REVIEW ARTICLE

Various Approaches Used to Increase the Growth and Yield of Linseed Crop

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Abstract

Linseed *(Linum usitatissimum)* is a significant rabi oilseed crop in India, ranking second in terms of cultivation area and seed production after rapeseed mustard. It is an ancient plant that has been cultivated for its fibre and oil for centuries. Oilseeds demand higher nutrition for their optimum production as they are energy-rich crops. Despite the continuous growth in terms of their area and the use of increased fertilizers, there has been no proportional growth in their production. This review intends to offer insights into the possibilities of agronomical as well as biotechnological breakthroughs in overcoming the difficulties faced in its production by a thorough analysis of recent studies and instances. Farmers and researchers can collaborate to increase the production and fulfill the rising demand for this significant oilseed crop by integrating various approaches of biotechnology. Various studies in support of this are discussed in detail in the present review.

Keywords: *Biotechnology, Fertilizers, Linseed, Oilseed crop, Production, Yield.*

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Introduction

Linseed makes an important place as an oilseed crop in the economic sector of India mainly because of its oil and fiber to fiber (Zuk *et al*., 2015). Despite its prominent position in the oilseed crop category and the vast area dedicated to its production, its productivity is less as compared to other oilseed crops. Its demand is increasing day by day. To keep pace with the increasing demand and supply more emphasis has been given to increasing its productivity by applying various agro techniques. The present paper focuses on some of the latest interactive methodologies such as the use of a sufficient amount of fertilizer (chemical and biofertilizers) along with various agronomic techniques adapted to increase its production.

Problems Faced by the Agriculture Sector in Oilseed Production

India used to be a significant exporter of oilseeds, meals, and edible oils, and was self-sufficient in the production of edible oilseeds and oils until the mid-1960s. However, due to stagnant production of growth and increasing population, the production of oilseeds became insufficient to meet the demand in the early 1970s. Edible oils overtook petroleum products as the main import by the middle of the 1980s, making up around 30% of the overall supply. Despite India having the second-largest area dedicated to the cultivation of oilseeds, this was the case. With the rise in demand for edible oils, the output of oilseeds was unable to keep up (Hamilton, 2009; Jat *et al*., 2019). To achieve maximum yield, the use of fertilizers and biocides was increased along with new cultivars in intensive agriculture. Agricultural productivity has increased steadily since the middle. As the applications of these chemicals readily disturbed the soil microbiome, their effects would be severely limited (Rahman *et al*., 2021).

The need to preserve soil fertility and to protect the environment from various detrimental activities, agronomic techniques has brought about the amendment of productive systems in agriculture. The use of beneficial microorganisms has gained popularity (Zaidi *et al*., 2003) along with other agro and biotechniques. The integrated nutrient-supply system, which involves the combined use of mineral fertilizers, organic manures, and biofertilizers, is gaining popularity as it enhances soil health and improves crop productivity.

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Oilseed Crop Status in Indian Agriculture

Oilseeds hold the second-largest share of agricultural trade in India after cereals, covering approximately 13% of the gross cropped area (Darekar and Reddy, 2017), cultivated across an area of 25.73 million hectares. Yield production of oilseeds in India was reported 26.67 million tonnes (Mt), with average productivity of 1037 kg per hectare (Rai *et al*., 2016). India ranks among the largest oilseed producers globally (Thapa *et al*., 2019), accounting for 12-15% of the oilseed world area and 6 to 7% of global vegetable oil production (Kumar and Padmaiah, 2010). The favorable agroecological conditions in India support the cultivation of all. There are nine annual oilseeds, seven of which are edible (groundnut, rapeseed-mustard, soybean, sunflower, sesame, safflower, and niger) and two that are not (castor and linseed). This diversity distinguishes India from other countries that cultivate annual oilseed crops (Kumar and Padmaiah, 2010).

Despite being one of the largest producer countries in the world, it is projected to continue its strong growth in imports rather than export at 1.8% p.a., which is predicted to reach 16 Mt by 2031 according to FAO (2022), to meet increasing demand driven by urbanization, from nine (9) annual oilseed crops the production of 45.64 Mt is projected by 2022-23, supposing an additional 15.58 Mt on top of the 30.06 Mt produced in the first quarter of 2016-17 (Table 1).

The productivity of oilseeds in India lags behind the global production levels primarily due to their predominant cultivation in rainfed conditions with inadequate and imbalanced nutrition. Energy-rich oilseed crops are grown in energy-starved conditions (Hegde and Babu, 2009). The soils in which oilseeds are cultivated are progressively deteriorating. The response of oilseed crops to general nutrient fertilization is declining. Given that oilseed crops have a high nutrient requirement, particularly for nitrogen (N), phosphorus (P), and potassium (K), the limited availability of these nutrients is a major constraint for biomass production. It is essential to develop an agricultural system that requires lower fertilizer inputs while ensuring higher fertilizer use efficiency. By integrating the use of chemical fertilizers, biofertilizers, and organic manure with appropriate agronomic practices, the increasing demand for oilseeds can be met effectively.

