: Rakshit A, Singh HB, editors. Advances in seed priming. Singapore: Springer; 2018. p. 23-40. https://doi.org/10.1007/978-981-13-0032-5_2
19. Devika OS, Singh S, Sarkar D, Prabhakar Barnwal P, Suman J, Rakshit A. Seed priming: a potential supplement in integrated resource management under fragile intensive ecosystems. Frontiers in Sustainable Food Systems. 2021;5:654001. https://doi.org/10.3389/fsufs.2021.654001
20. Marthandan V, Geetha R, Kumutha K, Renganathan VG, Karthikeyan A, Ramalingam J. Seed priming: a feasible strategy to enhance drought tolerance in crop plants. International Journal of Molecular Sciences. 2020;21(21):8258. https://doi.org/10.3390/ijms21218258
21. Bruce TJ, Matthes MC, Napier JA, Pickett JA. Stressful "memories" of plants: evidence and possible mechanisms. Plant Science. 2007;173(6):603-8. https://doi.org/10.1016/j.plantsci.2007.09.002
22. da Silva PB, Vaz TAA, Acencio ML, Bovolenta LA, Hilhorst HWM, da Silva EAA. Can osmopriming induce cross-tolerance for abiotic stresses in *Solanum paniculatum* L. seeds? A transcriptome analysis point of view. Seeds. 2023;2(4):382-93. https://doi.org/10.3390/seeds2040029
23. Araujo SS, Paparella S, Dondi D, Bentivoglio A, Carbonera D, Balestrazzi A. Physical methods for seed invigoration: advantages and challenges in seed technology. Frontiers in Plant Science. 2016;7:646. https://doi.org/10.3389/fpls.2016.00646
24. Singh P, Singh J, Ray S, Rajput RS, Vaishnav A, Singh RK, et al. Seed biopriming with antagonistic microbes and ascorbic acid induce resistance in tomato against Fusarium wilt. Microbiological Research. 2020;237:126482. https://doi.org/10.1016/j.micres.2020.126482
25. Sarkar D, Singh S, Parihar M, Rakshit A. Seed bio-priming with microbial inoculants: a tailored approach towards improved crop performance, nutritional security and agricultural sustainability for smallholder farmers. Current Research in Environmental Sustainability. 2021;3:100093. https://doi.org/10.1016/j.crsust.2021.100093
26. Piri R, Moradi A, Balouchi H, Salehi A. Improvement of cumin (*Cuminum cyminum*) seed performance under drought stress by seed coating and biopriming. Scientia Horticulturae. 2019;257:108667. https://doi.org/10.1016/j.scienta.2019.108667
27. Roslan MA, Zulkifli NN, Sobri ZM, Zuan ATK, Cheak SC, Rahman NAA. Seed biopriming with P- and K-solubilizing *Enterobacter hormaechei* sp. improves the early vegetative growth and the P and K uptake of okra (*Abelmoschus esculentus*) seedling. PLoS One. 2020;15(7):e0232860. https://doi.org/10.1371/journal.pone.0232860
28. Devika OS, Rakshit A. Economic appraisal of bio-priming mediated stress moderation in crop plants. Economic Affairs. 2019;64(3):563-9. https://doi.org/10.30954/0424-2513.3.2019.12
29. Nawaz H, Rehman HU, Ihsan MZ, Rizwan MS, Hussain N, Ali B, et al. Organic seed priming with curtailed seed rate compensated wheat grains productivity by upgrading antioxidant status against terminal drought at flowering and milking. Scientific Reports. 2024;14(1):4941. https://doi.org/10.1038/s41598-024-54767-6

30. Natarajan K. Panchagavya for plant. In: Proceedings of the National Conference Glory of Gomatha. Tirupati: Sri Venkateswara Veterinary University; 2007. p. 72-5.

31. FAO. Preparation and use of compost. Technical Centre for Agricultural and Rural Cooperation (CTA); 2006. p. 1-12.

32. Sreenivasa MN, Nagaraj N, Bhat SN. Organic liquid manures: source for beneficial microorganisms and plant nutrients. Organic Farming Newsletter. 2010;6(4):11-3.

33. Somasundaran. Response of green gram to varied concentrations of Panchagavya (organic nutrition) foliar application. Madras Agricultural Journal. 2003;90:169-72.

