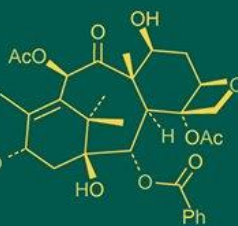
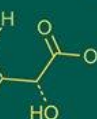
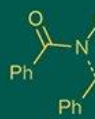


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Role of organic amendments and Biostimulants in improving linseed (*Linum usitatissimum* L.) production: A review

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Abstract

Linseed (*Linum usitatissimum* L.) is an important oilseed and fiber crop that is grown in many parts of the world, including South Asia. The soil fertility, however, is often inadequate, and, due to the excessive use of chemical fertilizers, the full potential of its yield is not realized, particularly since the overuse of chemical fertilizers can have detrimental effects on the environment. The use of organic amendments and biostimulants thus attracts the attention of the researchers and farmers due to these problems. The present review paper focuses on the effect of various organic inputs such as farmyard manure (FYM), vermicompost, seaweed extract, neem oil, moringa leaf extract, and vermiwash on the growth and yield of linseed along with soil health. The paper is a synthesis of findings of several studies conducted in various countries. The result indicates that such treatments can enhance the plant height, number of branches, number of capsules, seed weight, oil content, and total yield of seeds. These are organic inputs that work via improving soil structure, offering valuable nutrients, enhancing beneficial soil microbes, and minimizing environmental stress effects. These inputs can be used in combination and used together to achieve better results than used singly. Based on this review, it is concluded that using organic amendments with biostimulants may be an effective and sustainable approach to increase linseed production while minimizing the use of chemical fertilizers, as it is low cost and environmentally friendly.

Keywords: Linseed, *Linum usitatissimum*, farmyard manure, vermicompost, seaweed extract, neem oil, moringa leaf extract, vermiwash, biostimulants, organic amendments, yield

Introduction

Linseed (*Linum usitatissimum* L.) is an Old World crop of the Linaceae family and is one of the oldest cultivated crops in the world. It is cultivated primarily for its seed (high in oil and omega-3 fatty acids) and the stem fiber used for making linen cloth. It is grown in various parts of the world, such as India, Canada, Russia, China, and Ethiopia (Oomah, 2001) [18]. Linseed is a major rabi (winter) oilseed crop in India and is grown in Madhya Pradesh, Uttar Pradesh, Bihar and Chhattisgarh.

Although linseed is an important crop, the average productivity of the crop in India is low (400 to 500 kg/ha) as compared to its potential productivity (more than 1500 kg/ha) (AICRP on Linseed, 2022) [1]. This substantial difference between the actual and potential yield is primarily due to inadequate soil fertility management, inadequate irrigation, and not using suitable agronomic practices. Many farmers continue to rely on chemical fertilizers, which are costly and have a long-term impact on the environment and soil.

Over the last few years, there has been a growing interest in the use of organic amendments and biostimulants as organic alternatives or supplements to chemicals. Farmyard manure (FYM) and vermicompost are organic amendments that can enhance soil physical, chemical, and biological properties. Seaweed extract, moringa leaf extract, and vermiwash are all sources of biostimulants, which stimulate the growth of plants with natural growth-promoting substances like plant hormones, amino acids, vitamins, and micronutrients that give an addition to the growth and yield of plants.

Neem oil is another natural product that is used in farming. It is extracted from the seeds of *Azadirachta indica* and has been shown to not only control plant pests and pathogens but also positively affect plant growth and soil microbial activity (Sharma *et al.*, 2018) [26].

The review paper will provide a summary of the existing literature on the effect of FYM, vermicompost, seaweed extract, neem oil, moringa leaf extract, and vermiwash on the growth and yield of linseed. The paper also covers the benefits of these treatments from a soil health perspective and the outcomes when they are applied in concert. The aim is to provide the organic inputs in a way that allows farmers and researchers to effectively use them.

Importance and Production Status of Linseed

Linseed is a good source of oil and fiber. The seeds contain approximately 35-45% oil, which is one of the highest plant sources of alpha-linolenic acid (ALA), which is a good omega-3 fatty acid for human health (Moslem *et al.*, 2015) [16]. Linseed oil is used as a cooking oil, as a medicine, and in industry (for making paints, varnishes, and linoleum). The stem fiber is used to produce one of the oldest cloth fabrics in the world, linen.

