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Kanchan Uikey
M.Sc. Scholar, Department of
Agronomy, Sardar Patel
University, Balaghat, Madhya
Pradesh, India

JS Bisen
Associate Professor, Department of
Agronomy, Sardar Patel
University, Balaghat, Madhya
Pradesh, India

Uma Bermaiya
Senior Research Fellow, ICAR-
AICRP, PC Unit Sesame & Niger,
JNKVV, Jabalpur, Madhya
Pradesh, India

Devendra Turkar
Assistant Professor, Department of
Agronomy, Sardar Patel
University, Balaghat, Madhya
Pradesh, India

Corresponding Author:
Uma Bermaiya
Senior Research Fellow, ICAR-
AICRP, PC Unit Sesame & Niger,
JNKVV, Jabalpur, Madhya
Pradesh, India

Effect of integrated nutrient management on yield and yield attributes of linseed (*Linum usitatissimum* L.)

Kanchan Uikey, JS Bisen, Uma Bermaiya and Devendra Turkar

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Abstract

A field experiment was conducted during the *Rabi* season to evaluate the effect of integrated nutrient management on growth, yield attributes and productivity of linseed (*Linum usitatissimum* L.). The experiment comprised eight treatments including control, 100% recommended dose of fertilizers (RDF), and combinations of RDF with biofertilizers (PSB and *Rhizobium*) and vermicompost. The results revealed that integrated application of 100% RDF along with PSB and *Rhizobium* (T₅) significantly improved growth parameters, yield attributes and yield of linseed. The maximum plant height (56.83 cm), number of branches plant⁻¹ (7.11) and dry weight (8.27 g plant⁻¹) were recorded under T₅ at harvest. Yield attributes such as number of capsules plant⁻¹ (79.81), seeds capsule⁻¹ (8.80) and test weight (7.80 g) were also highest under the same treatment. Consequently, T₅ produced the highest seed yield (1350 kg ha⁻¹), straw yield (2697 kg ha⁻¹) and harvest index (33.36%), showing substantial improvement over control (903 kg ha⁻¹ seed yield). Among reduced fertilizer treatments, 75% RDF combined with vermicompost, PSB and *Rhizobium* (T₈) also recorded comparatively higher yield (1290 kg ha⁻¹), indicating partial substitution of chemical fertilizers through organic and biological sources. The study concluded that integration of RDF with dual biofertilizer inoculation significantly enhances growth, yield attributes and productivity of linseed under the prevailing agro-climatic conditions.

Keywords: Integrated nutrient management, linseed, PSB, *Rhizobium*, vermicompost, seed yield, harvest index, biofertilizers, productivity

1. Introduction

Linseed or flaxseed (*Linum usitatissimum* L.), commonly known as Alsí, Jawas and Aksebija in Indian languages (Anonymous, 2000) ^[1], belongs to the family Linaceae and is one of the oldest *Rabi* oilseed crops cultivated in central India. It is grown in more than 30 countries either as an oilseed or fibre crop, with fibre obtained from the stem and oil extracted from the seeds (Vaisey-Genser *et al.*, 2003) ^[19]. Linseed seeds contain about 41% oil, 20% protein and 28% dietary fibre and are particularly rich in polyunsaturated fatty acids, especially alpha-linolenic acid (omega-3), which accounts for 55–60% of total fatty acids (Morris, 2005; Bozan & Temelli, 2008) ^[11, 5]. Due to its health-promoting properties, including protective effects against cardiovascular diseases and certain cancers, linseed oil is increasingly used as a functional food (Herchi *et al.*, 2011) ^[9]. Globally, linseed is recognized as an important oilseed and fibre crop (Bainade *et al.*, 2019) ^[3], and its fibre is stronger than cotton (Taylor, 2012) ^[17]. In Madhya Pradesh, linseed occupied about 52 thousand hectares during rabi 2020 with productivity of 867 kg ha⁻¹, whereas in India it covered 179 thousand hectares with average productivity of 671 kg ha⁻¹ (Anonymous, 2021) ^[2]. The low productivity levels in the country do not reduce its economic significance which is a major contributor to the low productivity in the country due to poor and unbalanced management of nutrients (Verma *et al.*, 2005) ^[21]. The Integrated Nutrient Management (INM) as a complex of chemical and organic fertilizers, biofertilizers, and organic manures, is regarded as a necessary measure to maintain the crop yields and the soil fertility (Sharma and Saroa, 2017) ^[14]. Nitrogen plays a vital role in plant metabolism, growth and yield formation (Kumar *et al.*, 2000), while biofertilizers such as *Rhizobium* and Phosphate Solubilizing Bacteria (PSB) enhance nutrient availability and may reduce phosphorus fertilizer requirement by up to 50% without yield reduction (Yazdani *et al.*, 2009) ^[22]. Organic compounds such as vermicompost do not only provide macro- and micronutrients but also enhance the microbial activity in soil, the

processes of water retention, and humification (Sinha *et al.*, 2009; Patel *et al.*, 2021) ^[15, 12]. Thus, combination of organic and inorganic sources of nutrients is very essential to promote the effectiveness of nutrient utilization and maintain the health of the soil and growth and production of linseed in intensive cultivation systems (Gawai and Pawar, 2006) ^[6].

2. Materials and Methods

2.1 Experimental site

The field experiment was conducted during the *Rabi* season at Agronomy Research Farm, Sardar Patel University, located at Balaghat (M.P.). The district extends from 21°19' to 22°24' north latitude and 79°31' to 81°3' east longitude at an altitude of 498.77 m from mean sea level (MSL) in Madhya Pradesh. The average annual rainfall varies from 1000 to 1200 mm concentrated mostly from June to September. Before sowing,

composite soil samples (0–30 cm depth) were collected and analyzed for physicochemical properties such as pH, electrical conductivity (EC), organic carbon, and available nitrogen (N), phosphorus (P₂O₅), and potassium (K₂O) using standard procedures.

