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Response of paira linseed to supplemental foliar application of water-soluble fertilizers under foothill rainfed conditions of Nagaland

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Abstract

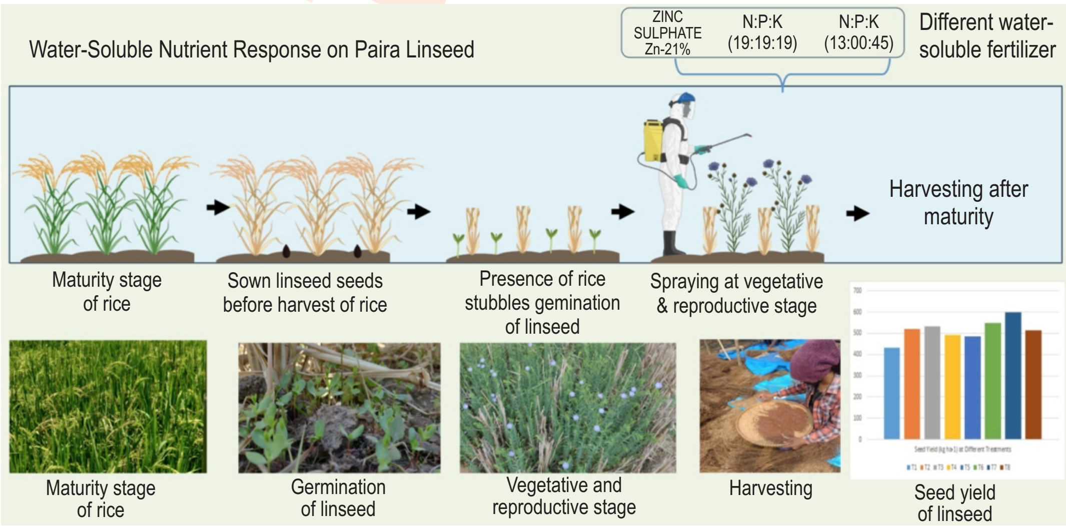
Aim: The study aimed to assess foliar fertilization as a resource-efficient method to improve the yield of paira linseed (*Linum usitatissimum* L.) under foothill rainfed conditions.

Methodology: Field trials were conducted during 2022–2023 and 2023–2024 rabi seasons to study the performance of paira linseed with supplemental application of water-soluble fertilizers under rainfed conditions. Eight (8) foliar spray treatments *viz.*, twice spray each of water spray (control), 1% NPK 19:19:19, 1% NPK 13:0:45, 2% Urea, 0.5% $ZnSO_4$, 1% NPK 19:19:19 with 0.5% $ZnSO_4$, 1% NPK 13:0:45 with 0.5% ZnSO4, and 2% Urea with 0.5% $ZnSO_4$ were tested at the experimental farm of SAS, Medziphema campus, Nagaland.

Results: The maximum seed yield was obtained with the combined application of 1% NPK 13:0:45 with 0.5% $ZnSO_4$, which was significantly higher than other treatments, except for the combined application of 1% NPK 19:19:19 with 0.5% $ZnSO_4$. The highest benefit-cost ratio (BCR) of 2.33 was obtained with twice spray of 1% NPK 13:0:45 with 0.5% $ZnSO_4$.

Interpretation: Supplementing the recommended nitrogen dose with combined foliar sprays of water-soluble fertilizers at vegetative and reproductive stages significantly enhanced the key physiological processes of paira linseed, highlighting its potential for increasing oilseed production under low-input rainfed conditions.

Key words: Growth, Linseed, Paira, Rainfed, Water-soluble fertilizers



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Introduction

Linseed, also known as flaxseed, is an important cash crop cultivated in many countries due to its uses in textiles, food, and pharmaceuticals industries. Linseed is mainly produced by Canada (40% of global production), Russia, China, Kazakhstan and the USA. In India, linseed cultivation covers a total area of 1.7 lakh hectares with a total production and productivity of 1.1 lakh tones (Directorate of Economics and Statistics, 2024). The productivity of linseed in India is much lower (604 kg ha^{-1}) as compared to the global average of 806 kg ha^{-1} (FAO, 2024), which is mainly due to the challenging conditions under which the crop is cultivated in most parts of the country. It is often grown under input-starved and moisture-stressed conditions in rainfed areas, where the crops are subjected to a number of biotic and abiotic stresses *viz.,* moisture stress, poor soil fertility, insufficient application of nutrients and traditional cultivation practices (Kumari *et al.,* 2021), which results in low productvity, and unstable yield performance. This situation not only affects the productivity of the crop, but also creates uncertainty regarding returns for farmers. In this context, it is essential to explore strategies and interventions that can enhance linseed productivity under such challenging conditions.