Linseed

Linseed is often referred to as the "robber crop" due to its reputation for depleting soil nutrients. However, it responds well to fertilizer applications. The recommended dosage of fertilizers varies across different agroecological regions. Yield also varies based on factors such as climate, soil type, agricultural practices, and the variety of linseed. It is cultivated extensively in both temperate and tropical regions. Well-managed crops can yield around 1.5 to 2.0 tonnes of seeds per hectare. Linseed can be grown as a standalone crop with proper fertilization or as an intercrop, with linseed/chickpea being a common intercropping system. It is typically sown in October during the winter season. Early sowing has been reported to reduce the risk of powdery mildew, rust, and linseed bud fly infestation in different regions (Vyas *et al*., 2020). The oil content of linseed seeds generally ranges by 45% (Čeh *et al*., 2020), up from 33%. Although linseed oil is largely used in industry, 25% of the country's total production of linseed oil is consumed domestically (AICRP, 2004).

This plant is acquiring prominence due to the high demand for its seed, which has high iodine content and a quick-drying property (Singh *et al*., 2013) and which makes it a valuable product for industrial applications. Seeds and oil are used in making several items in the industrial and pharmaceutical sectors (Yadav and Srivastava, 2002). Bhatty (1991) reported a range of 34.6% to 46.4% oil in a diverse collection of 201 accessions of linseed species. Its oil is a rich known source of unsaturated fatty acids, especially linolenic acid (Salunke *et al*., 1992; Khan *et al*., 2010) which makes it a valuable product. It is one of the omega-3 fatty acids, which is found in higher amounts in linseed and edible fish oils (Morris, 2007).

Table 1: Status of estimated area, production, and yield of oilseed crops in India

Crop	*Quinquennium ending 2016-17*			*Year 2022*		
	Area (m.ha.)	*Production (Mt)*	*Yield (tons/ha)*	*Area (m.ha.)*	*Production (Mt)*	*Yield (tons/ha)*
Soya bean	11.38	11.94	1.05	12.50	18.75	1.50
Groundnut	4.99	7.39	1.47	5.72	9.72	1.70
R&M	6.19	7.39	1.19	7.47	11.95	1.60
Sunflower	0.59	0.44	0.75	0.97	0.87	0.90
Safflower	0.16	0.08	0.53	0.27	0.22	0.80
Sesame	1.75	0.77	0.41	1.97	1.18	0.60
Niger	0.26	0.08	0.32	0.32	0.16	0.50
Castor	1.06	1.80	1.70	1.40	2.45	1.75
Linseed	0.28	0.14	0.49	0.57	0.34	0.60
Total	26.67	30.00	1.13	31.20	45.64	1.46

(Source: DFT Committee Estimates based on data compiled from DACNET)

Another valuable part of the plant that is used commercially after processing is the stem which provides good quality fiber having high strength and durability (Singh *et al*., 2011). These Fibres are known for their length and strength and are two to three times as strong as those of cotton (Taylor, 2012). Its fiber has been utilized in the production of textiles and coarse produce (Vyas *et al*., 2020).

Linseed Production in India and World

India has a significant position in the global oilseed scenario, accounting for 19% oilseed acreage area and 9% of production. India is sixth in linseed output after Kazakhstan, Canada, Russian, China, and the USA, but is fifth in acreage area of linseed (more than USA) (Fig. 1) (FAO 2019).

Madhya Pradesh is the leading state for linseed cultivation in India, followed by Uttar Pradesh, Chhattisgarh, Bihar, Rajasthan, Odisha, Karnataka, and West Bengal. These states not only have significant acreage and yield but also hold prominent positions in terms of area and production. Madhya Pradesh and Uttar Pradesh together contribute around 70% of the national linseed production (DAC&FW, 2018). In India, linseed is cultivated across an area of 3.420 lakh hectares, resulting in a production of 1.537 lakh tonnes. However, the average yield is 449 kg/ha, which is considerably lower than the global average productivity of 1006 kg/ha (Fig. 2) (Tandon *et al*., 2021). To address this yield gap, various agronomic practices have been implemented.