2.2 Experimental Details

The experimental crop was Linseed and Variety JL-66 developed at JNKVV and released in 2010. It matures in 107–114 days, short in height with white flowers and seeds are light brown in colour. The experiment was laid out in a Randomized Block Design (RBD) with three replications. A total of 8 plots were maintained during the study. Each plot measured 4.25 m × 3.25 m. The distance maintained between plots was 0.50 m and between replications was 1.0 m to avoid inter-plot interference.

Table 1: Treatment details

Treatments	Quantity
T ₁	Control
T ₂	100% Recommended Dose of Fertilizer (RDF)
T ₃	100 RDF + PSB 20 g kg ⁻¹ seeds
T ₄	100% RDF + <i>Rhizobium</i> 20 g kg ⁻¹ seeds
T ₅	100% RDF + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds
T ₆	75% RDF + 1 tonn/ha vermicompost + PSB 20 g kg ⁻¹ seeds
T ₇	75% RDF + 1 tonn/ha vermicompost + <i>Rhizobium</i> 20 g kg ⁻¹ seeds
T ₈	75% RDF + 1 tonn/ha vermicompost + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds

2.3 Crop Management Practices

The field was prepared by thorough ploughing followed by harrowing and leveling to obtain a fine tilth. The recommended dose of fertilizers was applied at the rate of 50 kg ha⁻¹ N, 40 kg ha⁻¹ P₂O₅, 20 kg ha⁻¹ and K₂O and apply 1 tonn ha⁻¹ vermicompost. The full dose of phosphorus and potassium along with half of nitrogen was applied as basal dose at the time of planting. The remaining half of nitrogen was top-dressed at 30 days after sowing. Before sowing the seeds were treated with a liquid formulation of PSB & *Rhizobium japonicum* @ 20 gm per kg seed. Irrigation was provided at regular intervals depending on soil moisture status and crop requirement. Standard plant protection measures were adopted to control pests and diseases as and when required. Weed management was carried out manually to maintain a weed-free environment.

2.4 Statistical analysis

The experimental data was analyzed by the Fisher method of analysis of variance. Critical differences were calculated at probability of 5% wherever F values was significant.

3. Results and Discussion

3.1 Plant Height

The Table 2 and Figure 1 data showed that plant height of linseed significantly increased with all the growth stages that were subjected to integrated nutrient management measures. The highest plant height (19.87 cm) at 30 DAS was also highest in T₅ (100% RDF + PSB + *Rhizobium*) which was significantly higher than the control (11.00 cm). The same superiority in combined application of RDF and biofertilizer was also observed by Gudadhe *et al.* (2005) ^[7] in mustard where the inoculation of *Azotobacter* and PSB with RDF in enhancing early vegetative growth was reported to increase the height of the plant. T₅ showed better values at 60 DAS and 90 DAS (41.23 cm and 51.27 cm respectively), and this is supported by the results of Tripathi *et al.* (2011) ^[18], who indicated an important

improvement in the height of plants with 100% RDF + FYM + biofertilizers. T₅ gave the maximum value of the plant height of 56.83 cm at harvest, then T₄ (54.77 cm) and T₃ (54.30 cm), and the control (49.03 cm) gave the lowest value. The observation of positive response of linseed to combination of nutrient application compares with the findings of Rahimi *et al.* (2011) ^[13] who have observed that there is a significant increase in height of the plant with increase in nitrogen in linseed. Similarly, Lawania *et al.* (2015) ^[10] reported improved growth characteristics when nitrogen, sulphur and biofertilizers were used together in linseed. Out of reduced fertilizer treatments, T₈ (75% RDF + vermicompost + PSB + *Rhizobium*) was better than 75% RDF treatments, which is agreeable to Bera *et al.* (2014) ^[4] and Hadiyal *et al.* (2017) ^[8], who noted that interaction of organic manure with biofertilizer enhances vegetative growth in terms of microbial activity and nutrient mobilization. The enhanced plant height in the nutrient management conditioned by the improved interaction between inorganic fertilizers with biofertilizers may be justified by the fact that inorganic and biofertilizers promote improved chlorophyll formation, protein synthesis, and cell lengthening. This is the message Sood *et al.* (2020) ^[16] conveyed as they concluded that the growth parameters and accumulation of dry matter in the presence of integrated nutrient supply eventually led to high crop performance in linseed. Consequently, the current results have a clear indication that the combination of 100 percent RDF and the use of 100 percent biofertilizers in inoculating the plants are capable of significantly improving plant height when compared to the use of single application of fertilizers or lower application of fertilizers.

3.2 Number of Branches plant⁻¹

The results provided in Table 2 and Figure 2 also showed that the number of branches per 1 of plant was significantly affected by integrated nutrient management treatments at all the growth stages. The most high number of branches was observed at T₈

(75 percent RDF + vermicompost + PSB + *Rhizobium*) (2.61), which was a significantly better control (1.55). The initial increase in number of branches with integrated nutrient supply is in line with Gudadhe *et al.* (2005) ^[7] who also have increased number of the branches in mustard upon inoculating *Azotobacter* and PSB with RDF together. But after 60 DAS, T₅ (100% RDF + PSB + *Rhizobium*) showed the definite superiority as they registered 6.02, 7.07 and 7.11 branches at 60, 90 and harvest respectively which were so different compared to control (4.88, 5.96 and 6.07). Tripathi *et al.* (2011) ^[18] found similar improvement in branches plant⁻¹ with integrated nutrient management and explained this increase as the higher nutrient availability and enhanced vegetative growth as a result of RDF + FYM + biofertilizers. The betterment of T₀ compared to sole RDF (T₂) is an indication of the extra value added to the growth of lateral growth by the biofertilizers. This observation supports the results of Rahimi *et al.* (2011) ^[13], who indicated that the higher the level of nitrogen was, the greater the vegetative development and yield components in linseed. Similarly, Lawania *et al.* (2015) ^[10] have also reported a substantial enhancement in the branching and yield characteristics of linseed when nitrogen and biofertilizers are used jointly. In addition, Sood *et al.* (2020) ^[16] highlighted that a combined nutrient provision enhances the production and yield of characteristics of dry matter that are associated with plants yields like branches plant⁻¹ in linseed. The increased branching may be explained by the balanced supply of nutrients, the better growth of roots, the increased photosynthetic efficiency and improved assimilate partitioning to lateral buds. Conversely, low levels of branching could be a result of the lack of nutrients to facilitate vegetative growth. Therefore, it is evident that the current results revealed that the combination of RDF and PSB and *Rhizobium*, especially at T₅, enhanced the branching of linseed significantly when applied alone or diluted.