Worldwide, the area of linseed is estimated to be approximately 2.5-3.0 million ha. Canada is the world's biggest producer of linseed, followed by Kazakhstan, Russia, China, and India. In India, the total area under linseed cultivation is estimated between 0.3 and 0.4 million ha, and the total production is estimated at 0.15-0.20 million tonnes (FAOSTAT, 2023) [7]. Productivity in India is very low as compared to other countries, indicating that there is a huge scope for improvement.

Soil degradation due to the excessive use of chemical fertilizers, inadequate levels of soil organic matter, and ignorance of balanced soil nutrient management are the major reasons for low productivity. The situation can be improved with sustainability in agriculture, using organic inputs.

Role of FarmYard Manure in Linseed Production

One of the oldest and most widely used organic amendments in agriculture is farmyard manure (FYM). It is a mixture of dung and urine of farm animals with crop residues and straw. FYM contains high levels of macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) and micronutrients and organic carbon. These nutrients are slowly released from the soil due to the application of FYM and also enhance soil structure, water-holding capacity, and soil biological activity.

Effect of FarmYard Manure on Soil Properties

The use of FYM has been found to enhance the soil organic carbon level, soil porosity, and soil nutrient status in several studies. Mahajan *et al.*, (2008) [13] had reported that addition of FYM at 10 tonnes/ha resulted in increased soil organic matter content and beneficial soil bacteria and fungi populations. This provides a more favorable soil for plant roots.

FYM also assists in increasing the cation exchange capacity (CEC) of soil, thus increasing the capacity of soil to hold and supply nutrients to plants for a longer period. This is particularly beneficial in sandy or light soil where nutrients can easily leach out.

Effect of FarmYard Manure on Linseed Growth and Yield

Many growth parameters have been found to be improved when FYM is applied to linseed crops. Gupta *et al.*, (2012) [9] observed that use of FYM at 10 t/ha resulted in higher

plant height, branches/plant, and dry matter of linseed. Tripathi *et al.*, (2015) [29] reported that the number of capsules per plant and 1000-seed weight of linseed were also significantly higher when applied with FYM.

A field experiment conducted in Chhattisgarh, India, by Nayak *et al.*, (2017) [17] revealed a higher seed yield of 18% in linseed plots of FYM 5 t/ha with the recommended dose of fertilizers than in linseed plots with only chemical fertilizers. The better yield was due to greater nutrient availability, better soil structure, and increased microbial activity.

The increase in oil content of linseed seeds with FYM application has also been found in several other studies. This may be due to the fact that FYM may provide sulphur to boost oil production in seeds (Singh & Singh, 2014) [27].

The role of Vermicompost in the production of Linseed

Vermicompost is a type of compost that is made with the help of earthworms (usually *Eisenia fetida* or *Lumbricus rubellus*). The earthworms decompose organic materials such as crop wastes, food waste from the kitchen, animal manure, etc. into a fine, rich organic material. Vermicompost is superior in several aspects to the traditional compost and FYM, as it contains higher nutrient content, larger microbial diversity and higher plant growth-promoting substances such as humic acids, enzymes, plant hormones, etc.

Nutrient Content and Soil Benefits of Vermicompost

Nitrogen (N) is generally 1.5 to 2.5%, phosphorus (P) is 1.0 to 1.5%, and potassium (K) is 1.0 to 1.5% of the dry weight in vermicompost (Edwards & Bohlen, 1996) [6]. It's also rich in calcium, magnesium, sulfur and a lot of micronutrients. Vermicompost provides nutrients in a readily available form. The nutrients in vermicompost are released slowly as compared to chemical fertilizers so that there is less waste due to leaching and plants can use it for a longer period of time.

The vermicompost has also been shown to enhance soil aggregation, aeration, and water-holding capacity. The use of vermicompost also enhanced the soil organic carbon, soil microbial biomass carbon, and enzyme activity (Anwar *et al.*, 2011) [2], which are all significant indicators of soil health.