Techniques Adopted to Increase the Productivity of Linseed

Linseed, cultivated since ancient times, has its origins in the Fertile Crescent around 7000 BC. Archaeological findings at Navdatoli, M.P. dating from 1600-1400 BC, revealed carbonized seeds of *Linum spp*. The diversity observed in India suggests that flax originated in the region and spread northwards and westwards. As an industrial oilseed crop, every part of the linseed plant holds commercial or medicinal significance. It is an annual, glabrous plant with one to many stems, ranging from 20 to 110

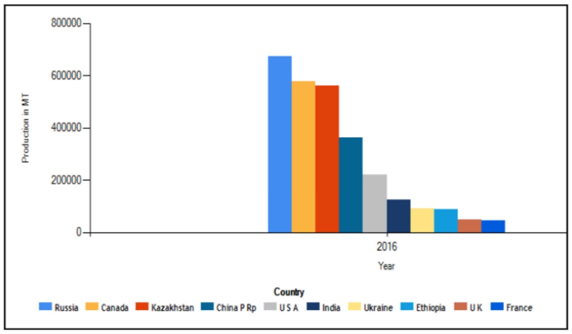

Fig. 1: Graph showing top 10 countries in Linseed production all over the World.

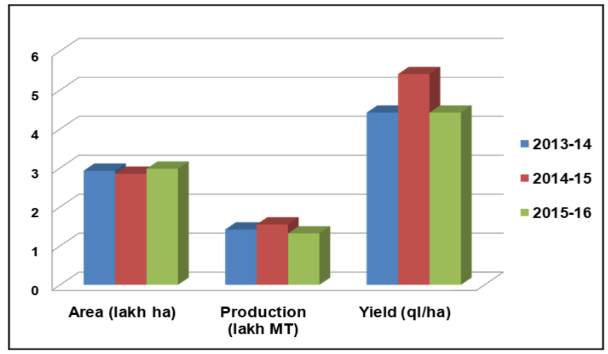

Fig. 2: Graph showing area, production and yield of Linseed in India (Source: Department of agriculture, cooperation & farmers' welfare, Ministry of agriculture & farmers' welfare, GoI)

cm in height. The leaves are alternate and sessile, with a linear-lanceolate shape, acuminate tips, and ciliate inner sides. Pollen grains possess three colpate openings, while styles are nearly free to the base and stigmas are clavate. The capsules are mostly indehiscent and globose, containing ovate seeds that vary in colour between brown and yellow. Two distinct morphological types are recognized: seed type and flax/dual-purpose type. The seeds serve as a vital source of omega-3 fatty acids, which contribute to the reduction of cancer and cardiovascular disease risks (Gaikwad and Jalali, 2020).

Linseed is gaining importance as an oilseed crop due to its technical-grade vegetable oil and high-quality fiber. The demand for edible oil stands at 18.94 Mt, with a supply of 10.08 Mt. The gap between demand and supply (47%, equivalent to 8.86 Mt) is fulfilled through edible oil imports (Anonymous, 2015). To meet market demands, various methods are adopted to increase linseed productivity. These methods include employing different types and combinations of fertilizers, optimizing fertilizer application methods, preventing runoff and nutrient losses, utilizing nitrification inhibitors (Elrys *et al.*, 2022), adopting organic and green manuring practices, incorporating leguminous crops in cropping systems, addressing imbalanced nutrient use, and implementing integrated nutrient management strategies (Abrol, 1993; Prasad, 1998).

Among the different agro-techniques- varietal selection, different combinations of nutrients applied, intercropping pattern, seeding density, and row spacing, and use of biofertilizers as a supplement to chemical fertilizers are discussed here briefly about the increase in the growth and yield production of the linseed crop (Table 2). Researchers have created improved linseed cultivars with improved features like greater production, disease resistance, and oil quality by utilizing various biotechnologies. Additionally, biotechnological methods provide options for stress management, nutrient management optimization, and general agronomic practice improvement.

Varietal and Cultivars Selection

Kumar *et al*. (2018) highlight the significant potential for increasing linseed yield by utilizing multi-character high-yielding varieties (Table 2). This suggests that advancements in breeding and genetic selection can contribute to enhancing linseed productivity.Despite the huge potential of this crop in the industrial and nutritional sectors of the country, productivity is always remaining a main issue. The national average yield of linseed has been quite low (Yadava *et al*., 2012). Socio-economic factors and less accessibility to high-yielding varieties is a major issue. Moreover, this low productivity status makes the area under linseed cultivation gradually decline (Chauhan *et al*., 2009).

It is reasonable to assume that varietal difference in nutrient-used efficiency exists within all the major crop species. Further increase in yield is based upon the understanding of the physiological basis of yield production. The response of fertilizer on the yield of a plant varies because of genotypic variation between the cultivars. This phenomenon is well described by Pettigrew (2008) in cotton plants. Genotypic variation among a variety of linseed crop species has been observed by many workers. Badiyala *et al*. (2003) reported in their experiments that among four varieties of linseed 'Surabhi', 'KL224', 'KL214' and 'Sweta'; KL224 and KL214 proved superior to the other two varieties using the same nutrient supply (Table 2). Kaushal (1995) has also reported similar results in which he reported a significant difference in the growth and yield between the varieties of linseed used.