3.3 Dry Weight (g plant⁻¹)

The data presented in Table 2 and depicted in Figure 3 revealed that dry weight of linseed increased progressively from 30 DAS to harvest under all integrated nutrient management treatments. The peak of dry weight (0.19 g plant minus 1 g plant⁻¹) was observed at T₅ (100% RDF + PSB + *Rhizobium*) which was better than control (0.14 g plant⁻¹). This positive response of early growth of dry matter under integrated nutrient application is consistent with the observations made by Gudadhe *et al.* (2005) ^[7] who concluded that production of the dry matter is increased as a result of combined use of RDF and biofertilizers. We found that at 60 DAS, T₅ was the only sample that had maximum dry weight (3.63 g plant⁻¹), with T₄ coming in close (3.58 g plant⁻¹), and control registering the lowest (2.80 g plant⁻¹) level. Also comparable increase in biomass accumulation was observed when integrated nutrient management was used in the studies given by Tripathi *et al.* (2011) ^[18] and was attributed to the availability of balanced nutrients and increased vegetative development. T₅ showed its superiority at 90 DAS and at harvest with 7.95 and 8.27 g plant⁻¹ dry weight, respectively, significantly higher than control (6.84 and 7.10 g plant⁻¹). The increased dry matter T₅ could be as a result of synergistic activity of chemical fertilizers and biofertilizers which leads to better fixation of nitrogen, solubilization of phosphorus and increased uptake efficiency of nutrients. This finding supports the research of Rahimi *et al.* (2011) ^[13] where the authors indicated that the accumulation of biomass in linseed grew with the increase in nitrogen concentration. Similarly, Lawania *et al.* (2015) ^[10] found that the use of nitrogen and biofertilizers

together in linseed led to a great improvement in the characteristics of dry matter and yield. Of the diluted treatments of fertilizer, T₈ (75% RDF + vermicompost + PSB + *Rhizobium*) had a relatively higher case of dry weight (7.73 g of plant at harvest) as compared to T₈ and T₉ which meant that vermicompost was advantageous in enhancing the soil microbial activity and nutrient mineralization. This observation is confirmed by Hadiyal *et al.* (2017) ^[8], Sood *et al.* (2020) ^[16], who clarified that integrated nutrient management increases the production of the dry matter by improving the health of the soil and the availability of nutrients.

3.4 Number of Capsules plant⁻¹

The data presented in Table 3 and illustrated in Figure 4 revealed that the number of capsules plant⁻¹ was significantly influenced by integrated nutrient management treatments. Among the treatment T₅ (100% RDF + PSB + *Rhizobium*) had the highest number of capsule plant⁻¹ (79.81), which was far much better than control (65.37). T₅ being better than sole RDF (T₂, 73.18) shows the extra advantage of dual biofertilizer inoculation and recommend fertilizer dose. Enhancement in capsules plant⁻¹ was also seen in more or less the same way; Rahimi *et al.* (2011) ^[13] found that yield components of linseed were increased significantly with the increase in nitrogen concentration applied. Similarly, Lawania *et al.* (2015) ^[10] showed increased capsules per plant at the use of combined nitrogen and biofertilizers in linseed. T₄ (100% RDF + *Rhizobium*) had a record of 78.44 capsules plant⁻¹ and was statistically equivalent to T₅, respectively indicating that the biological fixation of nitrogen played a significant role in reproductive development. This observation is in agreement with results of Tripathi *et al.* (2011) ^[18] who showed improved siliquae plant⁻¹ in RDF with the use of organic and biofertilizer sources. The treatment with 75% RDF percentage and the use of vermicompost and biofertilizers (T₆, T₇ and T₈) also showed moderate numbers of capsules (72.59, 72.40 and 73.14) having significant value when compared to the control but lower than the integrated treatment of 100 percent RDF. Several other studies also reported similar trends by noting the presence of improved yield attributes with combined use of biofertilizer as reported by Bera *et al.* (2014) ^[4], and also known as integrated nutrient management as reported by Sood *et al.* (2020) ^[16], which has been observed to improve yield contributing characters in linseed. The higher quantity of capsules in the treatments under integrated conditions could be explained by the better nutrient supply during the critical period of reproductive activity, higher photosynthetic activity and more appropriate distribution of assimilates to the reproductive organs. Nitrogen stimulates vegetative development and flower development, whereas phosphorus also has a major role in transfer of energy and reproductive processes. Biofertilizers also increase the mobility of the nutrients and the ability to absorb the nutrients leading to better capsule formation.