Effect of Vermicompost on Linseed Growth and Yield

Research on the use of vermicompost in linseed production has given positive results. Parihar *et al.*, (2016) [20] carried out a field experiment and observed that application of vermicompost at 3 t/ha significantly improved the plant height, branching, and capsule/plant in linseed plants as compared to the control treatment. They were able to conclude that vermicompost was more effective than FYM at the same rate due to its higher nutrient content and nutrient availability.

Kumar *et al.*, (2019) [12] found that application of vermicompost at 2.5 t/ha resulted in a 22-28% higher yield of linseed compared with the control treatment. They also observed that the oil content in seeds was higher in vermicompost. They proposed that the humic acids in vermicompost could have aided in better oil synthesis due to enhanced carbohydrate metabolism in the plants.

Mishra & Sinha (2020) [15] reported that vermicompost application, along with 75% of recommended nitrogen

fertilizer application, resulted in a yield similar to 100% of recommended nitrogen fertilizer application, which indicates that part of the nitrogen fertilizer can be replaced by vermicompost without reducing the yield. This is a valuable discovery for farmers that seek to cut their fertilizer expenses.

The use of Seaweed Extract in Linseed Production

Seaweed extracts are liquid extracts from the marine plant (seaweed). They are considered one of the most popular biostimulants used in modern agriculture. Seaweeds like *Ascophyllum nodosum*, *Sargassum spp.*, and *Kappaphycus alvarezii* are commonly used to make these extracts. They also contain diverse bioactive substances such as plant hormones (cytokinins, auxins, gibberellins, and betaines), polysaccharides (alginic acid and carrageenan), vitamins, amino acids, and mineral nutrients.

Mode of Action of Seaweed Extract

Seaweed extracts have a multitude of effects on plant growth when applied to crops. The plant hormones in seaweed extracts stimulate cell division and slow leaf senescence (aging) and extend the green and photosynthetic life of the plant. Seaweed extract contains betaines and other osmoprotectants that assist the plant in dealing with drought, salinity, and other environmental pressures (Craigie, 2011) [4].

Alginic acid is another component of seaweed extract that is beneficial to soil. It can also be applied directly to soil, or when it falls on the ground, it becomes a soil conditioner and helps to hold the soil together and retain water. Seaweed extracts also enhance the soil microbial activity.

Effect of Seaweed Extract on Growth and Yield of Linseed

Several studies have been conducted on the use of seaweed extract as foliar spray on linseed. Bulgari *et al.*, (2015) [3] investigated the effects of biostimulants such as extracts of seaweeds (SE) on the growth of various crops and concluded that when SE was applied, all three aspects of plant growth (shoots, roots, and nutrient uptake) were improved in a consistent manner.

Seaweed extract at a 2 to 3 ml/L application rate was shown to enhance plant height, branch number, number of capsules/plant, and yield of the seeds by 15 to 20% in the field experiments specifically carried out on linseed by Shalaby & El-Ramady (2014) [25]. They also observed that oil percentage and oil quality (specifically the fatty acid content) were improved.

Zodape *et al.*, (2011) [31] reported the enhancement of germination percentage, crop seedling vigor, and early establishment of crops due to seaweed extract, which can have a lasting positive impact on the final yield. The crop of linseed is very sensitive to competition from weeds at an early stage, and a good early start is, therefore, very important.

The timing and concentration of seaweed extract application are important factors. The majority of studies indicate that two to three foliar sprays (at vegetative, flowering, and capsule development stages) provide optimum results. Foliar spray concentrations of 2-5 ml/L are generally recommended.

Role of Neem Oil in Linseed Production

Neem oil is purified out of the seeds of the neem tree (*Azadirachta indica*), which is native to South Asia and has been used for centuries in traditional medicine and agriculture. Several active compounds are present in neem oil, the most significant ones being azadirachtin, nimbin, nimbidin, and salannin. Neem oil is a highly effective natural pesticide due to its insecticidal, fungicidal, bactericidal, and nematocidal effects.