Among ten linseed cultivars, Fontana *et al*. (1996) noted variances in oil output, 1000 seed weight, and seed yield.Kurt (1996) discovered notable variations among eight linseed cultivars in terms of plant height, capsule count, seed count, weight of 1,000 seeds and the harvest index. Among linseed varieties, Pandey *et al*. (2002) found substantial differences in biomass and primary productivity on a net basis. Singh (2001) found notable variations among 20 linseed cultivars in terms of days to blooming, seed production, height of the plant and the number of branches per plant. According to Gaikwad *et al*. (2020), growth and yield contributing characteristics of the crop were appreciably improved with the variety LSL-93 except for plant height, straw yield, and biological yield (kg ha^{-1}). Tenenbaum *et al*. (2002) conducted a study on eleven linseed genotypes and found high variability in plant's attributes related to fibre yields of production, oil, and fibre. Jain *et al*. (1995) observed that among various cultivars, linseed cv. Jawahar-23 exhibited the highest seed yield, followed by RLC-1, RLC-2, and T-397 (Table 2).

Different Combinations of Nutrients Applied

Different combinations of nutrient applications are the most important tool, used to enhance the productivity of the crop at desired levels. The interactive effect of nitrogen with

Table 2: List of various techniques used to improve crop yield in Linseed

Techniques adopted	*Crop- Linseed*	*Parameters Studied*	*Reference*
Selection of genotype	eleven genotypes	Fibre production, oil yield and straw yield	Rennebaum*et al*., 2002
Selection of cultivars and variety	Varietal selection - Surabhi, KL224, KL214, Sweta Varietal selection- LSL-93 Linseed cultivars Linseed cv Jawahar-23, RLC-1, RLC-2 and T-397	Yield Growth and yield Variation in seed yield, seed weight and oil yield Plant height, number of capsulesper plant, number of seeds per capsule, 1000 seed weight, and harvest index biomass, net primary productivity, flowering, seed yield, plant height, and number of branches per plant.Seed yield	Badiyala *et al*., 2003 Gaikwad*et al*., 2020 Fontana *et al*., 1996 Kurt, 1996 Pandey*et al*., 2002 Singh, 2001 Jain *et al*., 1995
Nutrient Management	Linseed	Seed yield Yield Yield and quality of fibre Quality and quantity of linseed	Dordas, 2010 Badiyala and Singh 1998; Kaushal 1995; Hocking and Pinkertone,1991 Husain and Zedan, 2008Yawalkar *et al*., 2002
Intercropping pattern	Intercropping of linseed and mustard	Growth and yield	Badiyala *et al*., 2007; Kumar *et al*., 2002
Seed density	A seed rate of 60 kg/ha is more effective than 40 kg/ha and 50 kg ha.	Yield-attributing characters, seed yield Yield, quality Fibre and seed yields	Badiyala *et al*., 2003 Nayital and Singh 1984 Bassi and Badiyala 1992
Row spacing	Row spacing of 45 cm Row spacing of 15 cm Row spacing of 30 cm Row spacing of 25 cm	Plant height and the number of branches increases capsules/plant , seed yield/ha, straw yield/ha, and oil yield/ha Seed yield Seed yield	Vender *et al*., 1995 Vender *et al*., 1995 Khare *et al*., 1996 Sharma and Hunsigi 1996 Teshome *et al*., 2020
Use of Biofertilizers as a Bio stimulants and Plant Growth Regulators	Mycorrhizal colonization Mycorrhizal inoculation dual inoculation of *Azotobacter* and PSB *Azospirillum* and *Rhizobium*	Growth yield Shoot dry weight Height of the plant boost linseed growth and yield	Thompson, 1991 Srinivasulu and Lakshman 2002 Hussein, 2007 Gupta *et al*., 2019
Plant growth regulators (PGRs)	administration of gibberellic acid (GA3)	increases plant height, branching, and yield	Verma *et al*., 2017
Plant growth-promoting rhizobacteria (PGPR)	beneficial soil bacteria	improve drought and salinity tolerance	Nagrale *et al*., 2023
Biotechnological advancementfor Genetic improvement	Genetic Engineering	increasing the oil's -linolenic acid level	Banniza *et al*., 2018
	Marker-Assisted Selection (MAS)	developed linseed varieties resistant to the *Fusariumoxysporum*-caused wilt	Gupta *et al*., 2017
For micronutrient availability	overexpression of iron acquisition genes	iron uptake and tolerance to iron deficiency	Yadav *et al*., 2017
Molecular Breeding Techniques	Marker-assisted selection (MAS)	disease resistance, oil content, and fatty acid composition	Barvkar *et al*., 2012
	Genomic selection (GS):	may improve the precision and effectiveness of selection	Panday *et al*., 2016
	Genotyping-by-sequencing (GBS)	find genetic variants and create high-density genetic maps	Demeke *et al*., 2017
Approaches for Stress Tolerance	overexpression of stress-related transcri ption factors, such as DREB and MYB	improve drought and salinity tolerance	Wang *et al*., 2021
Metabolic engineering for stress tolerance	engineering of osmoprotectant biosynthesis pathways	enhance drought and salt stress tolerance	Chen *et al*., 2018
RNA interference (RNAi) technology	By suppressing the expression of stress-responsive genes	enhance stress tolerance and improve crop performance under adverse conditions	Khare *et al*., 2018
Biotechnology for Quality Improvement Genetic modification for improved oil composition	introduction of desaturase and elongase genes	improve the composition of linseed oil,	Dong *et al*., 2019
Genomic diversity analysis for quality improvement	select and combine several alleles	contribute to superior quality	Sun *et al*., 2017