3.5 Number of Seeds capsule⁻¹

The statistics of Table 3 and Figure 4 revealed that integrated nutrient management treatments had a significant effect on the number of seeds capsule⁻¹. Seed capsule⁻¹ was greatest in T₅ (100% RDF + PSB + *Rhizobium*) which was significantly better than control (6.10). The growth under T₅ was also more than even sole RDF (T₂: 8.50), which means that there is an added advantage by using biofertilizer twice. Rahimi *et al.* (2011) ^[13] also found a comparable situation with seeds per capsule when nitrogen was supplied to seeds integrated which showed a

significant increase in yield components of linseed as the nitrogen level increased. Similarly, Lawania *et al.* (2015) ^[10] reported an increase in seeds capsule⁻¹ in the case of integrated use of biofertilizers and nitrogen in linseed. Of all the RDF-based treatments, 100% RDF + *Rhizobium* (T₄) registered 8.73 seeds capsule⁻¹ and was statistically comparable to T₅, which underlines the critical role of biological nitrogen fixation in the development of the reproductive organs. This observation agrees with Tripathi *et al.* (2011) ^[18], who indicated high number of seeds per siliqua in cases of combined use of fertilizer and biofertilizer. Treatments that were dotted with 75% RDF and biofertilizers (T₆, T₇ and T₈) rendered moderate values (7.87, 7.83 and 8.46), which were greater than control but less than 100 percent RDF-based integrated treatments. Bera *et al.* (2014) ^[4] also found some similar tendencies in their research and found that seed set improves with the inoculation of biofertilizer and Sood *et al.* (2020) ^[16], who also note that integrated nutrient management produces more yield in its characters of linseed. Hence, it is evident in the current results that 100% RDF with PSB and *Rhizobium* has a considerable effect of improving number of seeds capsule⁻¹ in linseed relative to single or less application of fertilizer.

3.6 Test Weight (g)

The results represented in Table 3 and depicted in Figure 5 indicated that test weight of linseed was significantly affected by various integrated nutrient management treatments. T under T₅ (100% RDF + PSB + *Rhizobacter*) produced the highest test weight (7.80 g) and was significantly better than control (6.17 g). The growth of test weight at T₅ was as well greater than singular RDF (T₂: 7.37 g) and indicates the extra benefit of dual biofertilizer inoculation and the suggested dose of fertilizer. The same improvement in test weight was found by Lawania *et al.* (2015) ^[10], who recorded a considerable increase in yield characteristics such as seed weight when nitrogen and biofertilizers were used in the integrated application in linseed. Of all the RDF based treatments T XIV (100% RDF + *Rhizobium*) had a 7.67 g test weight and was similar to T₅ indicating the relevance of biological nitrogen fixation in seed development. This result concurs with the report by Rahimi *et al.* (2011) ^[13] which indicated a weight gain of the kernel with an increase in nitrogen levels. Median treatments of 75% RDF and biofertilizers (T₆, T₇ and T₈) also gave moderate values (7.33, 7.73 g), which were also good at control even though slightly lower than full RDF integrated treatments. Tripathi *et al.* (2011) ^[18] also indicated similar observations by having higher weight of 1000 seeds at the end of integrated nutrient application in mustard. This increase in test weight in integrated treatments could be due to the availability of nutrients at the stage of seed filling and the increase of photosynthetic efficiency and translocation of assimilates to maturing seeds. Nitrogen is an important element in the formation of proteins and in filling of the seeds whereas phosphorus is involved in the transfer of energy needed in the development of grain. Biofertilizers also increase the efficiency of nutrient uptake leading to an improved seed growth and test weight. Sood *et al.* (2020) ^[16] also corroborated the current results by documenting that integrated nutrient management had a considerable effect on seed weight and total yield in linseed.

3.7 Seed Yield plant⁻¹ (g)

The figures in Table 3 and the graph in Figure 5 showed that there were numerically significant differences between seed yield per one treated with integrated nutrient management. The

maximum seed yield plant⁻¹ (5.48 g) and T₄ (5.25 g) and T₃ (4.84 g) were found respectively, and the minimum yield was found in control (2.46 g). Even though these differences are not statistically significant, the numerical existence of the superiority of T₅ compared to sole RDF (T₂: 4.58 g) indicates that dual biofertilizer inoculation combined with the recommended dose of fertilizer affects it positively. Rahimi *et al.* (2011) ^[13] also observed a similar pattern of increased seed yield in case of increased application of nitrogen where they found that the seed yield of linseed increased with increased application of nitrogen. The relative better yield at T₅ could be blamed to have better yield characteristics like number of capsules plant⁻¹, number of seeds capsule⁻¹ and test weight at the same treatment. The results are consistent with another study by Lawania *et al.* (2015) ^[10], who have found that there were notable improvements in seed yield of the linseed in cases where nitrogen and biofertilizers were used in combination. Similarly, Tripathi *et al.* (2011) ^[18] found an increase in seed yield when the combined management of nutrients RDF and biofertilizers was employed. Treatments that received 75% RDF as well as the use of vermicompost and biofertilizers (T₆, T₇ and T₈) yielded moderate levels (4.19, 4.27 and 4.78 g) which showed that organic and biologically produced fertilizers partly replaced reduced chemical fertilizer. It is possible that the enhancement of seed yield with integrated treatments can be explained by availability of balanced nutrients, the increase of nutrient uptake efficiency and redistribution of assimilates to reproductive organs. Nitrogen encourages vegetative growth and reproductive development and phosphorus encourages energy transfer and seed formation. Biofertilizers also play the role of fixing nitrogen and solubilizing phosphorus which enhances general crop performance. Sood *et al.* (2020) ^[16] also reported similar perceptions and pointed out that integrated nutrient management improved the yield performance of linseed by improving the growth and yield contributing characters. Therefore, the integrated use of RDF and PSB and *Rhizobium* (T₅) had the best numeric seed yield plant⁻¹ in comparison to the rest of the treatments, albeit non-statistically significant.