Relay cropping of linseed in paddy crop, known as the paira system, is a unique agricultural practice that has gained popularity in India. This system accounts for approximately 25% of the total linseed cultivation in the country (Kumar *et al.,* 2021) and offers a distinctive approach to cultivate linseed by eliminating the need for separate land preparation. In this innovative system, the crop is broadcast in standing paddy 10 to 15 days before harvesting of paddy, specifically between flowering and dough stages. This strategic timing allows the linseed crop to benefit from the existing resources in the field, also leading to potentially improved urtilization of residual resources. It is also worth noting that in the paira crop, only a minimal amount of nitrogen, typically ranging from 20-30 kg ha^{-1}, is applied to support the growth and development of the linseed plants. Hence, this system represents a sustainable and resource-efficient approach to linseed cultivation, which can be optimized to enhance productivity and maximize returns to the farmers.

Paira crop, although generally exhibiting lower productivity compared to pure linseed crop, has the potential for optimization through effective management practices such as supplemental nutrient management (Singh *et al.,* 2022). By reducing costs and implementing appropriate strategies, farmers can improve the yield and cultivation economics of the paira crop, making it a more viable and profitable option. Foliar fertilization helps improve crop performance and yield (Ishfaq *et al.,* 2022). It delivers nutrients directly to plant leaves, ensuring quick and targeted absorption (Niu *et al.,* 2021). This method gives faster results compared to soil application (Patil and Chetan, 2018). This method also bypasses the soil and root system, allowing for more efficient nutrient absorption and utilization by the plants, ultimately enhancing their growth and productivity (Malhotra *et al.,* 2020). Moreover, the timing of application and concentration of nutrients can be better optimized in case of foliar applications, in contrast to soil applications (Kentelky and Szekely-Varga, 2021), which also contributes towards the cost efficiency of this nutrient delivery system. Keeping in view the above facts, the present investigation was conducted to study the performance of paira linseed with supplemental application of water-soluble fertilizers under rainfed conditions.

Materials and Methods

Field investigation was conducted at the experimental farm of NU: SAS, Medziphema Campus, Chumoukedima, Nagaland during the *Rabi* seasons of 2022-23 and 2023-24 to evaluate the response of paira linseed to supplemental application of water-soluble fertilizers under rainfed conditions. The field was located 310 m above MSL with monthly temperature, relative humidity, rainfall and rainy days ranging from 9.6 to 30.1ºC, 41 to 97 %, 0.9 to 52.9 mm and 0 to 4 days, respectively, during the cropping period. The soil was clay loam in texture with a pH of 5.5. Soil test before sowing of the crop showed high organic carbon content (0.89 %) (Walkley and Black, 1934), high available nitrogen (564.48 kg ha^{-1}) (Subbiah and Asija, 1956), high available phosphorus (46.15 kg ha^{-1}) (Olsen *et al.,* 1954), medium available potassium (184.04 kg ha^{-1}) (Jackson, 1973) and DTPA-extractable zinc ≈ 0.47 mg kg^{-1} (Lindsay and Norvell, 1978). The classification of soil fertility status into low, medium, and high categories was based on standard ranges used in India (Malo and Saha, 2025). The experiment was laid out in randomized block design with three replications. Treatments comprised of eight foliar spray treatments, *viz.,* water spray (control), 1% NPK 19:19:19, 1% NPK 13:0:45, 2% Urea, 0.5% $ZnSO_4$, 1% NPK 19:19:19 with 0.5% $ZnSO_4$, 1% NPK 13:0:45 with 0.5% $ZnSO_4$, and 2% Urea with 0.5% $ZnSO_4$. Spray volume of 500 l of water per hectare was used for the application of water soluble fertilisers using knapsack sprayer. The treatment wise quantity of nutrients applied to the crop is presented in Table 1. The water-soluble fertilizers were sprayed specifically at active vegetative stage and capsule initiation stage.