other nutrients concerning linseed is less explored. Nitrogen is an important nutrient and makes it a vital, aspect of the management techniques which is highly affecting the linseed seed yield as reported by Dordas, (2010). Nitrogen, as an essential nutrient, is absorbed from the soil in the form of nitrate and is facilitated by transporters. Through a series of enzymatic reactions involving glutamine synthetase (GS) and glutamate synthetase (GOGAT cycle), nitrate is converted into ammonium and subsequently transformed into amino acids. This process allows plants to utilize nitrogen for various biological processes and metabolic pathways. The initiation of inorganic N utilization is mediated by Nitrate Reductase enzymes Nitrite Reductase enzymes, and the GS/GOGAT cycle which converts inorganic nitrogen to organic nitrogen and is playing a vital role in the N assimilation of crops (Liu *et al*., 2020).

By applying nitrogen at different rates, a significant increase in the performance and yield of linseed is reported by Badiyala and Singh (1998) and Kaushal (1995) under an ultra-system of cultivation.Nitrogen application in combination with phosphorus and sulfur responds better for oilseed crops, as reported by Aulakh *et al*. (1989) in their experiment applying nitrogen, sulfur, and phosphorus at the rate of 60, 40, and 30 kg ha^{-1}. Hocking and Pinkerton (1991) observed positive outcomes when applying a graded dose of nitrogen to linseed, highlighting the correction of nitrogen deficiency through fertilizer application. Given that linseed has a finite amount of nitrogen reserves that may be distributed to seeds and capsules, they underlined the need of supplying an appropriate nitrogen supply during seed filling. Furthermore, Husain and Zedan (2008) also reported that higher nitrogen concentrations led to better fibre output and quality. Zafar *et al*. (2019) reported a reduction in seed yield in linseed due to excessive nitrogen application, which led to enhanced vegetative growth. Therefore, boosting linseed production requires the careful administration of seed rates and nutrients, particularly nitrogen, phosphorus, and potash (Singh *et al*., 2013) (Table 2).

The application of sulfur along with nitrogen reduced the nitrate content in the leaves due to higher nitrate reductase activity and increases the accumulation of nitrogen content in the plant (Abdin *et al*., 2003).Phosphorus and sulfur are essential nutrients that have a significant impact on both the quality and quantity of linseed. Yawalkar *et al*. (2002) highlighted the importance of these nutrients in improving linseed production. Vyas *et al*. (2020) conducted a study and found that the application of phosphorus and sulfur had a significant effect on various growth parameters of linseed.

The Zn concentration in grain is often significantly correlated with the concentrations of other macro- and micronutrients as reported by Garvin *et al*. (2006) and McDonald *et al*. (2007). Nitrogen-use efficiency is a vital factor in optimizing plant productivity, biomass, crop quality, and protein content. The efficient utilization of nitrogen resources is crucial for plant growth. To enhance the optimal utilization of fertilizers, nutrient management strategies such as combining with other nutrients, splitting fertilizer applications, and employing effective crop management strategies can be implemented. Abdin *et al*. (2005) emphasized the importance of these strategies for improving nitrogen-use efficiency and achieving higher productivity.

Intercropping Pattern

Different methods adopted during the cultivation of linseed also gave profound results in enhancing growth and yield. Badiyala *et al*. (2012) evaluated the intercropping of linseed and mustard with increasing rates of nitrogen. The growth of both crops showed improvement over the control and achieved a significant increase in yield. Similar results were observed by Kumar *et al*. (2002) on the linseed mustard intercropping pattern (Table 2). The yield of chickpeas was adversely affected by intercropping with Indian mustard, barley, and linseed reported by Ahlawat *et al*., 2005.

