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Effect of Seed Pelleting with Microbial and Organic Filler Materials on Growth and Yield of Linseed (*Linum usitatissimum* L.)

RACHANA HS[1*], SR DODDAGOUDAR[1], BS GANIGARA[2], SANGEETA I MACHA[1] AND N ANANDA [3]

[1]Department of Seed Science and Technology, University of Agricultural Sciences, Raichur, Karnataka-584104, India
[2]Department of Seed Science and Technology, College of Agriculture, Bheemarayanagudi, University of Agricultural Sciences, Raichur, Karnataka-585287, India
[3]AICRP on linseed, MARS, University of Agricultural Sciences, Raichur, Karnataka-584104, India
*rachugowda1920@gmail.com

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ABSTRACT: Linseed (*Linum usitatissimum* L.) is an important oilseed crop, but its small seed size often hampers uniform sowing and seedling establishment. Seed pelleting is an effective technique to enhance seed handling, precision planting, and delivery of beneficial bio-inoculants. A field experiment was conducted to evaluate the effect of different pelleting materials on emergence, growth, yield, and yield attributes of linseed. Eight treatments comprising microbial inoculants (*Trichoderma viride*, *Azospirillum brasilense*, *Metarhizium anisopliae*), organic leaf powders (*Pongamia pinnata*, *Prosopis juliflora*, *Azadirachta indica*), fly ash, and an unpelleted control were tested in a randomized block design with three replications. Seed pelleting significantly improved crop performance compared to the control. Pelleting with *Metarhizium anisopliae* at a 1:3 ratio recorded the highest field emergence (98.25%), plant height (42.93 cm), number of branches (5.47), capsules per plant (39.94), 1000-seed weight (8.66 g), seed yield per plant (1.83 g), and yield per hectare (894 kg ha^{-1}). The unpelleted control showed the lowest values for all parameters. The study concludes that microbial-based pelleting with *Metarhizium anisopliae* is an effective and eco-friendly strategy to enhance seedling vigour, crop establishment, and productivity of linseed.

Keywords: Filler materials, linseed, pelleting, seed yield

Linseed (*Linum usitatissimum* L.), a vital winter oilseed crop belonging to the family Linaceae, is cultivated worldwide for its dual-purpose utility as a source of edible oil and natural fibre. The crop is believed to have originated in the Mediterranean region and Southwest Asia and is known locally in India as Agasi, Jawas, or Alashi. Among the more than 200 species within the genus *Linum*, *L. usitatissimum* is the only species cultivated extensively for commercial purposes. Linseed seeds possess exceptional nutritional value, being rich in á-linolenic acid (55–60%), an essential omega-3 fatty acid associated with reduced serum cholesterol levels and improved cardiovascular health [1]. In addition, linseed is a valuable source of lignans with anticancer properties and contains approximately 41% oil, 28% dietary fibre, 21% protein, along with several essential micronutrients [2].

Globally, linseed is grown over an area of about 32.23 lakh ha with a total production of 30.68 lakh tonnes and an average productivity of 952 kg ha^{-1} [3]. India contributes nearly 14.88% of the global area and 6.57% of world production, ranking third in area and fourth in production. Within the country, linseed is predominantly cultivated in Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, Karnataka, and Assam, with an average national productivity of 698 kg ha^{-1}, which remains considerably lower than the global average [4].

Despite its economic and nutritional importance, linseed cultivation faces several agronomic constraints that limit productivity. The extremely small seed size makes uniform sowing difficult, often leading to higher seed rates, uneven plant population, wastage of high-quality seed, and increased labor costs associated with thinning. Poor crop establishment consequently remains a major challenge, particularly under rainfed and marginal production systems. Enhancing the effective seed size is therefore considered a practical approach to overcome these limitations, and seed pelleting has emerged as a promising pre-sowing seed enhancement technique [5].

Seed pelleting is a process in which individual seeds are coated with inert or bioactive filler materials and suitable adhesives to form spherical or globular units of uniform size and weight. This modification facilitates precision sowing, improves seed handling, and ensures uniform seed placement and crop stand establishment [6]. Beyond physical enhancement, seed pelleting provides an opportunity to deliver nutrients, biofertilizers, plant growth-promoting microorganisms, and protective agents directly to the seed, thereby creating a favorable micro-environment for germination and early seedling growth. The filler materials improve moisture retention around the seed, while bioactive components enhance seedling vigor, nutrient uptake, and stress tolerance. Importantly, well-formulated pellets remain intact during handling and sowing but disintegrate rapidly upon soil contact, allowing unobstructed germination [7].