3.8 Seed Yield (kg ha⁻¹)

The results in Table 3 and Figure 6 showed that there was a significant effect on seed yield of linseed by integrated nutrient management treatments. The maximum seed production (1350 kg ha⁻¹) was obtained with T₅ (100% RDF + PSB + *Rhizobium*) and significantly high than with control (903 kg ha⁻¹). The growth percentage in T₅ was approximately 49.5 percent as compared to control which means the positive response of linseed to combined nutrient supply is strong. The excellent performance of T₅ compared to a single application of RDF (T₂: 1203 kg ha⁻¹) is a clear indication of the added value of dual biofertilizer inoculation. Similar increase in the seed yield of linseed was documented by Rahimi *et al.* (2011) ^[13] who found out that an increase in the level of nitrogen resulted in an increase in seed yield. Of the 100% treatment based on RDF, T₄ (100% RDF + *Rhizobium*) was found to be 1243 kg ha⁻¹, whereas T₃ (1230 kg ha⁻¹) was greater than the RDF alone, which had a negative role to play. These findings correspond to Lawania *et al.* (2015) ^[10], who found higher seed yield with the application of both nitrogen and biofertilizers in linseed. On the same note, Tripathi *et al.* (2011) ^[18] noted that seed yield was improved with integrated nutrient management using RDF and biofertilizer. Out of the 75% RDF treatments, T₈ (1290 kg ha⁻¹) showed better performance as compared to T₆ and T₇, indicating that vermicompost with dual biofertilizers might partially

replace the lower dose of chemical fertilizer. Similar results were obtained by Verma and Yadav (2017) ^[20] who emphasized that a combination of inorganic fertilizers with vermicompost and biofertilizers was highly productive in terms of rainfed linseed. The increased seed yield in the case of integrated treatments could be explained by the improved growth parameters, the increase in the number of capsules per plant⁻¹, the increase in the seeds capsule⁻¹ and in the test weight in cases of the same treatments. Even distribution of nutrients in the vegetative and reproductive stages increases the photosynthetic efficiency, assimilation partitioning and seed filling. Biofertilizers also help in biological fixation of nitrogen and increased mobilization of nutrients that results in better utilisation of nutrients. A comparable conclusion was made by Sood *et al.* (2020) ^[16] who have found that the integrated nutrient management enhanced yield and nutrient uptake in linseed significantly.

3.9 Straw Yield (kg ha⁻¹)

The data presented in Table 3 and illustrated in Figure 6 revealed that straw yield of linseed was markedly influenced by integrated nutrient management treatments. The highest straw production (2697 kg ha⁻¹) was obtained at T₅ (100 percent RDF + PSB + *Rhizobium*) which was significantly more than control (2063 kg ha⁻¹). The growth under T₅ was approximately 30.7 percent better than control which means that vegetative biomass growth is increased by combined nutrient provision. The fact that T₅ is greater than solitary RDF (T₂: 2530 kg ha⁻¹) indicates the added advantage of the use of dual biofertilizer inoculation in enhancing vegetative development. Rahimi *et al.* (2011) ^[13] also reported a similar increase in the yield of straw under integrated nutrient management, noting that with an increase in the application of nitrogen levels, biomass yield in linseed also increased.

T₄ (2567 kg ha⁻¹) and T₃ (2563 kg ha⁻¹) were also found to induce more straw output than RDF alone among the 100% RDF-based treatments, which showed the beneficial effect of *Rhizobium* and PSB on vegetative growth. These results fit

Lawania *et al.* (2015) ^[10] who have found that the use of nitrogen and biofertilizer combined resulted in a significant increase in the yield attributes and biomass during the growing of linseed. In the same way, Tripathi *et al.* (2011) ^[18] found that stover yield was high in the integrated nutrient management practices. TUMC- T₈ (2633 kg ha⁻¹) had a better performance as compared to T₆ and T₇, and thus it might be argued that vermicompost and dual biofertilizers may partially offset the lowered chemical fertilizer levels. Verma and Yadav (2017) ^[20] also reported similar findings, as they recorded an improved biomass production when inorganic fertilizers, vermicompost and biofertilizers were used together in linseed-based systems.