Seeding Density and row Spacing

Seed rate plays a crucial role in plant growth and achieving optimal plant density, which in turn affects crop yields. Badiyala *et al*. (2003) conducted a study on a linseed variety and found that a seed rate of 60 kg ha^{-1} resulted in significantly higher yield-related parameters, seed yield, gross returns, and net returns compared to seed rates of 40 kg ha^{-1} and 50 kg ha^{-1} (Table 2). Similarly, Nayital and Singh (1984) reported a significant impact of crop establishment method, seed rate, and nitrogen fertilization on yield, quality, and economic aspects of linseed in the north-western Himalayas.Seeds, when applied at different rates, also grade the growth and development of the crops by influencing the nutrient uptake and contents of each of the crop plants. The effect of seed rate and nitrogen on fiber and seed yields of linseed was reported by Bassi and Badiyala (1992).

Row spacing is a critical factor influencing crop growth and production potential, as it optimizes the use of nutrients, moisture, and light interference. Vender *et al*. (1995) found that a row spacing of 45 cm resulted in significantly greater plant height and number of branches in linseed. However, for yield-related characteristics such as the number of capsules per plant, seed yield per hectare, straw yield per hectare, and oil yield per hectare, a row spacing of 15 cm was more favourable. Khare *et al*. (1996) determined that 30 cm row spacing produced a higher average seed yield than 25 cm row spacing. Similarly, Sharma and Hunsigi (1996) found that the seed yield of two linseed genotypes was greater with 30 cm spacing than with 10 cm spacing. Teshome *et al*. (2020) found that a seed rate of 40 kg ha^{-1} and a row spacing of 25 cm had significant effects on linseed plant yield and yield components.

Use of Biofertilizers as Supplement to Chemical fertilizers

Agricultural production is not synchronized with the growth in fertilizer consumption these days. The declining use efficiency of fertilizers and soil productivity is another issue of concern. Agricultural growth has continuously slowed down. Chemical fertilizers can only provide an immediate nutrient boost but can have negative effects on soil health and the environment in the long run. Biofertilizers, on the other hand, have a more sustainable approach, improving soil fertility and reducing environmental impacts over time. However, the choice between the two depends on various factors such as crop type, soil conditions, and farming practices. A balanced approach that considers the specific needs of the crops and the environmental context is often recommended.

Biofertilizers are substances that contain beneficial living microorganisms that enhance soil fertility and plant growth by facilitating the decomposition of organic matter in the soil. They play a beneficial role in linseed cultivation and can be used in increasing linseed production. Certain strains of bacteria, such as *Rhizobia*, can fix atmospheric nitrogen into a form that plants can use. Linseed requires a good supply of nitrogen for optimal growth and biofertilizers containing nitrogen-fixing bacteria can help meet the plant's nitrogen requirements. These bacteria form a symbiotic relationship with the linseed plant, forming nodules on the plant's roots and converting atmospheric nitrogen into a usable form. Singh *et al.* (2014) reported the significant response of nitrogen-fixing biofertilizers in improving the seed yield of mustard.

Biofertilizers having phosphate-solubilizing bacteria (PSB) and VAM make phosphorus more available to plants. Since linseed requires phosphorus for various physiological processes, so PSB and VAM can enhance the uptake of phosphorus from the soil, promoting better growth and development (Jayakumar *et al.*, 2021). The growth and yield of linseed were correlated by Thompson (1991) to the mycorrhizal colonization rate in field studies. Linseed has shown very much dependency (greater than 90%) on biofertilizers. Srinivasulu and Lakshman (2002) conducted a study to determine the response of niger and linseed to mycorrhizal inoculation. Inoculation of VAM significantly increased shoot dry weight in the two oil-yielding plants. The increase was more significant in the case of linseed than in niger. A significant increase in zinc and phosphorus content was also observed in linseed.Dual inoculation of *Azotobacter* and PSB to linseed showed higher values of plant height as compared to *Azotobacter* and PSB alone (Hussein, 2007). Improvement in the nutrient content in soil is observed by El-Nagdy *et al.*, (2010) upon combined application of fertilizers and biofertilizers in linseed crops.Some biofertilizers contain beneficial microorganisms that can suppress harmful plant pathogens. These microorganisms, such as certain strains of bacteria or fungi, can inhibit the growth of pathogenic organisms in the soil and on plant surfaces. By using biofertilizers with disease-suppressive properties, farmers can reduce the risk of disease outbreaks in their linseed crops (Table 2).

It's important to note that the effectiveness of biofertilizers can vary depending on factors such as the specific strain of microorganisms used, environmental conditions, and crop management practices. It's recommended to consult with agricultural experts or local agricultural extension services to determine the most suitable biofertilizer products and application methods for linseed cultivation in the specific region.

Biotechnological Advancements

Linseed is gaining optimum profit from the developments in biotechnology, which have shown promise in increasing crop output.