34. Naresh RK, Shukla AK, Kumar M, Arvind Kumar, Gupta RK, Vivek, et al. Cowpathy and Vedic Krishi to empower food and nutritional security and improve soil health: a review. Journal of Pharmacognosy and Phytochemistry. 2018;7(1):560-75.

35. Sireesha O. Effect of plant products, panchagavya and bio-control agents on rice blast disease of paddy and yield parameters. International Journal of Research in Biological Sciences. 2013;3:48-50.

36. Saritha M, Vijayakumari B, Hiranmai YR, Kandari LS. Influence of selected organic manures on the seed germination and seedling growth of cluster bean (*Cyamopsis tetragonoloba* (L.) Taub). Science, Technology and Arts Research Journal. 2013;2(2):16-21.

37. Xu HL. Effects of a microbial inoculant and organic fertilizers on the growth, photosynthesis and yield of sweet corn. Journal of Crop Production. 2001;3(1):183-214. https://doi.org/10.1300/J144v03n01_16

38. Sowmeya TV, Macha SI, Vasudevan SN, Shakuntala NM, Ramesh G. Influence of priming on seed quality of fresh and old seed lots of carrot (*Daucus carota* L.). Journal of Pharmacognosy and Phytochemistry. 2018;7(1):1114-7.

39. Kumar A, Chaurasia AK, Marmat SM. Effect of organic and inorganic seed priming on seed quality parameter in chilli (*Capsicum annuum* L.) seeds. Biological Forum – An International Journal. 2021;13(3):200-5.

40. Gopal V, Gurusiddappa LH. Influence of Jeevamrutha (fermented liquid manure) on growth and yield parameters of tomato (*Solanum lycopersicum* L.). World Journal of Environmental Biosciences. 2022;11:1-7. https://doi.org/10.51847/WFD516GS8o

41. Ram AAM. Panchagavya is a bio-fertilizer in organic farming. International Journal of Advances in Scientific Research. 2017;2(5):54-7.

42. Pal S, Sharma TR, Nagar OP. Effect of cow urine and plant growth promoting rhizobacteria (PGPR) on seed germination, growth and survival of karonda (*Carissa carandas* L.) seedlings. International Journal of Current Microbiology and Applied Sciences. 2019;8(11):1967-78. https://doi.org/10.20546/ijcmas.2019.811.230

43. Dhama K, Rathore R, Chauhan RS, Simmi T. Panchgavya (cowpathy): an overview. International Journal of Cow Science. 2005;1(1):1-15.

44. Maity P, Rijal R, Kumar A. Application of liquid manures on growth of various crops: a review. International Journal of Current Microbiology and Applied Sciences. 2020;11:1601-11.

45. Food and Agricultural Organization of United Nations. Zero budget natural farming. Agro-ecology knowledge hub; 2016.

46. Boye J, Zare F, Pletch A. Pulse proteins: processing, characterization, functional properties and applications in food and feed. Food Research International. 2010;43(2):414-31. https://doi.org/10.1016/j.foodres.2009.09.003

47. Palekar S. Text book on shoonya bandovalada naisargika krushi. Bangalore: Agri Prakashana; 2006. p. 67.

48. Singh A, Rawat D, Gautam R, Yadav S. Effect of seed bio-priming with cold tolerant Pseudomonas fluorescens and soil application of cow urine on germination, growth and nutrient uptake in pea. Journal of Agriculture, Biology and Applied Statistics. 2023;2(1):1-9. https://doi.org/10.47509/JABAS.2023.v02i01.01

49. Sadhukhan R, Bohra JS, Choudhury S. Effect of fertility levels and cow urine foliar spray on growth and yield of wheat. International Journal of Current Microbiology and Applied Sciences. 2018;7(3):907-12.

50. Tiwari S, Chaurasia AK, Nithyananda N, Bara BM. Effect of organic priming on seed germination behaviour and vigour of chickpea (*Cicer arietinum* L.). Journal of Pharmacognosy and Phytochemistry. 2018;7(4):1064-7.

51. Pathak RK, Ram RA. Bio-enhancers: a potential tool to improve soil fertility, plant health in organic production of horticultural crops. Progressive Horticulture. 2013;45(2):237-54.