3.10 Harvest Index (%)

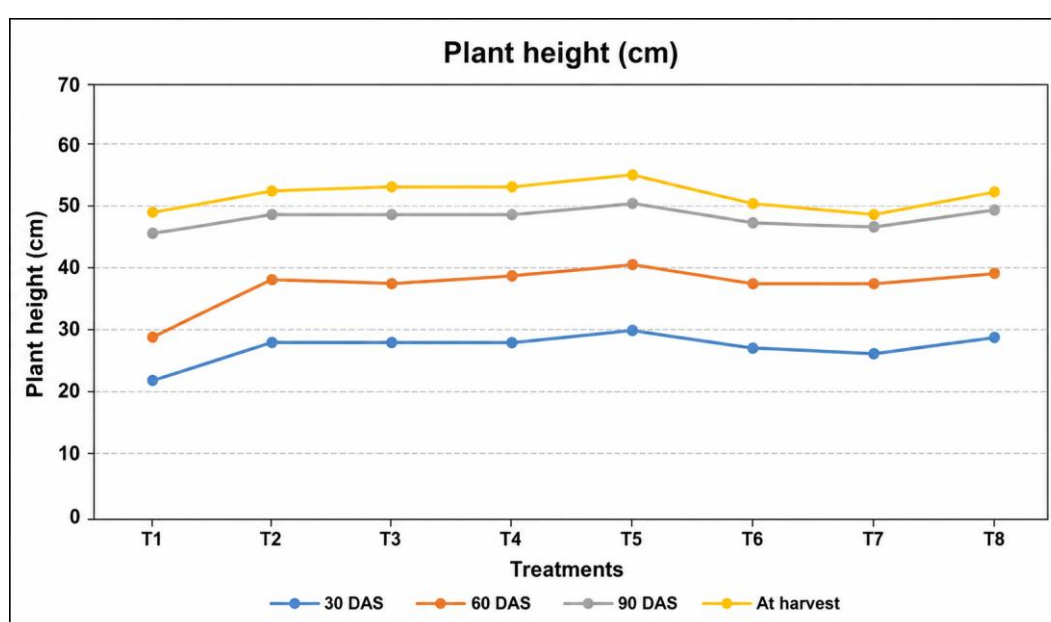
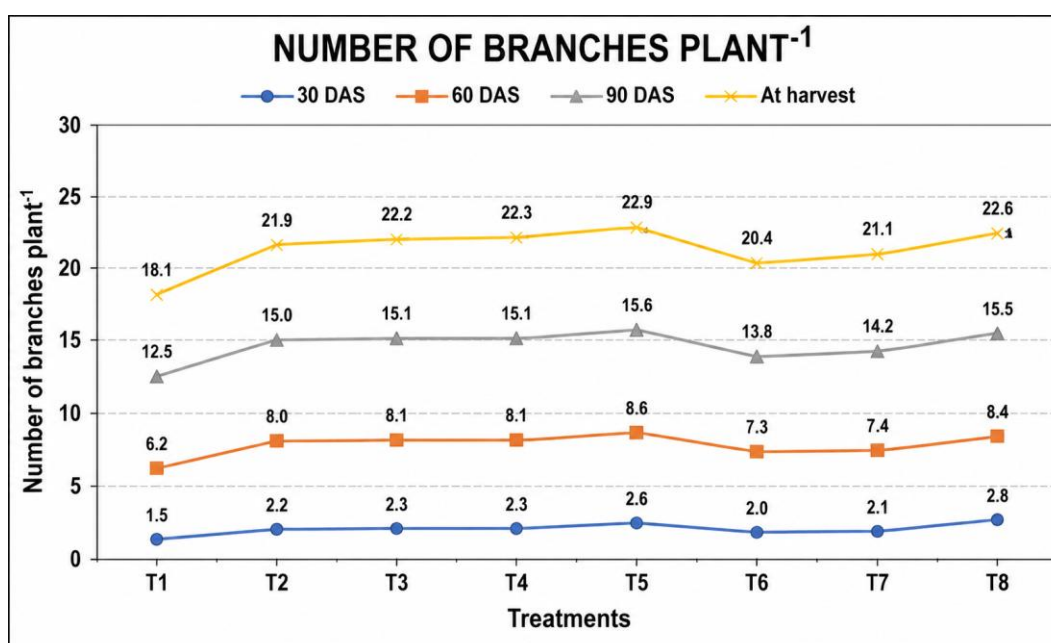
The data presented in Table 3 and illustrated in Figure 6 indicated that harvest index (%) of linseed was influenced by integrated nutrient management treatments. The greatest harvest index of T₅ (100% RDF + PSB + *Rhizobium*) was 33.36 then T₈ (32.87) and T₄ (32.64), and the lowest index was 30.46 under control. The enhancement in harvest index at T₅ implies an increase in partitioning of assimilates to economic yield (seed) over vegetative biomass. Rahimi *et al.* (2011) ^[13] also reported a comparable improvement in harvest index when using combined nutrient supply, which showed better yield components and economic yield of linseed at increased levels of nitrogen. The excellence of T₅ compared to single RDF (T₂: 32.19) implies the positive impact of dual biofertilizer inoculation on enhancing the use of nutrients and assimilate translocation to seeds. This observation is consistent with Lawania *et al.* (2015) ^[10] who cited a great advance in yield attributes and seed yield with the concomitant use of nitrogen and biofertilizers in linseed. Similarly, Tripathi *et al.* (2011) ^[18] found increased yield performance and effective nutrient utilization with integrated practices of nutrient nutritional management. Out of the lower fertilizer regimes, T₈ had a relatively higher harvest index (32.87) than T₆ and T₅, and it was found that vermicompost and biofertilizers complemented nutrient balance and source sink relationship even at lower level of RDF.

Table 2: Effect of integrated nutrient management on plant height (cm), Number of branches plant⁻¹ and Dry weight (g) of linseed at growth stages

Treatment No.	Treatments	Plant height (cm)				Number of branches plant ⁻¹				Dry weight (g)			
		30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T ₁	Control	11	28.5	45.57	49.03	1.55	4.88	5.96	6.07	0.14	2.8	6.84	7.1
T ₂	100% Recommended Dose of Fertilizer (RDF)	17.8	38.67	48.93	53.43	2.33	5.67	6.93	7	0.16	3.53	7.54	7.66
T ₃	100 RDF + PSB 20 g kg ⁻¹ seeds	17.93	38.1	48.9	54.3	2.39	5.76	6.96	7.06	0.17	3.55	7.62	7.83
T ₄	100% RDF + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	17.77	39.2	49.03	54.77	2.37	5.79	6.99	7.08	0.18	3.58	7.77	7.96
T ₅	100% RDF + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	19.87	41.23	51.27	56.83	2.47	6.02	7.07	7.11	0.19	3.63	7.95	8.27
T ₆	75% RDF + 1 ton/ha vermicompost + PSB 20 g kg ⁻¹ seeds	17.07	37.97	48.17	50.83	2.11	5.48	6.33	6.48	0.16	3.5	7.47	7.66
T ₇	75% RDF + 1 ton/ha vermicompost + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	15.73	37.97	48.17	48.33	2.14	5.54	6.54	6.51	0.16	3.37	7.37	7.53
T ₈	75% RDF + 1 ton/ha vermicompost + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	18.63	39.67	50.47	53.13	2.61	5.96	6.96	6.92	0.17	3.62	7.55	7.73
	SEM (±)	0.6	0.76	0.74	0.79	0.09	0.11	0.04	0.03	0.01	0.02	0.12	0.14
	CD at 5%	1.82	2.31	2.25	2.41	0.28	0.34	0.12	0.08	0.02	0.06	0.38	0.43

Table 3: Effect of integrated nutrient management on number of capsules plant⁻¹, seeds capsule⁻¹, test weight (g), seed yield plant⁻¹ (g), seed yield (kg ha⁻¹), straw yield (kg ha⁻¹) and harvest index (%) of linseed