Linseed variety 'Shekhar' was broadcasted in standing paddy during the first week of November (2 weeks prior to harvesting of paddy) using a seed rate of 40 kg ha^{-1}. Paddy was harvested at knee height stage and nitrogen at 20 kg ha^{-1} was uniformly broadcast in all the plots when the linseed seedlings attained a height of 10 cm. All other standard cultural operations and pest and disease management were maintained with uniformity throughout all the plots. Data on plant height, number of branches, dry weight of plant, phenological attributes, number of capsules per plant, number of seeds per capsule, test weight and seed yield were collected to analyze the crop's response to various treatments. Leaf chlorophyll content (mg g^{-1}) was recorded at 10 days after foliar sprays at both vegetative and reproductive stages. Total chlorophyll content of the leaves was estimated by following the method of Arnon (1949). Economic parameters, *viz.,* cultivation cost, GMR (gross monetary returns), NMR (net monetary returns) and BCR (benefit-cost ratio) were calculated based on prevailing market prices. The data collected throughout the experiment was statistically evaluated using the usual ANOVA approach as described by Gomez and Gomez (2010). The correlation matrix tables and heat maps were developed using R Studio-2024.04.2-764.

Results and Discussion

With respect to leaf chlorophyll content, except for the application of 2% urea with 0.5% $ZnSO_4$ at vegetative stage, all the other treatments were observed to record substantially higher leaf chlorophyll content compared to control (Table 2). Also, at both stages, application of either 1% NPK 13:0:45 or NPK 19:19:19 with 0.5% $ZnSO_4$ was observed to record significantly higher leaf chlorophyll content compared to sole application of 0.5% $ZnSO_4$. The increase in leaf chlorophyll content due to foliar application of water-soluble fertilizers may be attributed to the enhanced mineral nutrient concentration in leaves, which promotes chlorophyll biosynthesis and improves the functional status of the photosynthetic apparatus (Stadnik *et al.,* 2025; Akhter *et al.,* 2025). Foliar feeding enables faster nutrient absorption and efficient utilization compared to soil application, leading to healthier leaves and better chlorophyll development (Niu *et al.,* 2021). Significantly higher chlorophyll content recorded with the combined application of 1% NPK 13:0:45 or NPK 19:19:19 with 0.5% $ZnSO_4$ could be attributed to the synergistic interaction of nitrogen and zinc that supported both the structural and functional components of chlorophyll. Nitrogen ensures that the basic building blocks for chlorophyll are available, while zinc aids in the synthesis and stability of chlorophyll, ensuring its proper functioning and longevity within the plant tissues (Pouyanfar *et al.,* 2022; Dwivedi *et al.,* 2021).

Significant differences were recorded between various treatments in terms of number of primary and secondary branches and plant dry weight (Table 2). The number of primary and secondary branches per plant was recorded to be significantly higher with combined spray of 1% NPK 13:0:45 or 19:19:19 with 0.5% $ZnSO_4$, which were at par with each other and significantly higher compared to application of 2% Urea with 0.5% $ZnSO_4$ and sole applications of 2% Urea and 0.5% $ZnSO_4$ as well as control. Whereas, all foliar water-soluble fertilizer treatments recorded significantly higher plant dry weight compared to control, among the treatments, 1% NPK 13:0:45 with 0.5% $ZnSO_4$ resulted in significantly higher dry weight, which was statistically similar to 1% NPK 19:19:19 with 0.5% $ZnSO_4$, both treatments recoding significantly higher plant dry weight compared to sole applications of 2% urea or 0.5% $ZnSO_4$. Recent field studies have confirmed that foliar application of NPK at about 1% concentration at vegetative and reproductive stages significantly enhances seed yield compared to soil-only fertilization (Mishra *et al*., 2025). Additionally, foliar zinc has been shown to increase overall crop performance and nutrient uptake under stress conditions (Ghanem *et al*., 2025), supporting the higher benefit–cost ratios observed with combined NPK + Zn treatments.

