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Performance of different linseed (*Linum usitatissimum* L.) genotypes for morpho-physiological and biochemical traits under irrigated and utera conditions

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ABSTRACT

A field experiment was conducted during rabi 2024-25 at AICRP farm on Linseed, College of Agriculture, Nagpur, to assess the morpho-physiological and biochemical performance of twenty linseed genotypes, including two checks, under irrigated and utera conditions. The experiment was laid out in a factorial randomized block design with three replications. Irrigated conditions resulted in greater plant height (61.81 cm), leaf area index (1.50), total dry matter accumulation (10.31 g plant⁻¹), leaf relative water content (70.79%), primary branches (7.57 plant⁻¹), secondary branches (13.75 plant⁻¹), total chlorophyll content (2.02 mg g⁻¹) and seed oil content (40.99%) than utera conditions. In contrast, plants under utera conditions reached 50% flowering (54.92 days) and maturity (111.72 days) earlier than those under irrigated condition with 50% flowering 60.37 days and days to maturity with 118.97 days. Sowing conditions and genotypes significantly influenced all the evaluated traits. Their interaction effect was significant for all parameters except primary and secondary branches. Among the genotypes, NL-403 recorded the greatest plant height (68.38 cm), while NL-527 exhibited the highest total dry matter accumulation (9.94 g plant⁻¹) and earliest mean flowering (52.00 days). NL-519 recorded the highest leaf area index (1.55), leaf relative water content (70.75%), and seed oil content (42.04%), whereas NL-426 recorded the highest total leaf chlorophyll content (2.15 mg g⁻¹). PKV NL-260 and NL-513 produced the highest numbers of primary (7.83 plant⁻¹) and secondary branches (14.83 plant⁻¹), respectively. NL-429 recorded the earliest mean maturity (107.00 days). Overall, NL-403, NL-527, NL-519, NL-426, PKV NL-260, NL-513 and NL-429 displayed favourable performance across multiple traits and may be considered promising for further evaluation under irrigated and utera production systems.

Keywords: Linseed, Utera condition, Irrigated condition, LAI, Relative water content, Chlorophyll, Biochemical traits, Seed oil content

Introduction

Linum usitatissimum L., commonly known as flax or linseed, belongs to the *Linaceae* family and has a chromosome number of $2n = 30$. It is an annual plant growing 30-100 cm tall, with a main stem and shallow, branching taproot that can extend 90-120 cm into light soils. In dense planting for fiber production, it tends to produce a single stem, while sparse planting encourages branching. The fruit is a five-celled capsule containing around ten seeds (Bisen *et al.*, 2025) [1]. It is an important rabi oilseed crop valued for its nutrient-rich oil and industrially useful fibre. However, its productivity is often limited because it is mainly cultivated under rainfed and moisture-deficient conditions. Water stress, particularly during flowering and seed development, can adversely affect plant growth, physiological processes, yield components, and seed yield (Anastasiiu *et al.*, 2016) [2]. Irrigation plays an important role in ensuring adequate moisture availability during critical stages of linseed growth. A timely and sufficient supply of water can support cell expansion, canopy development, chlorophyll maintenance, photosynthetic activity, dry matter accumulation, branching, seed development, and oil synthesis. Irrigated conditions may therefore provide a favourable environment for realizing the morpho-physiological and biochemical potential of different linseed genotypes. However, genotypes may vary in their response to improved moisture availability, making their evaluation under irrigated conditions essential for identifying those with desirable growth, physiological, and biochemical attributes. The utera system offers an efficient approach for growing linseed in rice-fallow areas by broadcasting seed into the standing rice crop prior harvest and utilizing the residual soil moisture available after rice harvest (Bhowmick *et al.*, 2005) [3]. Although linseed is suitable for this system because of its short duration and low input requirement, declining soil moisture may restrict its growth and productivity. Genotypic differences in chlorophyll content, relative water content, dry-matter accumulation, biomass partitioning, and

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yield-related traits may determine crop performance under such conditions. The study was therefore undertaken to identify physiologically efficient, adaptable, and productive linseed genotypes with potential suitability for cultivation under irrigated and utera production systems.

Materials and methods

The experimental material comprised twenty diverse linseed genotypes, including two checks, PKV NL-260 and LSL-93, obtained from AICRP on Linseed, College of Agriculture, Nagpur. The field experiment was conducted during *rabi* 2024–25 at the AICRP on Linseed farm, College of Agriculture, Nagpur. The experiment was laid out in a factorial randomized block design with three replications under irrigated and utera conditions. A spacing of 30 cm × 10 cm was maintained, with a gross plot size of 3.00 m × 2.20 m. Recommended cultural practices were followed to raise a healthy crop under both conditions. Five plants were randomly selected from each plot for recording plant-based observations. Plant height (cm), leaf area index (LAI), total dry matter accumulation (g plant⁻¹), leaf relative water content (%) by Barrs and Weatherly method and total chlorophyll content in leaves (mg g⁻¹) by colorimetric method were recorded at 90 DAS. The numbers of primary and secondary branches (plant⁻¹) were recorded at harvest, whereas days to 50% flowering (days) and days to maturity (days) were recorded on a plot basis. Seed oil content (%) by soxhlet's procedure was estimated after harvest. The experimental data were statistically analysed according to the procedure described by Panse *et al.* (1967) [4].