Role in Neem Oil in Plant Protection

Control of pests and disease is essential to a good yield of linseed. Aphids, bud fly (*Dasyneura lini*), rust (*Melampsora lini*), and wilt (*Fusarium oxysporum*) are the common diseases. A number of these pests and diseases have been found to be responsive to neem oil. Sharma *et al.* (2018) [26] found that the application of neem oil at 2% foliar spray did not cause any harm to beneficial insects such as bees and predaceous beetles and significantly reduced the aphid population in linseed.

This is because neem oil affects the growth and reproduction of insects. The active substance is azadirachtin, which is a feeding deterrent and also interferes with the molting process of insects, stopping them from becoming adults. This implies that neem oil works on a broad spectrum of insect pests at all life stages.

Impact of neem oil on plant growth and soil

Neem oil also has some direct plant growth-promoting effects apart from its protective effect. Neem products, as a soil drench, can stimulate soil microbial activities and can also release small quantities of nutrients, such as nitrogen, as a result of decomposition (Panda, 2010). Neem oil cake, a byproduct of oil extraction, is known to be beneficial for soils, but the oil has some soil benefits as well.

Koul *et al.*, (2004) [11] discussed neem use in agriculture and reported that neem-extracted products can enhance the efficiency of nitrogen fertilizers by suppressing the activity of nitrification bacteria in soil. This indicates that using neem oil in combination with nitrogen fertilizer leads to reduced N losses by leaching and volatilization and higher availability of N to plants.

Different studies report that foliar application of neem oil can help to promote the production of chlorophyll in leaves, resulting in enhanced photosynthetic activity and thus yield. Caution, however, must be taken when using a high concentration (above 5%), as this may result in phytotoxicity (burning of leaves) in some crops.

Potential of Moringa Leaf Extract in Linseed Production

Moringa (*Moringa oleifera* Lam.) is commonly known as the "miracle tree" or "drumstick tree," as it has been used to benefit every part of the plant. Moringa leaf extract (MLE) has recently attracted a lot of attention in agriculture as a powerful biostimulant. The leaves of moringa are rich in nutrients, amino acids, vitamins (especially vitamins B, C, and E), and plant hormones, especially zeatin (a cytokinin).

Bioactive Compounds and Mode of Action of Moringa Leaf Extract

The role of moringa leaves in agriculture is more significant with the zeatin content. Zeatin is a natural cytokinin, which stimulates cell division, postpones senescence, and enhances nutrient mobilization in the plant. The zeatin in moringa

leaves has been estimated to be around 4 mg/g fresh weight, a significantly higher amount than is present in most other plants (Fuglie, 2000) [8].

High levels of potassium, calcium, iron, and other minerals, along with high levels of phenolic compounds and antioxidants, are also present in moringa leaf extract. When sprayed as a foliar application, moringa leaf extract can easily be absorbed through the leaves and deliver these essential nutrients and growth-stimulating compounds to the plant where they are required.

Effect of Moringa Leaf Extract on Linseed Growth and Yield

The application of moringa leaf extract for linseed crops is a relatively new body of research, and results obtained thus far are very promising. Hammad & Ali (2014) [10] reported that the use of moringa leaf extract at a 3% foliar application significantly enhanced the chlorophyll content of the leaf, rate of photosynthesis, and dry matter production in crops. The same results are likely to occur in linseed.

Moringa leaf extract under water stress could improve the water relations and antioxidant enzyme activity in a number of oilseed crops and also increase the chlorophyll content, which resulted in significantly higher seed yields compared to the control (Rady *et al.*, 2015) [23]. This is particularly true for linseed, which is often cultivated under water stress.

A moringa leaf extract applied at the vegetative and flowering stages resulted in more capsules per plant, seeds per capsule, and 1000-seed weight in linseed, as reported by Mekki *et al.*, (2015) [14]. The seed yield was increased by about 18 to 25% compared to untreated control plants. They concluded that the increase in seed yield and weight resulted from the partitioning of photosynthates from the leaves to the seeds due to the presence of cytokinins and other growth-promoting components in moringa leaf extract.