The choice of filler material is critical in determining the effectiveness of seed pelleting. Fly ash, a by-product of thermal power plants, is composed mainly of oxides of silicon, aluminum, iron, and calcium, and contains 0.5–3.5% essential nutrients such as nitrogen, phosphorus, potassium, and sulfur, along with trace elements. When used as a pelleting material, fly ash has been reported to enhance seed germination, seedling vigor, and early establishment due to improved nutrient availability and moisture retention [8].

Microbial inoculants further enhance the functional value of seed pelleting. *Trichoderma viride* is known to stimulate plant growth by enhancing photosynthetic efficiency through the upregulation of genes associated with chlorophyll biosynthesis and photosystem activity [9]. Under physiological or environmental stress conditions, plants often accumulate reactive oxygen species (ROS), which impair photosynthetic machinery and cellular metabolism; association with *Metarhizium anisopliae* has been shown to mitigate oxidative stress by reducing ROS accumulation and protecting cellular integrity [10]. Similarly, *Azospirillum brasilense*, a well-established plant growth-promoting rhizobacterium, produces indole-3-acetic acid (IAA), an auxin that enhances root proliferation, nutrient uptake, and overall plant growth and development [11].

In addition to microbial inoculants, organic leaf powders such as *Pongamia pinnata*, *Prosopis juliflora*, and *Azadirachta indica* have gained importance as eco-friendly pelleting materials. These botanicals are reported to improve soil water-holding capacity in the rhizosphere, enhance nutrient availability, and create a conducive microenvironment for seed germination and early seedling growth [12]. Their biodegradable nature and compatibility with organic farming systems further support their use in sustainable seed enhancement technologies.

Considering the importance of linseed and the potential advantages of seed pelleting using microbial and organic filler materials, the present investigation was undertaken to evaluate the effect of seed pelleting with selected microbial inoculants and organic fillers on the growth and yield performance of linseed. The study aims to identify the most effective filler material and seed-to-filler ratio for optimizing seed pelleting practices and improving crop establishment, productivity, and sustainability in linseed cultivation systems.

MATERIAL AND METHODS

A field experiment was conducted during the Rabi season of 2024–25 at the Agricultural Research Station, Dhadesugur, Raichur District, Karnataka, to evaluate the effect of seed pelleting with different filler materials on the performance of linseed. The experiment comprised eight treatments, including seven pelleting materials applied at optimized seed-to-filler ratios that were standardized earlier through laboratory experiments based on seed germination and seedling vigour, along with an unpelleted control. The treatments were: T_1 —Control (unpelleted), T_2 —Fly ash (1:6), T_3 —*Trichoderma viride* (1:6), T_4 —*Azospirillum brasilense* (1:3), T_5 —*Metarhizium anisopliae* (1:3), T_6 —*Pongamia pinnata* leaf powder (1:5), T_7 —*Prosopis juliflora* leaf powder (1:3), and T_8 —*Azadirachta indica* leaf powder (1:3). The experiment was laid out in a randomized complete block design (RCBD) with three replications.

Seeds of linseed variety RMLS-11 were pelleted manually (Figure 1) using gum acacia (4%) as an adhesive. The seeds were uniformly spread in a thin layer in a container, after which the adhesive solution was sprayed evenly over the seeds, followed by gradual addition of the pelleting material. The container was then shaken thoroughly to ensure uniform coating of the seeds. This procedure was repeated until the desired seed-to-filler ratio was attained. The pelleted seeds were subsequently shade-dried to ensure proper adhesion and stability prior to sowing.

Spread Seeds on a plastic container
(Lay the seeds evenly on a tray in a thin layer)
↓
Moisten the seeds
(Lightly spray adhesive to ensure even wetting of the seeds)
↓
Add pelleting powder
(Introduce the pelleting material to the wet seeds in the container)
↓
Shake the container
(Shake the container vigorously to evenly coat the seeds with pelleting powder and prevent clumping)
↓
Repeat the pelleting process
(Continue the rotation process multiple times to achieve the desired pellet size)
↓
Grade the pellets
(Use different sieves to sort the pellets based on size for uniformity)

Figure 1. Methodology of manual seed pelleting

The recommended dose of fertilizers was applied, with 50 per cent of nitrogen and 100 per cent of phosphorus and potassium supplied as a basal application at the time of sowing through urea, diammonium phosphate (DAP), and muriate of potash (MOP), respectively. The remaining 50 per cent of nitrogen was top-dressed at 25 days after sowing in the form of urea, applied as a band placement to ensure efficient nutrient utilization.

Field emergence was recorded at 20 days after sowing, while growth and yield parameters were assessed at harvest following standard agronomic and crop evaluation procedures. The collected data were subjected to statistical analysis using analysis of variance (ANOVA) in accordance with the methodology described by [13], to determine the significance of treatment effects.