Results and Discussion

Plant height

Plant height at 90 DAS was significantly influenced by sowing conditions, genotypes, and their interaction. The mean plant height under irrigated conditions was 61.81 cm, which was significantly higher than 52.33 cm recorded under utera conditions, indicating a reduction of 15.33% under utera. Among the genotypes, NL-403 recorded the greatest mean plant height of 68.38 cm and surpassed all other genotypes. It was followed by NL-527 (66.29 cm), which exhibited a plant height comparable to NL-517 (65.06 cm). The plant height of NL-517 was also comparable to that of NL-529 (64.58 cm), whereas LSL-93 recorded the lowest value of 47.82 cm. The significant interaction indicated that the genotypes responded differently to the two sowing conditions. Under irrigated conditions, NL-403 attained the maximum plant height of 74.00 cm and surpassed NL-527 (71.52 cm) and the remaining genotypes. Under utera conditions, NL-403 again recorded the maximum plant height of 62.76 cm, with a response comparable to NL-527 (61.07 cm) and NL-517 (60.72 cm). These results are consistent with the findings of Singh *et al.* (2018) [5].

Leaf area index (LAI)

Leaf area index at 90 DAS was significantly influenced by sowing conditions, genotypes, and their interaction. Plants grown under irrigated conditions recorded a higher mean LAI of 1.50 than those grown under utera conditions (1.01), indicating a reduction of 32.67% under utera. Among the genotypes, NL-519 recorded the highest mean LAI (1.55), with values comparable to NL-378 (1.53) and NL-527 (1.50), whereas NL-512 recorded the lowest value (0.93). Under irrigated conditions, NL-519 exhibited the maximum LAI (1.84), with comparable values recorded by NL-378 (1.82), NL-527 (1.77), NL-529 and NL-522 (1.73 each), and PKV NL-260 (1.72). Under utera conditions, NL-519 again recorded the highest LAI (1.27), followed by NL-378 (1.23), NL-527 (1.22), NL-522 and PKV NL-260 (1.18 each), and NL-529 (1.17), all of which exhibited comparable canopy development. Better moisture availability under irrigated conditions may have promoted leaf expansion and canopy development, whereas the gradual depletion of residual soil moisture under utera conditions likely restricted leaf growth. The consistently higher LAI of NL-519, NL-378, and NL-527 reflects their better ability to maintain canopy

development under both growing conditions. Similar findings were reported by Kumar *et al.* (2019) [6].

Leaf relative water content (%)

Relative water content at 90 DAS was significantly influenced by sowing conditions, genotypes, and their interaction. Plants grown under irrigated conditions maintained a mean RWC of 70.79%, compared with 57.68% under utera conditions, indicating a reduction of 18.52% under utera. Among the genotypes, NL-519 recorded the highest mean RWC (70.75%) and surpassed all other genotypes, whereas NL-512 recorded the lowest mean value (59.07%). The interaction effect indicated that genotypic responses varied between the two growing conditions. Under irrigated conditions, NL-353 recorded the highest RWC (76.16%), with comparable values observed in NL-519 (75.48%), NL-527 (75.02%), NL-522 (74.95%), NL-390 (73.99%), and NL-510 (73.13%). Under utera conditions, NL-519 maintained the highest RWC (66.02%) and surpassed all other genotypes. Adequate soil moisture under irrigated conditions helped plants maintain better leaf hydration, whereas the progressive depletion of residual soil moisture under utera conditions reduced leaf water status. The ability of NL-519 to maintain a comparatively higher RWC, particularly under utera conditions, indicates better regulation of plant water balance under limited moisture availability. Similar findings were reported by Soltys-Kalina *et al.* (2016) [7].