Moringa leaf extract can also be easily and economically prepared. Soaking fresh moringa leaves in water overnight, straining them, and diluting them to the desired concentration are ways to make farmers make it. This is quite an easy-to-use and useful biostimulant for smallholders.

The importance of Vermiwash in Linseed cultivation

Vermiwash is the liquid that passes through a vermicompost bed after watering. The water collects nutrients and plant growth promoters, enzymes, beneficial microorganisms, and organic acids from the vermicompost and from the earthworms as they flow through the bed. This ends up as a nutrient-rich liquid, which is applied as a foliar spray or a soil drench.

Composition and Properties of Vermiwash

Vermiwash is a source of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and a variety of micronutrients. It also has plant growth regulators such as auxins, gibberellins, and cytokinins and beneficial bacteria such as *Pseudomonas*, *Bacillus*, and *Azotobacter* (Prabha *et al.*, 2007) [22]. These bacteria can also fix nitrogen from the air, make the phosphorus soluble, and produce antibiotics, which help plants fight off diseases.

The pH of vermiwash is generally slightly acidic to neutral (6.5 to 7.0), and it has a light brown color. When properly diluted (typically 1:10 or 1:20 with water), it is safe for use on all crops as a foliar spray.

Effect of Vermiwash on Growth and Yield of Linseed

The use of vermiwash in linseed is still in its early stages of research and is expanding. However, Yadav & Agarwal (2011) [30] observed that foliar spray of vermiwash (10% concentration, twice) on several crop plants such as linseed significantly enhanced plant height, number of leaves, leaf area index, and biomass production. These effects were attributed to the synergistic effects of nutrients and plant hormones present in vermiwash.

A more recent study conducted by Pathak *et al.*, (2020) [21] showed that the use of vermiwash at 0.2 liters per acre as a foliar application at three growth stages (tillering, pre-flowering, and post-flowering) increased the yield of linseed by approximately 15-20% compared to the control. They also noted an increase in oil content and oil yield per hectare, the most economically important quality parameters in linseed.

Vermiwash is also known to have a beneficial effect on the resistance of plants to disease. Tharmaraj *et al.*, (2011) [28] reported that application of vermiwash may trigger systemic resistance in plants, which helps in combating fungal and bacterial pathogens. This is important because vermiwash can be used for both purposes: a nutrient source and a plant health promoter in linseed.

An advantage of vermiwash is its easy production on the farm by any farmer who already has a vermicompost unit. The production expenses are quite low and may be continuous in production as long as there is a working vermicompost bed. This renders it a good feed for low-income farmers.

Combined effects of Organic amendments and Biostimulants

The last but not the least important finding of recent research is that any combination of organic amendments (FYM/vermicompost) with biostimulants (seaweed extract/moringa leaf extract/vermiwash) often gives better results than any of these inputs alone. This is called a synergistic effect, which means that the inputs work together and enhance each other's effectiveness.

The reason for this synergism is not hard to understand. FYM and vermicompost are organic amendments that enhance the soil environment by increasing organic matter in soil, enhancing soil structure, and increasing microbial activity. Healthy soil will be able to absorb nutrients and water more readily. The application of biostimulants on top of this allows the plant to be in a better condition to react to the growth-promoting substances of the biostimulants. This leads to greater growth and yield improvement than could be achieved by either input alone.

Vermicompost and moringa leaf extract were applied to oilseed crops in a study by Devi *et al.*, (2017) [5]. The results showed that the application of vermicompost and moringa leaf extract together produced a yield that was 28-35% higher than the control, while the application of vermicompost alone produced a yield that was 18% higher and the application of moringa leaf extract alone produced a yield that was 15% higher. This suggests that this combination is unquestionably effective.

Likewise, Sarkar *et al.*, (2021) [24] reported that the three-way treatment of FYM, seaweed extract, and vermiwash resulted in maximum plant height (82.4 cm), maximum capsules per plant (38.6), maximum 1000 seed weight (7.8 g), and maximum yield of seeds (1456 kg/ha) as compared

to any single treatment and control. The combination also resulted in better oil content (43.2%) and oil yield (629 kg/ha).