RESULTS AND DISCUSSION

The data presented in Table 1 indicate that seed pelleting with *Metarhizium anisopliae* at a seed-to-pelleting material ratio of 1:3 (T_5) resulted in a significantly higher field emergence (98.25%), whereas the unpelleted control (T_1) recorded the lowest emergence (86.00%). The enhanced emergence observed under *M. anisopliae* treatment may be attributed to its multifunctional role as both an entomopathogenic fungus and a plant growth–promoting microorganism [14]. In addition, its broad-spectrum antimicrobial activity likely suppressed early soilborne pests and pathogens, thereby facilitating uniform and rapid seedling establishment [15]. These findings are in close agreement with those of Pawar [16], who reported significantly higher seedling emergence (94%) following seed treatment with *M. anisopliae* compared to the untreated control (87%).

At harvest, treatment T_5 (*M. anisopliae* at 1:3) also recorded significantly greater plant height (42.93 cm) and number of branches per plant (5.47) compared to the control, which exhibited the lowest values for both plant height (36.28 cm) and number of branches (4.60) (Table 1). These results corroborate earlier findings [17], wherein seed treatment with *M. anisopliae* significantly enhanced plant height (68.75 cm) and number of branches (9.7) in okra relative to the untreated control (45.75 cm and 8.9, respectively). Several studies have similarly reported that seed inoculation with beneficial microorganisms improves

Table 1. Growth, seed yield and its attributing parameters in linseed as influenced by different pelleting materials

Treatments	Field emergence @ 20 DAS (%)	Plant height (cm)	Number of branches per plant	Number of capsules per plant	Number of seeds per capsule	1000 seed weight (g)	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})
T_1: Control	86.00	36.28	4.60	33.77	7.40	7.35	1.57	785
T_2: Fly ash at 1:6	88.25	37.75	4.79	34.22	7.78	7.35	1.69	793
T_3: *Trichoderma viride* at 1:6	92.25	41.39	5.35	39.41	8.43	8.56	1.79	875
T_4: *Azospirillum brasilense* at 1:3	89.25	40.21	4.84	37.90	8.27	8.39	1.59	800
T_5: *Metarhizium anisopliae* at 1:3	98.25	42.93	5.47	39.94	8.62	8.66	1.83	894
T_6: *Pongamia pinnata* leaf powder at 1:5	92.92	41.76	4.97	39.21	8.41	8.27	1.79	887
T_7: *Prosopis juliflora* leaf powder at 1:3	89.59	38.38	4.78	38.73	8.12	8.23	1.71	825
T_8: *Azadirachta indica* leaf powder at 1:3	86.59	37.31	4.77	34.13	8.03	7.88	1.64	790
Mean	90.39	39.50	4.95	37.17	8.13	8.09	1.70	831
S. Em. +	2.67	1.44	0.18	1.55	0.30	0.30	0.06	27
C. D. at 5%	8.09	4.38	0.55	4.70	NS	0.90	0.17	81