52. Choudhary S, Kushwaha M, Seema, Singh P, Sodani, Kumar S. Cow urine: a boon for sustainable agriculture. International Journal of Current Microbiology and Applied Sciences. 2017;6(2):1824-9. http://doi.org/10.20546/ijcmas.2017.602.205

53. Bharadwaj M, Lakhawat SS, Upadhaya B, Pilania S, Jain D, Bunker RN. Effect of organic liquid manures on vegetative growth and yield of pea (*Pisum sativum* L.). Journal of Pharmaceutical Innovation. 2021;10(9):1360-4.

54. Sivasubramanian K, Ganeshkumar M. Influence of vermiwash on the biological productivity of marigold. Madras Agricultural Journal. 2004;91(4-6):221-5. https://doi.org/10.29321/MAJ.10.A00095

55. Rai N, Bansiwal. Vermiwash: an excellent source of nutrition for plant growth. Electronic Journal of Environmental Sciences. 2008;1:19-21.

56. Mujeera F, Malathy S. Studies on growth promoting effects of vermiwash on the germination of vegetable crops. International Journal of Current Microbiology and Applied Sciences. 2014;3(6):564-70.

57. Vijaykumari B, Hiranmai YR, Gowri P, Kandari LS. Effect of Panchagavya, humic acid and micro herbal fertilizer on yield and postharvest soil of soya bean (*Glycine max* L.). Asian Journal of Plant Sciences. 2012;11(2):83-6. https://doi.org/10.3923/ajps.2012.83.86

58. Srimathi P, Mariappan N, Sundaramoorthy L, Paramathma M. Efficacy of Panchagavya on seed invigoration of biofuel crops. Scientific Research and Essays. 2013;8(41):2031-7. https://doi.org/10.5897/SRE2013.5629

59. Shubha S, Devakumar N, Rao GGE, Gowda SB. Effect of seed treatment, Panchagavya application, growth and yield of maize. Proceedings of the 4th ISOFAR Scientific Conference. 2014;2:631-4. https://doi.org/10.3220/REP_20_1_2014

60. Kala BK, Eswari REA. Effect of Panchagavya on seed germination, seedling growth and nutrient content of some leafy vegetables. International Journal of Scientific Research in Biological Sciences. 2019;6(6):56-60.

61. Jadhav S, Singh S, Gupte A. Effect of seed priming and direct soil application of agro-organic waste formulations on growth of *Triticum aestivum* and *Brassica nigra*. Journal of Advanced Scientific Research. 2021;51-8.

62. Marmat SM, Chaurasia AK, Singh V, Kumar A. Impact of halo-priming and Panchagavya on seed quality parameters in tomato (*Solanum lycopersicum* L.) seeds. The Pharma Innovation Journal. 2021;10(10):87-90.

63. Vaishnavi D, Chaurasia AK, Kerketta A, Jyothi M, Navya V. Effects of Panchagavya, Beejamrutha, botanical seed treatment on seed quality parameters in chickpea (*Cicer arietinum* L.). The Asian Journal of Microbiology, Biotechnology & Environmental Sciences. 2021;23(4):573-7.

64. Ramesh AS, Rai PK, Nagar S. Influence of chemicals, botanicals and growth regulator treatments on plant growth and yield attributing traits of lentil (*Lens culinaris* L.) variety: K-75.

International Journal of Plant & Soil Science. 2021;33(19):124-9. https://doi.org/10.9734/ijpss/2021/v33i1930608

65. Deepak PD, Chaurasia AK, Dawson J, Kumar A. Effect of salinity and efficacy of Panchagavya on seed quality parameters in sorghum (*Sorghum bicolor*). The Pharma Innovation Journal. 2021;10(9):2002-7.

66. Vaithiyanathan T, Priyadharshini P, Santhi K. Influence of Panchagavya on seed germination of *Vigna radiata* L. Journal of Emerging Technologies and Innovative Research. 2022;9(8).

67. Devaraj G, Rai PK. Standardization of selected organic seed priming treatment on growth, yield and yield attributing traits of cow pea (*Vigna unguiculata* L.) var. C-152. Frontiers in Crop Improvement. 2022;10(3):1255-9.