Treatment No.	Treatments	Number of capsules plant ⁻¹	Number of seeds capsule ⁻¹	Test weight	Yield plant ⁻¹ (g)	Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index (%)
T ₁	Control	65.37	6.1	6.17	2.46	903	2063	30.46
T ₂	100% Recommended Dose of Fertilizer (RDF)	73.18	8.5	7.37	4.58	1203	2530	32.19
T ₃	100 RDF + PSB 20 g kg ⁻¹ seeds	75.11	8.6	7.5	4.84	1230	2563	32.41
T ₄	100% RDF + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	78.44	8.73	7.67	5.25	1243	2567	32.64
T ₅	100% RDF + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	79.81	8.8	7.8	5.48	1350	2697	33.36
T ₆	75% RDF + 1 tonn/ha vermicompost + PSB 20 g kg ⁻¹ seeds	72.59	7.87	7.33	4.19	1160	2577	31.04
T ₇	75% RDF + 1 tonn/ha vermicompost + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	72.4	7.83	7.53	4.27	1193	2600	31.46
T ₈	75% RDF + 1 tonn/ha vermicompost + PSB 20 g kg ⁻¹ seeds + <i>Rhizobium</i> 20 g kg ⁻¹ seeds	73.14	8.46	7.73	4.78	1290	2633	32.87
	SEM (±)	0.58	0.09	5.54	3.31	31.32	21.21	0.58
	CD at 5%	1.77	0.28	NS	NS	95	64.34	1.75

**Fig 1:** Plant height (cm) of linseed as influenced by integrated nutrient management at different growth stages**Fig 2:** Number of branches plant⁻¹ of linseed under different integrated nutrient management treatments

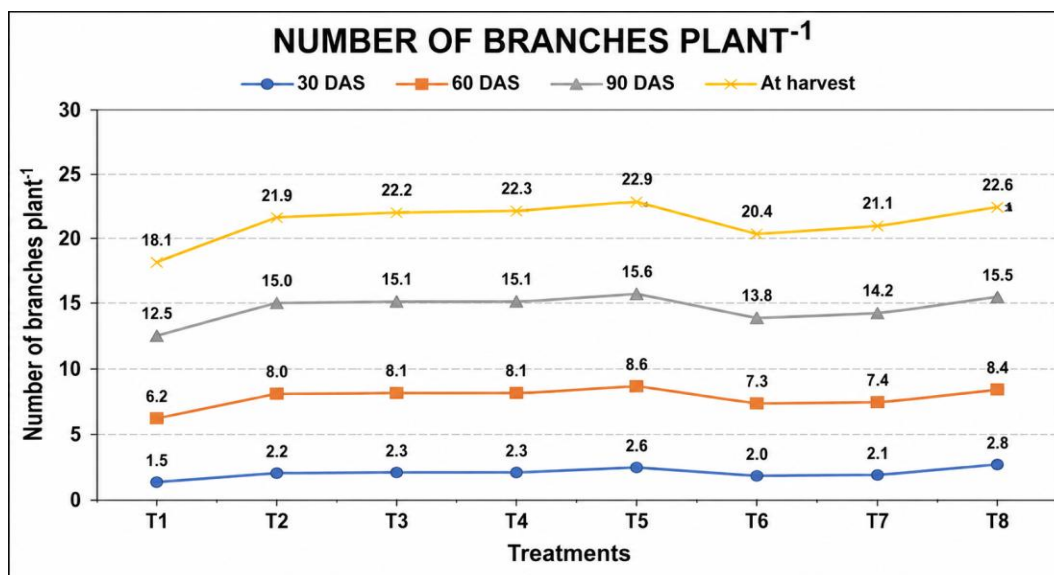


Fig 3: Dry matter accumulation (g plant^{-1}) of linseed as affected by integrated nutrient management

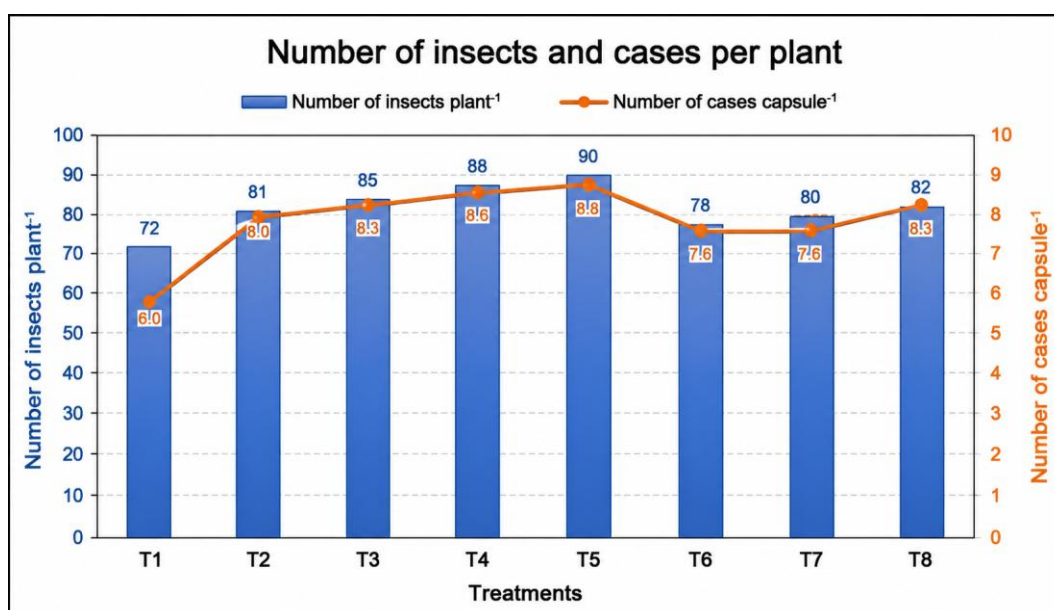


Fig 4: Number of capsules plant⁻¹ and Number of seeds capsule⁻¹ of linseed under integrated nutrient management treatments