The combined foliar application of water-soluble NPK and $ZnSO_4$ significantly enhanced plant growth and biomass accumulation. This improvement can be attributed to increased nutrient uptake and efficient utilization via foliar delivery, which raised leaf N, P, and K concentrations and supported higher shoot biomass. Elevated chlorophyll levels during vegetative and reproductive stages under combined treatments likely improved the photosynthetic efficiency, leading to greater carbohydrate assimilation and dry matter production (Shah *et al.,* 2023; Chaudhary *et al.,* 2023). Compared with control, all foliar fertilizer treatments resulted in significantly higher plant dry weight, however, the synergistic effect of NPK with Zn was particularly evident. The balanced supply of macro- and micronutrients enhanced nutrient assimilation, enzyme activity, and chlorophyll biosynthesis, thereby stimulating metabolic processes beyond the response to individual nutrients. Significantly greater chlorophyll content under combined treatments during key growth stages contributed to enhanced photosynthetic activity and biomass accumulation (Kumar *et al.,* 2024). Chlorophyll is widely recognized as a reliable indicator of photosynthetic rate (Shah *et al.,* 2023) and yield potential (Chaudhary *et al.,* 2023). Adequate chlorophyll content at critical stages ensures efficient photosynthesis and dry matter partitioning, thereby strengthening biomass production and overall crop performance (Kumar *et al.,* 2021).

Table 1: Treatment wise quantity of nutrients applied to the crop

Treatments	Quantity of nutrients applied to the crop (kg ha^{-1})			
	N	P_2O_5	K_2O	Zn
Water spray (control)	0.00	0.00	0.00	0.00
Two sprays of 1% NPK 19:19:19	1.90	1.90	1.90	0.00
Two sprays of 1% NPK 13:0:45	1.30	0.00	4.50	0.00
Two sprays of 2 % Urea	9.20	0.00	0.00	0.00
Two sprays of 0.5% $ZnSO_4$	0.00	0.00	0.00	1.05
Two sprays of 1% NPK 19:19:19 with 0.5% $ZnSO_4$	1.90	1.90	1.90	1.05
Two sprays of 1 % NPK 13:0:45 with 0.5% $ZnSO_4$	1.30	0.00	4.50	1.05
Two sprays of 2 % Urea with 0.5% $ZnSO_4$	9.20	0.00	0.00	1.05

Table 2: Effect of supplemental foliar application of water-soluble fertilizers on growth attributes of paira linseed (pooled data 2022-23 and 2023-24)

Treatments	Leaf chlorophyll content 10 days after spray (mg g^{-1})		Plant height (cm)	Number of branches per plant		Plant dry weight (g)		Days to 50 % flowering	Days to maturity
	VS*	RS*		Primary	Secondary	CDS*	Harvest		
Water spray(control)	0.84	2.16	54.33	2.20	11.39	1.84	3.69	86.00	151
Two sprays of 1% NPK 19:19:19	1.04	3.39	59.95	2.73	15.12	2.12	5.19	86.00	151
Two sprays of 1% NPK 13:0:45	1.09	3.64	58.77	2.67	14.99	2.17	5.65	87.00	151
Two sprays of 2 % Urea	0.99	3.15	55.27	2.33	13.79	2.00	4.85	86.00	151
Two sprays of 0.5% $ZnSO_4$	0.96	2.94	54.77	2.40	12.98	1.94	4.57	86.00	151
Two sprays of1% NPK 19:19:19 with 0.5% $ZnSO_4$	1.14	3.67	61.87	2.80	16.53	2.21	5.97	85.33	151
Two sprays of 1 % NPK 13:0:45 with 0.5% $ZnSO_4$	1.22	3.80	59.34	2.93	18.10	2.33	6.54	86.67	151
Two sprays of 2 % Urea with 0.5% $ZnSO_4$	1.07	3.56	57.28	2.47	14.70	2.13	5.74	87.00	151
SEm ±	0.07	0.28	3.07	0.20	1.06	0.10	0.37	1.96	-
CD ($P \leq 0.05$)	0.15	0.60	NS	0.42	2.28	0.22	0.80	NS	-

* VS- Vegetative stage, RS- Reproductive stage and CDS- Capsule development stage

Table 3: Effect of supplemental foliar application of water-soluble fertilizers on yield attributes, yield and economics of paira linseed (pooled data 2022-23 and 2023-24)