The other advantage of these inputs is that they cut down on the production costs. Organic amendments reduce the amount of chemical fertilizers required. Use of less fertilizer is still possible when biostimulants are used, due to the plant's better ability to use the available nutrients. This may help to cut the farmers' input cost, particularly in a crop such as linseed, which may have thin profit margins.

Discussion

The literature review indicates that all the organic inputs employed, such as FYM, vermicompost, seaweed extract, neem oil, moringa leaf extract, and vermiwash, have considerable potential to enhance the production of linseed. All of these inputs benefit the linseed crop in a different way and, in combination, can deal with several factors that can limit linseed production. The primary mechanisms by which FYM and vermicompost function are creating a better soil environment. They help build soil organic matter, make nutrients available to plants, boost soil microbial activity, and boost soil physical structure. Such effects are permanent since the benefits of organic amendments can last for one or more seasons after application and take time to break down. Vermicompost seems to be more effective per unit weight than compost due to the higher nutrient content and the presence of plant growth promotion factors. The main mode of action for seaweed extract, moringa leaf extract, and vermiwash is as a foliar biostimulant. These are rich in many plant hormones, amino acids, vitamins, and micronutrients that have a direct growth-inducing effect on plants and their metabolism. The inputs are fast-acting; sometimes plant growth response is noticed within 1-2 weeks after application. The impacts of their use may be short-lived, however, so applications at different growth stages of a crop are suggested. Neem oil has a special role in this category, as it is used as both a growth promoter and a plant protection product. It is a very valuable input because it is beneficial for the control of common pests and diseases of linseed and for its use in increasing nitrogen efficiency in the soil and stimulating chlorophyll synthesis. But careful management of its use is required to prevent phytotoxicity. A lack in the present literature is the few field-level experiments conducted on linseed alone. Much of the information cited in this review has been obtained from experiments conducted on other crops (such as wheat, mustard, or soybean) and applied to linseed. Further research is required on linseed with more specific information regarding the crop, especially in the major linseed-growing areas of India. The quality of organic inputs is another important factor to consider. The nutrient value of FYM, vermicompost, and vermiwash can differ significantly from the raw materials used, the process of making the compost, and the age of the compost. Farmers should be aware of this variation and attempt to make the inputs as uniform as possible. Laboratory analysis of organic inputs prior to application may help to ensure the proper proportion of nutrients being applied. The effectiveness of these inputs will also be influenced by environmental conditions. Organic amendments can be particularly useful in dry or droughty soils since they produce better water-holding capacity. Biostimulants such as seaweed extract could yield more favorable results in cool and humid climates, as they

can help the plant to resist colder climates and slower nutrient uptake.

Conclusion

This review paper has compiled information available about the use of six organic amendments and biostimulants, FYM, vermicompost, seaweed extract, neem oil, moringa leaf extract, and vermiwash, to enhance linseed production. From the literature reviewed, the following conclusions can be drawn: Manure from industries in the farmyard and vermicompost are good soil amendments that can also enhance the fertility and yields of linseed when applied at appropriate rates. Vermicompost is more effective than FYM because of its high nutrient content and plant growth promoters. Seaweed extract and moringa leaf extract are effective biostimulants that can be applied as foliar sprays to enhance linseed growth, photosynthesis, stress tolerance, and seed yield. The optimum number of applications is 2-3 at critical growth stages. Neem oil is a natural compound that can be used for pest and disease control of linseed as well as enhance the nitrogen-use efficiency of the soil. It may be a good component to an integrated crop management plan. Vermiwash is a simple and cheap biostimulant that can be manufactured on the farm. It not only enhances the nutrition of the plants but also helps in protecting the plants from diseases. Vermiwash is easily generated and applied by farmers having vermicompost units.

The combination of organic amendments with biostimulants gives better results than using individual inputs. It can be an effective, cost-efficient, and eco-friendly method to enhance the yield, oil content, and oil yield of linseed. Further investigations should be carried out under field conditions with linseed in various agroclimatic zones, the best combinations and doses of these inputs, and the economic gains for the farmers. The development of location-specific recommendations for the use of organic amendment and biostimulants in linseed is going to be a significant contribution towards more sustainable linseed production.

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