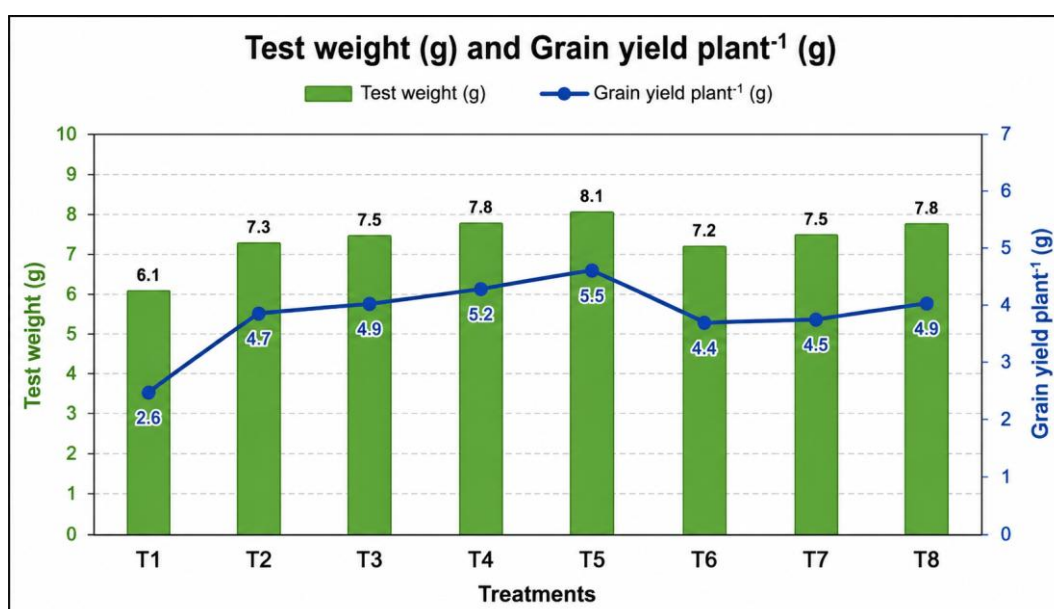


Fig 5: Test weight (g) and yield plant⁻¹ (g) of linseed under different integrated nutrient management treatments

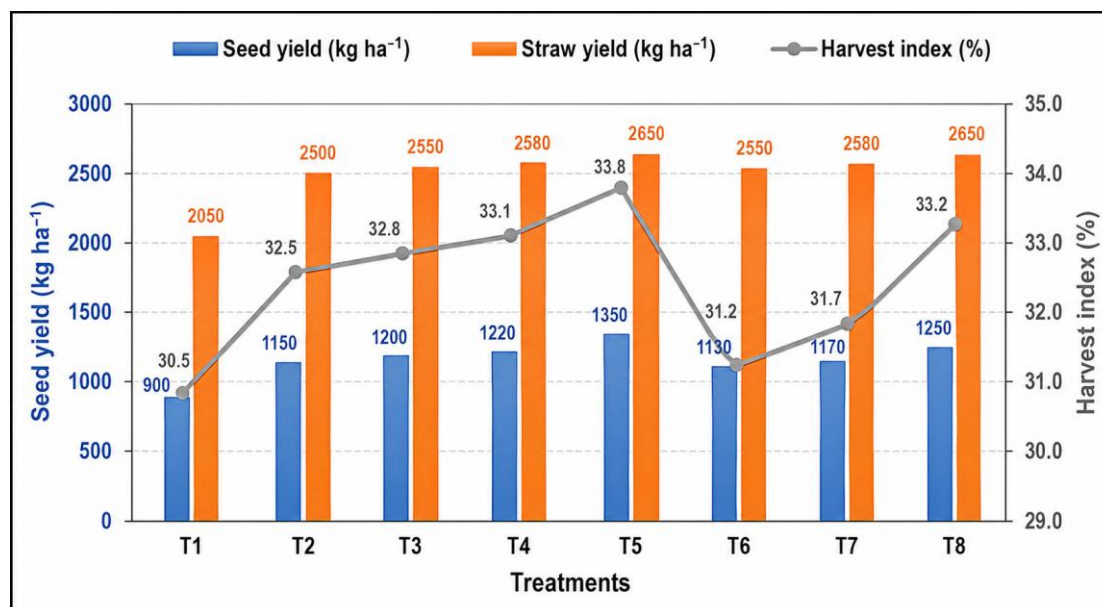


Fig 6: Seed yield (kg ha⁻¹), Straw yield (kg ha⁻¹) and Harvest index (%) of linseed under integrated nutrient management practices

4. Conclusion

According to the outcomes of the experiment, one can conclude that integrated nutrient management significantly enhanced the growth, yield properties and productivity of linseed. The culture T₅-100% of RDF + PSB + *Rhizobium* was observed to be performing better on most parameters. It had the highest harvest height (56.83 cm), the highest number of branches of the plant per 1 (7.11), the highest dry weight (8.27 g plant⁻¹), the greatest number of capsules per plant (79.81), the greatest number of seeds per cap (8.80), and the greatest test weight (7.80 g). Therefore, T₅ gave maximum seed yield plant⁻¹ (5.48 g), maximum seed yield (1350 kg ha⁻¹), maximum straw yield (2697 kg ha⁻¹), and high harvest index (33.36%), whereas the control given 903 kg kg ha⁻¹ seed yield and 30.46% harvest index. Even though the lower fertilizer treatment T₈ (75% RDF + vermicompost + PSB + *Rhizobium*) was also doing well by registering 1290 kg ha⁻¹ seed yield and harvest index of 32.87%, it was still marginally lower compared to T₅. The lowest values of the growth and yield parameters were always observed in the control treatment which confirmed that it is necessary to have balanced nutrient application. Therefore, the combination of recommended dose of fertilizers with dual biofertilizer inoculation (PSB + *Rhizobium*) was the most effective in optimal vegetation growth, yield characteristics, biomass and total productivity of linseed under the current agro-climatic conditions.

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