	Number of capsules per plant	Number of seeds per capsule	1000 seed weight (g)	Seed yield (kg ha^{-1})	Cost of cultivation (Rs. ha^{-1})	GMR* (Rs ha^{-1})	NMR* (Rs. ha^{-1})	BCR*
Water spray (control)	23.39	6.82	7.91	431.49	8356	17260	8904	2.07
Two sprays of 1% NPK 19:19:19	34.00	7.81	8.22	518.97	10176	20759	10583	2.04
Two sprays of 1% NPK 13:0:45	35.50	7.85	8.27	531.25	10216	21250	11034	2.08
Two sprays of 2 % Urea	32.17	7.50	8.10	492.88	9136	19715	10579	2.16
Two sprays of 0.5% $ZnSO_4$	29.83	7.48	7.97	486.74	9072	19470	10398	2.15
Two sprays of 1% NPK 19:19:19 with 0.5% $ZnSO_4$	38.39	8.14	8.25	548.13	10232	21925	11693	2.14
Two sprays of 1 % NPK 13:0:45 with 0.5% $ZnSO_4$	41.78	8.19	8.39	598.77	10272	23951	13679	2.33
Two sprays of 2 % Urea with 0.5% $ZnSO_4$	35.33	7.67	8.17	512.83	9192	20513	11321	2.23
SEm ±	2.83	0.28	0.28	25.58	-	-	-	-
CD ($P \leq 0.05$)	6.08	0.60	NS	54.87	-	-	-	-

* GMR-Gross monetary returns, NMR-Net monetary returns and BCR- Benefit cost ratio

The investigated foliar spray treatments demonstrated a significantly greater number of capsules per plant and seeds per capsules in comparison to the control (Table 3). Foliar sprays of 1% NPK 13:0:45 with 0.5% $ZnSO_4$ and1% NPK 19:19:19 with 0.5% $ZnSO_4$, where found to be at par with each and recorded significantly higher number of capsules and seeds per capsules compared to sole sprays of 2% urea or 0.5% $ZnSO_4$. Increased availability and uptake of nutrients with combined application of NPK and $ZnSO_4$ may have increased photosynthetic rate and accumulation of photosynthates as well as active translocation of photosynthates from source to sink thereby resulting in better expression of yield attributes. Previous reports have also attributed enhanced yield attributes *viz.,* capsules and grains per plant to better availibility of nutrients (Roy *et al.,* 2009); enhanced source sink relationship (Dwivedi *et al.,* 2021) and enhanced photosynthesis, increased leaf sugar content and efficient redistribution of leaf sugar content to developing organs (Galeriani *et al.,* 2022). Further, significantly higher number of primary and secondary branches recorded with combined sprays of either 1% NPK 13:0:45 or NPK19:19:19 with 0.5% $ZnSO_4$ may have led to higher number of flowering sites and potentially higher number of capsules. Dwivedi *et al.* (2021) and Yang *et al.* (2022),