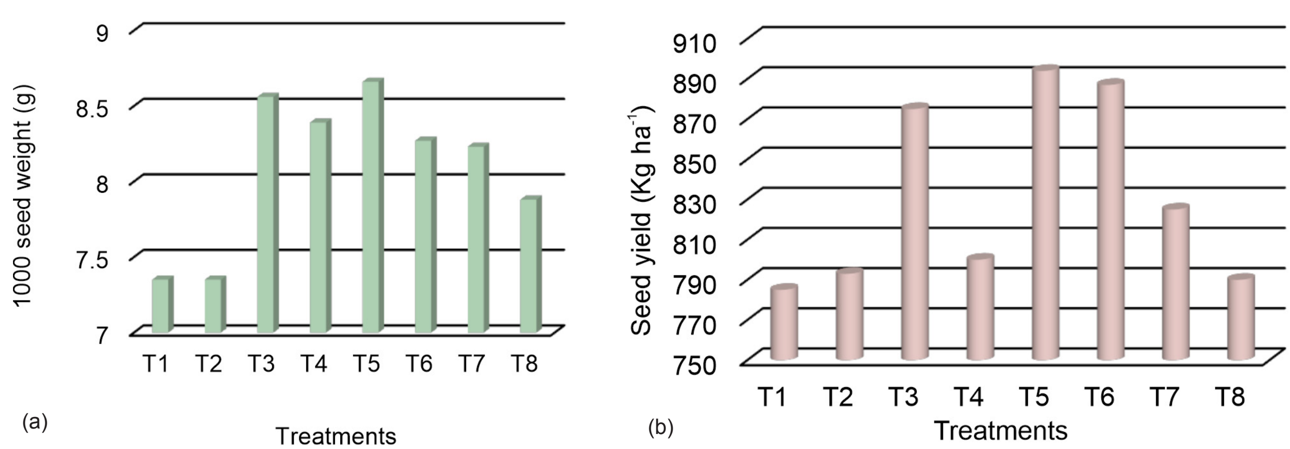
NS: Non-significant

germination [18] and subsequent plant growth [19]. The growth-promoting effects of *M. anisopliae* are primarily attributed to its ability to stimulate root proliferation, enhance nutrient acquisition, and synthesize phytohormones such as auxins and gibberellins, which promote stem elongation during early vegetative growth [15]. Furthermore, improved root development and balanced hormonal regulation, particularly involving cytokinins, are critical for axillary bud initiation and subsequent branch formation [15].

The number of capsules per plant differed significantly among treatments, whereas the number of seeds per capsule did not vary significantly (Table 1). Treatment T_5 recorded the highest number of capsules per plant (39.94) and numerically greater number of seeds per capsule (8.62), while the unpelleted control registered the lowest values (33.77 capsules per plant and 7.40 seeds per capsule, respectively). Adequate nutrient availability during the reproductive phase enhances flower retention, reduces floral abortion, and ultimately increases capsule formation [20]. Additionally, the biocontrol activity of *M. anisopliae* against soilborne pests and pathogens likely reduced physiological stress during flowering and capsule development, thereby improving flower-to-capsule conversion and seed filling [21]. However, despite recording numerically higher values, *M. anisopliae* treatment did not exert a statistically significant influence on the number of seeds per capsule, a trend consistent with earlier observations in French bean [22].

The significantly highest 1000-seed weight (8.66 g) was recorded in treatment T_5 (*Metarhizium anisopliae* at a 1:3 seed-to-pelleting material ratio), which was superior to all other treatments and the unpelleted control (T_1: 7.35 g) (Table 1; Figure 2a). This increase in test weight indicates that microbial-based pelleting positively influenced seed development and assimilate partitioning in linseed. The improvement in seed weight observed in the present study is in agreement with the findings of Pawar [14], who reported a significant enhancement in test weight of chickpea seeds from 17.0 g in the control to 22.1 g following treatment with beneficial fungi. Enhanced nutrient uptake and growth-promoting effects associated with entomopathogenic fungi [23], including improved root system architecture and nutrient assimilation efficiency, likely contributed to more effective seed filling and increased seed weight [24].

As presented in Table 1, seed pelleting with *M. anisopliae* at 1:3 (T_5) resulted in the highest seed yield, both on a per-plant basis (1.83 g plant^{-1}) and per unit area (894 kg ha^{-1}), which was markedly superior to all other treatments (Figure 2b) and the unpelleted control (1.57 g plant^{-1} and 785 kg ha^{-1}, respectively). These findings are consistent with earlier reports in chickpea [16] and okra [17], where *M. anisopliae* significantly improved seed yield by sustaining plant vigour throughout the crop growth cycle. The ability of the fungus to colonize the root zone enhances nutrient and water uptake efficiency, thereby promoting overall plant growth and productivity [25]. Furthermore, its dual role as a biocontrol agent and plant



T_1: Control; T_2: Fly ash (1:6); T_3: *Trichoderma viride* (1:6)
T_4: *Azospirillum brasilense* (1:3); T_5: *Metarhizium anisopliae* (1:3); T_6: *Pongamia pinnata* leaf powder (1:5)
T_7: *Prosopis juliflora* leaf powder (1:3); T_8: *Azardirachta indica* leaf powder (1:3)

Figure 2. Effect of seed pelleting with different filler materials on (a) 1000 seed weight (g) and (b) seed yield (kg ha^{-1}) of linseed

growth promoter likely contributed to sustained physiological activity, reduced pest and disease incidence [26], and improved resource-use efficiency, ultimately resulting in higher yield [22].

CONCLUSION

Seed pelleting with different microbial and botanical filler materials significantly improved the field performance of linseed compared to unpelleted seeds. All pelleting treatments positively influenced field emergence, growth, and yield attributes; however, seed pelleting with *Metarhizium anisopliae* at an optimal ratio of 1:3 emerged as the most effective treatment. This treatment consistently promoted better crop establishment, enhanced vegetative growth, superior yield attributes, and higher seed yield, demonstrating its clear advantage over other filler materials. Therefore, microbial-based pelleting using *M. anisopliae* can be recommended as an efficient and eco-friendly seed enhancement technique for improving linseed productivity.

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