Genetic Improvement

It involves the application of biotechnological approaches to enhance the traits and characteristics of a crop through genetic engineering and marker-assisted selection. Here are some details on genetic improvement in the context of linseed:

Genetic engineering, often known as genetic modification, involves the manipulation of an organism's DNA to introduce or remove specific genes. Genes that provide desirable features, such as greater yield, enhanced oil quality, disease resistance, or tolerance to abiotic challenges, can be inserted into the linseed plant via genetic engineering techniques.Specific genes can now be inserted into linseed plants using genetic engineering techniques, improving their agronomic qualities. To produce linseed cultivars with different fatty acid profiles, for instance, researchers have successfully inserted genes encoding enzymes involved in fatty acid metabolism. According to a study by Banniza*et al.*, (2018), linseed was successfully modified with a gene producing a 12-desaturase enzyme, increasing the oil's -linolenic acid level.

Marker-Assisted Selection (MAS)

Breeders can choose plants with desired features based on genetic markers that are closely related to those attributes using the marker-assisted selection technique. By enabling breeders to screen and choose plants at an early stage without needing to do a thorough phenotypic evaluation, this method streamlines the breeding process. Through genomic research, markers connected to desirable features in linseed, such as high yield, oil content, disease resistance, or particular fatty acid profiles, can be found.Breeders can choose individuals who have the necessary qualities and include them in breeding programs by assessing the presence or absence of these genetic markers in linseed plants. This quickens the production of improved linseed types. For instance, Gupta *et al.*, (2017) developed linseed varieties resistant to the *Fusarium oxysporum* caused wilt disease, resulting in lower yield losses and increased productivity.

Gene Editing

Linseed's genome can be modified specifically using tools provided by gene editing technologies like CRISPR-Cas9. This method offers the potential to improve the production and agronomic aspects of linseed by specifically altering or deleting genes linked to particular attributes.Genetic changes that increase yield, quality, or tolerance to biotic or abiotic challenges can be introduced through gene editing.Researchers can develop linseed cultivars with improved resistance or tolerance by specifically targeting genes linked to disease susceptibility or sensitivity to environmental conditions.These methods of genetic improvement have the potential to hasten the creation of enhanced linseed cultivars with desirable features. However, while putting genetic engineering techniques into practice, it is crucial to take into account the legal landscape and public acceptability of genetically modified crops. To make sure that genetic improvement technologies are used in linseed farming safely and responsibly, close cooperation between researchers, breeders, and regulatory organizations is required.

Biostimulants and Plant Growth Regulators

Attention has been drawn to bio-stimulants and plant growth regulators as useful instruments for boosting the development and production of crops, including linseed. When used in the right amounts, these chemicals can have a positive impact on plant physiological systems and enhance nutrient uptake, root growth, and overall plant growth.Biostimulants are compounds or microorganisms that, when added to plants or the soil around them, stimulate the body's natural processes to improve nutrient availability, stress tolerance, and overall plant performance. Beneficial bacteria and fungi are microbial-based biostimulants that help plants grow by improving the nutrient cycle and promoting nutrient uptake. For instance, it has been demonstrated that *Azospirillum* and *Rhizobium* bacteria can boost linseed growth and yield by encouraging nitrogen fixation (Gupta *et al*., 2019).

Plant growth regulators (PGRs) govern several physiological processes in plants, such as cell division, elongation, and differentiation, whether they are synthetic or naturally occurring substances. They can be used to control a plant's reactions to stress, flowering, fruiting, and growth. PGRs have been used in the cultivation of linseed to enhance branching, flowering, and seed setting, thus increasing production. In the case of linseed, for instance, it has been demonstrated that the administration of gibberellic acid (GA3) increases plant height, branching, and yield (Verma *et al*., 2017).

Linseed growth and productivity may benefit from the combined use of biostimulants and plant growth regulators. These chemicals help boost crop performance and production by promoting nutrient uptake, root growth, and important physiological processes.Biotechnological approaches for micronutrient availability: Micronutrients play a crucial role in plant growth and development. Biotechnological interventions, such as the use of chelating agents and genetic engineering, have been explored to enhance the availability and uptake of micronutrients in linseed. For example, the overexpression of iron acquisition genes in linseed has resulted in improved iron uptake and increased tolerance to iron deficiency (Yadav *et al*., 2017).

Molecular Breeding Techniques

The field of crop improvement has been transformed by molecular breeding techniques, which have made it possible to choose and create enhanced linseed varieties with advantageous characteristics. These methods speed up breeding and improve the effectiveness of trait selection by utilizing molecular markers, genomics, and genetic engineering.

Marker-Assisted Selection (MAS)

To aid in the selection of desirable individuals for breeding programs, MAS uses molecular markers that are intimately linked to the target features. For features including disease resistance, oil content, and fatty acid composition in linseed, MAS has been used (Barvkar*et al*., 2012).