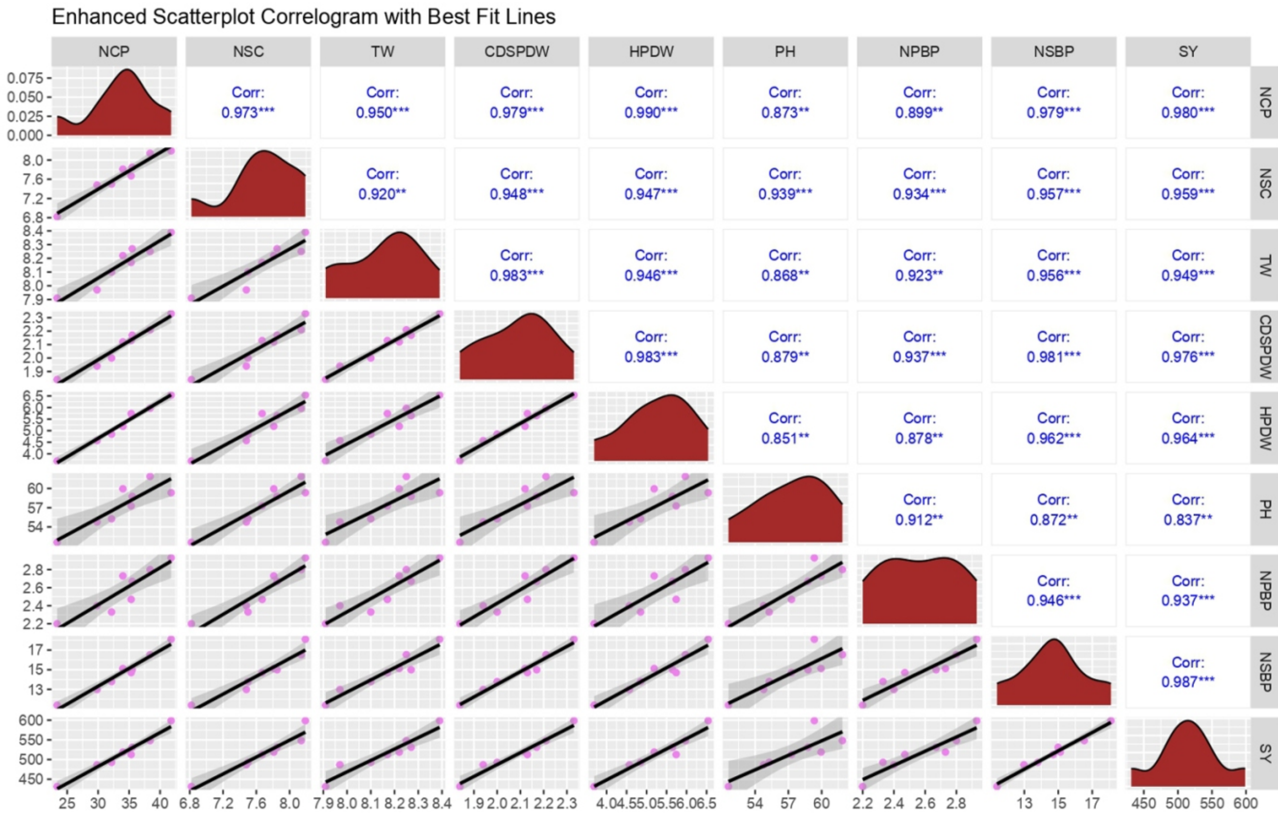

Fig. 1: Correlation matrix of pooled data (2022-23 and 2023-24) on growth and yield attributes with seed yield in enhanced scatterplot correlogram with best fit lines. * NCP-Number of capsules per plant, NSP-Number of seeds per capsule, TW-1000 seed Test weight (g), SY-Seed yield (kg ha^{-1}), CDSPDW-Plant dry weight at capsule development stage (g), HPDW-Plant dry weight at harvest (g), PH-Plant height (cm), NPBP-Number of primary branches per plant, NSBP-Number of secondary branches per plant.

also reported that the number of branches ultimately determines the number of panicles or pods.

All the foliar nutrient sprays tested recorded significantly higher seed yields than control, with the yield values ranging from 486.74 to 598.77kg ha^{-1} (Table 3). Seed yield recorded (598.77 kg ha^{-1}) with two applications of 1% NPK 13:0:45 with 0.5% $ZnSO_4$ was found to be significantly higher compared to all other treatments except application of 1% NPK 19:19:19 with 0.5% $ZnSO_4$ (548.13 kg ha^{-1}), which was found to be statistically at par. The seed yield recorded with 1% NPK 19:19:19 with 0.5% $ZnSO_4$ was also significantly higher than the yields from the sole applications of 2% urea and 0.5% $ZnSO_4$. Field studies and trials have demonstrated that these combinations can lead to significant yield improvements in crops due to enhanced nutrient availability and better overall plant health (Kumar *et al.,* 2021; Bhalavi *et al.,* 2023). Despite the absence of basal phosphate application and phosphorus in the foliar spray of NPK 13:0:45, the yield was statistically similar to that obtained with NPK 19:19:19. This response may be explained by adequate residual soil phosphorus from previous fertilization or natural mineralization, which satisfied crop P demand (Niu *et al.,* 2021).