68. Kumar RK, Thirukumaran K, Karthikeyan R, Latha MR. Effect of seed priming with various organic and inorganic compounds on cotton seed germination and seedling development. International Journal of Plant & Soil Science. 2022;34(22):1-10. https://doi.org/10.9734/ijpss/2022/v34i2231344

69. Raju GV, Bara BM, Rai PK. Pre-sowing seed treatments with Panchagavya, Jeevamrutha and Beejamrutha on growth, yield and yield attributing traits in chickpea (*Cicer arietinum* L.) variety-RVG202. International Journal of Plant & Soil Science. 2022;34(22):1183-7. https://doi.org/10.9734/ijpss/2022/v34i2231483

70. Sravani P, Dayal A, Rai PK, Sahi VP. Influence of pre-sowing seed treatments with botanical and organics on yield attributing traits and seedling parameters of cluster bean (*Cyamopsis tetragonoloba* L.) variety: RGC1066. International Journal of Environment and Climate Change. 2023;13(11):1123-35. https://doi.org/10.9734/ijecc/2023/v13i113262

71. Devi KB, Rawat M, Kaur T. Effect of seed priming on the seed quality of carrot (*Daucus carota* L.). The Pharma Innovation Journal. 2023;12(8):569-73.

72. Geetharani P, Devi ES, Famitha S, Gowshika R, Velmurugan T, Vignesh M, et al. Impact of organic seed priming amendments and botanicals on seed quality parameters of bhendi. The Pharma Innovation Journal. 2023;12(12):1920-4.

73. Nhu NTH, Chuen NL, Riddech N. The effects of bio-fertilizer and liquid organic fertilizer on the growth of vegetables in the pot experiment. Chiang Mai Journal of Science. 2018;45(3):1257-73.

74. Kumawat H, Singh DP, Choudhary R, Singh PB. Effect of fertility levels and liquid biofertilizers on growth and yield of wheat (*Triticum aestivum* L.). The Pharma Innovation Journal. 2021;10(9):1365-9.

75. Sinha RK, Valani D, Chauhan K, Agarwal S. Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. International Journal of Agricultural Health Safety. 2014;1:50-64.

76. Rana A, Joshi M, Prasanna R, Shivay YS, Nain L. Biofortification of wheat through inoculation of plant growth promoting Rhizobacteria and Cyanobacteria. European Journal of Soil Biology. 2012;50:118-26. https://doi.org/10.1016/j.ejsobi.2012.01.005

77. Chakraborty T, Akhtar N. Biofertilizers: characteristic features and applications. Biofertilizers: Study and Impact. 2021;429-89. https://doi.org/10.1002/9781119724995.ch15

78. Kataria A, Sharma J, Jhamaria C. A review on biofertilizers with special reference to liquid biofertilizers. Indian Journal of Natural Sciences. 2022;13(73):45527-37.

79. Verma NP, Kuldeep YK, Yadav N. Study of liquid biofertilizers as an innovative agronomic input for sustainable agriculture. International Journal of Pure and Applied Bioscience. 2018;6(1):190-4.

80. Sahoo R, Mohanty S, Dangar TK. Field evaluation of native *Azotobacter* and *Azospirillum* spp. formulations for rice productivity in laterite soil. ORYZA-An International Journal on Rice. 2013;50(1):65-9.

81. Joseph B, Patra RR, Lawrence R. Characterization of plant growth promoting rhizobacteria associated with chickpea (*Cicer arietinum* L.). International Journal of Plant Production. 2007;1:141-52.

82. Bhardwaj D, Ansari MW, Sahoo RK, Tuteja N. Biofertilizers function as key players in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. Microbial Cell Factories. 2014;13(1):1-10. https://doi.org/10.1186/1475-2859-13-66

83. Kalayu G. Phosphate solubilizing microorganisms: promising approach as biofertilizers. International Journal of Agronomy. 2019;2019:4917256. https://doi.org/10.1155/2019/4917256

84. Patel HR, Patel HF, Maheriya VD, Dodia IN. Response of Kharif greengram (*Vigna radiata* L. Wilczek) to sulphur and phosphorus fertilization with and without biofertilizer application. The Bioscan. 2013;8(1):149-52.

85. Oerke EC. Crop losses to pests. The Journal of Agricultural Science. 2006;144(1):31-43. https://doi.org/10.1017/S0021859605005708

86. Correa OS, Soria MA. Potential of *Bacilli* for biocontrol and its exploitation in sustainable agriculture. In: Plant growth and health promoting bacteria. Berlin, Heidelberg: Springer; 2010. p. 197-209. https://doi.org/10.1007/978-3-642-13612-2_8

87. Chauhan R, Patel PR. Evaluation of seed biopriming against chilli (*Capsicum frutescence* L.) cv. GVC 111 *in vitro*. Journal of Pharmacognosy and Phytochemistry. 2017;6(6):17-9.