Genomic selection (GS)

For complicated traits, GS combines high-throughput genotyping and phenotyping data to forecast an individual's performance. According to Panday *et al*., (2016), this strategy may improve the precision and effectiveness of selection in linseed breeding programs.

Genotyping-by-Sequencing (GBS)

GBS is a low-cost genotyping technique that locates and genotypes genome-wide markers using next-generation sequencing technology. To find genetic variants and create high-density genetic maps in linseed, GBS has been used (Demeke *et al*., 2017).

Biotechnological Approaches for Stress Tolerance

Biotechnological interventions offer promising strategies to enhance stress tolerance in linseed, enabling the crop to withstand adverse environmental conditions. These approaches involve the manipulation of genes, signaling pathways, and physiological processes to enhance stress tolerance and improve crop performance under challenging conditions. Like, plant growth-promoting rhizobacteria (PGPR) are advantageous bacteria found in the soil, which can augment plant tolerance to stressful conditions. In the case of linseed, the utilization of PGPR has been demonstrated to ameliorate drought and salinity tolerance through the facilitation of nutrient absorption, stimulation of root development, and activation of stress-related mechanisms (Nagrale *et al*., 2023).

Genetic Engineering for Stress-Responsive Genes

Genetic engineering methods enable the incorporation of stress-responsive genes into linseed to amplify its capacity for stress tolerance. One illustration of this is the upregulation of stress-related transcription factors like DREB and MYB, which have demonstrated efficacy in enhancing linseed's ability to withstand drought and salinity stress (Wang *et al*., 2021).

Metabolic Engineering for Stress Tolerance

Metabolic engineering approaches involve the manipulation of metabolic pathways to enhance stress tolerance in linseed. For instance, the engineering of Osmo-protectant biosynthesis pathways, such as proline and glycine betaine, can enhance drought and salt stress tolerance in linseed (Chen *et al*., 2018).

RNA Interference (RNAi) Technology

RNAi-mediated gene silencing offers a powerful tool to downregulate the expression of stress-related genes in linseed. By suppressing the expression of stress-responsive genes, RNAi technology can enhance stress tolerance and improve crop performance under adverse conditions (Khare *et al*., 2018).

Biotechnology for quality Improvement

Genetic modification for improved oil composition: To improve the composition of linseed oil, genetic engineering approaches allow for the alteration of fatty acid production pathways. Determinable fatty acids, such as omega-3 fatty acids, can be found in higher concentrations in linseed oil thanks to the introduction of desaturase and elongase genes (Dong *et al*., 2019).Genomic diversity analysis for quality improvement: Analysis of genomic diversity can shed light on the genetic variation underlying linseed quality parameters. Breeders can create strategies to select and combine several alleles that contribute to superior quality in linseed by studying the genetic basis of quality traits (Sun *et al*., 2017).

Conclusion

Modern biotechnological developments have become effective tools along with agronomic practices for enhancing linseed output. Key genes related to stress tolerance, soil adaptation, and nutritional improvement can be altered using genetic engineering approaches. By using various techniques, it is possible to alter metabolic pathways to enrich linseed with valuable nutrients and bioactive substances. While genomic diversity research sheds light on the genetic variation underlying quality factors, marker-assisted and genomic selection help identify linseed variants with superior qualities.To maximize linseed growth and production, biostimulants, plant growth regulators, and nutrient management techniques have all been researched. These include the use of plant growth regulators for increased plant growth and development, biotechnological techniques for effective nutrient management, and the use of biostimulants for improved nutrient absorption and stress tolerance.Overall, there is a lot of opportunity to improve linseed growth, yield, and quality by combining conventional agronomic methods with biotechnology innovations. Farmers and breeders can fulfill the rising demand for linseed products by adopting these strategies to address the issues facing the agricultural sector. However, socio-economic and environmental effects of implementing biotechnology treatments in linseed farming must also be taken into account though. For these technologies to be used safely and sustainably, appropriate laws, risk assessments, and public education are essential.The assessment concludes by emphasizing the importance of various agronomical and biotechnological developments in resolving the difficulties faced by linseed production. The growth, production, and quality of linseed can be increased by utilizing the possibilities of genetic engineering, metabolic engineering, marker-assisted selection, and genomic analysis, aiding in the region's economic growth and food security.

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Authors Contribution

LS, AS, SB and Shivangi are involved in the complete writing of the article. JPM, SU and SKD are involved in the overall idea, conception and design of the article, and for giving crucial inputs and supervision from time to time. AA is involved in the overall formatting and editing, critical revision of tables and graphs, and improvement of the article.

Conflict of Interest

All the authors have no conflict of interest.

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