Additionally, foliar-applied phosphorus generally has lower absorption and translocation efficiency compared to nitrogen and potassium (Henningsen *et al.,* 2022). In this context, the higher uptake efficiency of N and K under NPK 13:0:45 may have compensated for the lack of foliar P, maintaining comparable yield. Furthermore, given the acidic nature (low pH) of the experimental soil, increased solubility and mobilization of native phosphorus reserves could have enhanced its availability to plants (Malik *et al.,* 2024). Significanty enhanced seed yields as recorded with combined applications of NPK and $ZnSO_4$ may be due higher availibity and uptake of nutrients under those treatments, as discussed earlier, leading to higher production of photosynthates well as growth resulting in better expression of yield attributes *viz.* capsules per plant and seeds per capsule which was finally reflected in seed yield (Sameer *et al.,* 2021).

Earlier workers have also reported that significantly enhanced plant dry weight, branches per plant, capsules per plant and seeds per capsule were associated with higher seed yield (Khan *et al.,* 2020; Yang *et al.,* 2022). Although the experimental soil was rich in available nitrogen (564 kg ha^{-1}), the crop still responded positively to additional foliar nitrogen application. This response may stem from the fact that foliar feeding delivers nitrogen directly to leaf tissues, ensuring immediate availability during key growth stages. In contrast, soil-applied nitrogen despite its abundance may not be fully accessible to plants due to losses via leaching, denitrification, volatilization, or microbial immobilization (Govindasamy *et al.,* 2023). The correlation analysis carried out among the nine agronomic traits showed several strong and statistically significant relationships with seed yield (Fig. 1). Notably, the seed yield had the highest positive correlation with the number of secondary branches per plant (r = 0.987), suggesting that plants producing more branches tend to generate greater vegetative growth, which in turn supports higher grain production. This was followed by strong associations with the number of capsules per plant (r = 0.980) and the number of seeds per capsule (r = 0.959), both of which directly contribute to yield. Other traits like test weight (r = 0.949) and plant dry weight measured during capsule development (r = 0.948) were also highly correlated, indicating that both the size of individual seeds and the accumulation of biomass during critical growth stages play important roles. Additionally, the plant dry weight at harvest (r = 0.946), the number of primary branches (r = 0.937), and plant height (r = 0.837) showed significant positive correlations, though their contributions appeared slightly less pronounced compared to other parameters.

These findings, most of which were significant at $p < 0.001$, point to the importance of improving traits like branching, biomass accumulation, capsule formation, and seed size as practical strategies for boosting seed yield. Similar patterns have been reported in linseed and flax studies: Mirik *et al.* (2021) found that the number of capsules per plant was the most important selection criterion for seed yield in flax breeding lines, based on correlation, regression, and path analysis. Likewise, Yadav *et al.* (2024) in a genetic variability and trait-association study in linseed reported strong positive correlations among yield and its components, supporting the importance of branching, capsule number, and seed number in yield determination.

The treatments, twice spray of 1% NPK 13:0:45 with 0.5% $ZnSO_4$ and twice spray of $ZnSO_4$ @ 0.5% were found to record the highest and lowest cultivation cost (Table 2), which was due to comparatively higher or lower market price associated with those treatments as compared to remaining treatments. Twice spray of 1% NPK 13:0:45 with 0.5% $ZnSO_4$ was found to record the highest GMR, NMR and BCR, followed by twice the spray of 1% NPK 19:19:19 with 0.5% $ZnSO_4$ with respect to GMR and NMR and the twice spray of 2% Urea with 0.5% $ZnSO_4$ with respect to BCR. Variation in economic parameters, as observed, might be attributed to significantly higher seed yields or comparatively lower cultivation cost associated with concerned treatments (Singh *et al.,* 2018; Kumar *et al.,* 2024). In line with the above, it may also be noted that despite recording lower GMR and NMR compared to combined spray of NPK 19:19:19 and $ZnSO_4$, combined application of Urea and $ZnSO_4$ was found to record comparatively higher BCR compared to the former treatment, which could be attributed to lower cultivation cost associated with the treatment.

Based on the findings of the present study it can be concluded that, in addition to the recommended RDF of 20 kg N ha^{-1}, supplemental combined foliar sprays of either 1% NPK 13:0:45 or 2% Urea along with $ZnSO_4$ @ 0.5% at vegetative and reproductive stages can be adopted to enhanced the crop growth and yield response as well as economic returns under rainfed conditions for paira linseed.

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