88. Mukhtar I. Influence of *Trichoderma* species on seed germination in okra. Mycopath. 2008;6(1&2):47-50.

89. Karthika C, Vanangamudi K, Nagendran K. Influence of seed biopriming and organic manure nutrition on okra organic seed production. Advance Research Journal of Crop Improvement. 2016;7(1):1-9. https://doi.org/10.15740/HAS/ARJCI/7.1/1-9

90. Monalisa SP, Beura JK, Tarai RK, Naik M. Seed quality enhancement through biopriming in common bean (*Phaseolus vulgaris* L.). Journal of Applied and Natural Science. 2017;9(3):1740-3. https://doi.org/10.31018/jans.v9i3.1431

91. Somasundaram G, Bhaskaran M. Effect of seed priming on germination and vigour in low and high longevity rice genotypes. International Journal of Agricultural Science and Research. 2017;7(2):373-80.

92. Vishwas S, Chaurasia AK, Bara BM, Debnath A, Parihar NN, Brunda K, et al. Effect of priming on germination and seedling establishment of chickpea (*Cicer arietinum* L.) seeds. Journal of Pharmacognosy and Phytochemistry. 2017;6(4):72-4.

93. Raja K, Anandham R, Sivasubramaniam K. Co-inoculation of liquid microbial cultures and compatibility with chemicals for improvement of seed germination and vigour in paddy. International Journal of Current Microbiology and Applied Sciences. 2018;7(1):2077-85. https://doi.org/10.20546/ijcmas.2018.701.250

94. Balaji DS, Narayana GS. Effect of various bio-priming seed enhancement treatments on seed quality in certain minor millets. Plant Archives. 2019;19(1):1727-32.

95. Tejaswini U, Prashant SM, Shakuntala NM, et al. Investigation on maximization of seed quality and through integrated approach in prosomillet (*Panicum miliaceum* L.). International Journal of Current Microbiology and Applied Sciences. 2019;8(9):161-8. https://doi.org/10.20546/ijcmas.2019.809.021

96. Negi S, Bharat NK, Kumar M. Effect of seed biopriming with indigenous PGPR, *Rhizobia* and *Trichoderma* sp. on growth, seed yield and incidence of diseases in French bean (*Phaseolus vulgaris* L.). Legume Research-An International Journal. 2019;44(5):593-601. https://doi.org/10.18805/LR-4135

97. Rai AK, Das H, Basu AK. Seed quality of okra produced after bio-priming. International Journal of Current Microbiology and

Applied Sciences. 2019;8:2166-73. https://doi.org/10.20546/ijcmas.2019.806.257

98. Raja K, Anandham R, Sivasubramaniam K. Infusing microbial consortia for enhancing seed germination and vigour in pigeonpea (*Cajanus cajan* L.) Mill sp. Current Science. 2019;117(12):2052-8.

99. Raja K, Sivasubramaniam K, Anandham R. Seed infusion with liquid microbial consortia for improving germination and vigour in blackgram [*Vigna mungo* (L.) Hepper]. Legume Research-An International Journal. 2019;42(3):334-40. https://doi.org/10.18805/LR-3948

100. Raja K, Anandham R, Sivasubramaniam K. Seed and seedling vigour improvement through seed infusion with liquid microbial consortia in sorghum, *Sorghum bicolor* (L.) Moench. Research on Crops. 2019;20(3):652-60. https://doi.org/10.31830/2348-7542.2019.096

101. Raja K, Sivasubramaniam K, Anandham R. Seed treatment with liquid microbial consortia for germination and vigour improvement in tomato (*Solanum lycopersicum* L.). Journal of Applied Horticulture. 2019;21(3):195-200. https://doi.org/10.37855/jah.2019.v21i03.33

102. Tomer A, Singh R, Prasad D, Singh SK. Influence of seed biopriming with different isolates of *Pseudomonas fluorescens* on the growth of paddy. Journal of Biopesticides. 2020;13(2):103-9. https://doi.org/10.57182/jbiopestic.13.2.103-109

103. Ragadevi K, Jeyakumar P, Djanaguiraman M, Kalaiselvi T. Seed biopriming improved growth and morpho-physiological traits in early vegetative phase of compact cotton. Biological Forum – An International Journal. 2021;13(4):1082-8.

104. Sajjan AS, Waddinakatti S, Jolli RB, Goudar GD. *In vitro* investigation of biopriming on seed quality parameters in green gram [*Vigna radiata* (L.)]. Legume Research-An International Journal. 2021;44(1):98-100. https://doi.org/10.18805/LR-4071

105. Girase IP, Rai PK, Bara BM, Singh BA. Effect of plant extracts on seed germination behaviour and vigour of okra [*Abelmoschus esculentus* (L.) Moench]. International Journal of Current Microbiology and Applied Sciences. 2019;8:830-5. https://doi.org/10.20546/ijcmas.2019.808.095

106. Renugadevi J, Natarajan N, Srimathi P. Efficacy of botanicals in improving the seeds and seedling quality characteristics of cluster bean. Legume Research-An International Journal. 2008;31(3):164-8.

107. Vijayan R, Bastine D, Palathingal VF. Efficacy of botanicals on seed quality enhancement in cowpea [*Vigna unguiculata* (L.) Walp.] on yield and yield attributes. International Journal of Plant & Soil Science. 2023;35(23):41-9. https://doi.org/10.9734/ijpss/2023/v35i234214

108. Afzal I, Hussain B, Basra SMA, Rehman H. Priming with moringa leaf extract reduces imbibitional chilling injury in spring maize. Seed Science and Technology. 2012;40(2):271-6. https://doi.org/10.15258/sst.2012.40.2.13

109. Yasmeen A, Basra S, Ahmed M, Wahid A, Nouman W, Rehman HU. Exploring the potential of *Moringa oleifera* leaf extract (MLE) as a seed priming agent in improving wheat performance. Turkish Journal of Botany. 2013;37(3):512-20. https://doi.org/10.3906/bot-1205-19

110. Iqbal MA. Cluster bean (*Cyamopsis tetragonoloba* L.) germination and seedling growth as influenced by seed invigoration techniques. American-Eurasian Journal of Agricultural and Environmental Sciences. 2015;15(2):197-204. https://doi.org/10.5829/idosi.aejaes.2015.15.2.12506

111. Prabha D, Negi S, Kumari P, Negi YK, Chauhan JS. Effect of seed priming with some plant leaf extract on seedling growth characteristics and root rot disease in tomato. International Journal of Agriculture System. 2016;4(1):46-51. https://doi.org/10.20956/ijas.v4i1.240

112. Gunasekar J, Kamaraj A, Padmavathi S. Effect of botanical seed priming on seed quality characters in blackgram [*Vigna mungo* (L.) Hepper] cv. CO6. Plant Archives. 2017;17(2):1383-7.

113. Ashraf R, Sultana B, Riaz S, Mushtaq M, Iqbal M, Nazir A, et al. Fortification of phenolics, antioxidant activities and biochemical attributes of radish root by plant leaf extract seed priming. Biocatalysis and Agricultural Biotechnology. 2018;16:115-20. https://doi.org/10.1016/j.bcab.2018.07.012

114. Prakash M, Narayanan GS, Anandan R, Sunil Kumar B. Effect of organic seed treatment and foliar spray on growth, yield and resultant seed quality in sesame (*Sesamum indicum* L.). The Indian Society of Oilseeds Research. 2019;36(1).

115. Muthuselvan K, Subbaiyan M. Organic seed priming and foliar nutrition with medicinal herbs to enhance seedling vigour and yield potential in maize (*Zea mays* L.). Journal of Pharmacognosy and Phytochemistry. 2019;8(2):693-8.

116. Srikanth K, Chaurasia AK. Influence of botanicals, coconut water and PGPR treatments on plant growth, nodulation, yield and seed quality parameters of chickpea (*Cicer arietinum* L.). The Pharma Innovation Journal. 2021;10(12):2799-802.

117. Khan S, Ibrar D, Bashir S, Rashid N, Hasnain Z, Nawaz M, et al. Application of moringa leaf extract as a seed priming agent enhances growth and physiological attributes of rice seedlings cultivated under water deficit regime. Plants. 2022;11(3):261. https://doi.org/10.3390/plants11030261

118. Vadivel TS, Sala M. Effect of pre-sowing seed treatments using botanical leaf extract on growth characters in blackgram (*Vigna mungo* [L.] Hepper) cv. VBN 6. Journal of Agriculture Research and Technology. 2023;38.

119. Sarkar S, Kundu SS, Ghorai D. Validation of ancient liquid organics -Panchagavya and Kunapajala as plant growth promoters. Indian Journal of Traditional Knowledge. 2014;13:398-403.

120. Rani M, Kaushik P, Bhayana S, Kapoor S. Impact of organic farming on soil health and nutritional quality of crops. Journal of the Saudi Society of Agricultural Sciences. 2023;22:560-9. https://doi.org/10.1016/j.jssas.2023.07.002

121. Ponisio LC, Gonigle LK, Mace KC, Palomino J, de Valpine P, Kremen C. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B: Biological Sciences. 2015;282(1799):20141396. https://doi.org/10.1098/rspb.2014.1396

122. Freibauer A, Rounsevell MD, Smith P, Verhagen J. Carbon sequestration in the agricultural soils of Europe. Geoderma. 2004;122(1):1-23. https://doi.org/10.1016/j.geoderma.2004.01.021

123. Papadopoulos A, Bird NRA, Whitmore AP, Mooney SJ. Does organic management lead to enhanced soil physical quality? Geoderma. 2014;213:435-43. https://doi.org/10.1016/j.geoderma.2013.08.033

124. Devakumar N, Shubha S, Gowder SB, Rao GGE. Microbial analytical studies of traditional organic preparations Beejamrutha and Jeevamrutha. Building Organic Bridges. 2014;2:639-42. https://doi.org/10.3220/REP_20_1_2014

125. Chandra Nayaka S, Niranjana SR, Uday Shankar AC, et al. Seed biopriming with novel strain of *Trichoderma harzianum* for the control of toxigenic *Fusarium verticillioides* and fumonisins in maize. Archives of Phytopathology and Plant Protection. 2010;43(3):264-82. https://doi.org/10.1080/03235400701803879

126. Devika OS, Paul S, Sarkar D, Rajput RS. *Trichoderma*: A part of possible answer towards crop residue disposal. Journal of Applied and Natural Science. 2019;11(2):516-23. https://doi.org/10.31018/jans.v11i2.2090

127. Godlewska K, Pacyga P, Michalak I, Biesiada A, Szumny A, Pachura N, et al. Systematic investigation of the effects of seven plant extracts on the physiological parameters, yield and nutritional quality of radish (*R aphanus sativus* var. *sativus*). Frontiers in Plant Science. 2021;12:651152. https://doi.org/10.3389/fpls.2021.651152

128. Zulfiqar F, Navarro M, Ashraf M, Akram NA, Munné-Bosch S.

Nanofertilizer use for sustainable agriculture: Advantages and limitations. Plant Science. 2019;289:110270. https://doi.org/10.1016/j.plantsci.2019.110270

129. Duarah I, Deka M, Saikia N, Deka Boruah HP. Phosphate solubilizers enhance NPK fertilizer use efficiency in rice and legume cultivation. 3 Biotech. 2011;1:227-38. https://doi.org/10.1007/s13205-011-0028-2

130. Nagaraju A, Sudisha J, Murthy SM, Ito S-i. Seed priming with *Trichoderma harzianum* isolates enhances plant growth and induces resistance against *Plasmopara halstedii*, an incitant of sunflower downy mildew disease. Australasian Plant Pathology. 2012;41:609-20. https://doi.org/10.1007/s13313-012-0165-z

131. Paul S, Rakshit A. Effect of seed bio-priming with *Trichoderma viride* strain BHU-2953 for enhancing soil phosphorus solubilization and uptake in soybean (*Glycine max*). Journal of Soil Science and Plant Nutrition. 2021;21:1041-52. https://doi.org/10.1007/s42729-021-00420-4

132. Voko MP, Kulkarni MG, Finnie JF, Van Staden J, et al. Seed priming with vermicompost leachate, *Ecklonia maxima* extract-Kelpak and smoke-water induce heat stress amelioration and growth in *Vigna unguiculata* L. seedlings. South African Journal of Botany. 2022;147:686-96. https://doi.org/10.1016/j.sajb.2022.02.025

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