No. of primary and secondary branches (plant⁻¹) at harvest

The numbers of primary and secondary branches plant⁻¹ at harvest were influenced by sowing conditions and genotypes, whereas the interaction effect was non-significant. Irrigated conditions produced more primary branches (7.57 plant⁻¹) than utera conditions (6.18 plant⁻¹), representing a reduction of 18.36% under utera. Among the genotypes, PKV NL-260 recorded the highest number of primary branches (7.83 plant⁻¹), with comparable values observed in NL-521 (7.67 plant⁻¹), NL-378, NL-517 and NL-529 (7.50 plant⁻¹ each), and NL-390 (7.33 plant⁻¹). In contrast, LSL-93 produced the fewest primary branches (6.00 plant⁻¹). A similar trend was observed for secondary branches. Irrigated conditions recorded 13.75 secondary branches plant⁻¹ compared with 11.98 branches plant⁻¹ under utera, indicating a reduction of 1.77 branches plant⁻¹ or 12.87%. Among the genotypes, NL-513 produced the highest number of secondary branches (14.83 plant⁻¹), with comparable values recorded by NL-378 (14.67 plant⁻¹), NL-353 (14.33 plant⁻¹), and NL-527 (13.83 plant⁻¹). NL-510 recorded the fewest secondary branches (10.33 plant⁻¹). Better branching under irrigated conditions may be attributed to the timely and adequate availability of soil moisture, which promoted vegetative growth. In contrast, lower moisture availability under utera conditions may have restricted plant growth and branch formation. These observations are consistent with those of Kariuki *et al.* (2016) [8] and Soto-Cerda *et al.* (2014) [9].

Days to 50% flowering (days) and maturity (days)

Days to 50% flowering and maturity were influenced by sowing conditions, genotypes, and their interaction. Plants under utera conditions reached 50% flowering in 54.92 days compared with 60.37 days under irrigated conditions, indicating an advancement of 9.03%. Among the genotypes, NL-527 recorded the earliest flowering (52.00 days), with comparable durations observed in NL-510 (52.17 days), LSL-93 (52.67 days), and NL-512 (52.83 days). Under utera conditions, LSL-93 flowered earliest at 47.67 days. Maturity also occurred earlier under utera conditions (111.72 days) than under irrigated conditions (118.97 days), representing an advancement of 6.09%. Among the genotypes, NL-429 recorded the earliest mean maturity (107.00 days), with comparable durations observed in NL-390 (107.33 days) and NL-403 (108.50 days). Under utera conditions, NL-519 matured earliest (104.67 days), whereas NL-386 under irrigated conditions matured latest (126.67 days). Earlier flowering and maturity under utera conditions may be associated with declining moisture availability, which shortened the crop growth period. The interaction effect further indicated that the genotypes responded differently to the two sowing

conditions. These observations agree with the findings of Dash *et al.* (2014) [10].

Total chlorophyll content in leaves (mg g^{-1})

Total leaf chlorophyll content at 90 DAS was influenced by sowing conditions, genotypes, and their interaction. Plants grown under irrigated conditions recorded higher total leaf chlorophyll content (2.02 mg g^{-1}) than those grown under utera conditions (1.60 mg g^{-1}), indicating a difference of 0.42 mg g^{-1} and a reduction of 20.79% under utera. Among the genotypes, NL-426 recorded the highest mean total leaf chlorophyll content (2.15 mg g^{-1}), with a comparable value observed in NL-519 (2.13 mg g^{-1}), whereas LSL-93 recorded the lowest mean value (1.35 mg g^{-1}). The significant interaction effect indicated that the genotypes responded differently to the two sowing conditions. Under irrigated conditions, NL-426 and NL-429 recorded the highest total leaf chlorophyll content (2.65 mg g^{-1} each), whereas NL-510 under utera conditions recorded the lowest value (1.17 mg g^{-1}). Adequate moisture availability under irrigated conditions may have helped plants maintain total leaf chlorophyll content up to 90 DAS. In contrast, limited moisture availability under utera conditions may have accelerated chlorophyll degradation and leaf ageing. These observations are in accordance with the findings of Sadak *et al.* (2020) [11].

Conclusion

The present study revealed substantial variation in the morpho-physiological and biochemical responses of linseed genotypes to irrigated and utera conditions. Irrigated condition was more favourable for vegetative growth and physiological functioning, resulting in greater plant height, leaf area index, total dry matter accumulation, leaf relative water content, primary and secondary branches, total leaf chlorophyll content and seed oil content. In contrast, utera conditions accelerated flowering and maturity, indicating a shorter crop duration under progressively declining residual soil moisture. NL-403 recorded the greatest plant height, NL-527 exhibited the highest total dry matter accumulation and earliest mean flowering and NL-519 performed favourably for leaf area index, leaf relative water content, and seed oil content. NL-426 maintained the highest total leaf chlorophyll content, while PKV NL-260 and NL-513 produced the highest numbers of primary and secondary branches, respectively. NL-429 recorded the earliest mean maturity. These findings identify NL-403, NL-527, NL-519, NL-426, PKV NL-260, NL-513, and NL-429 as valuable trait-specific genetic resources. Further multi-environment evaluation of these genotypes may facilitate the identification and development of linseed cultivars with improved morpho-physiological and biochemical performance under irrigated and utera production systems.

Table 1. Performance of different linseed genotypes for morpho-physiological and biochemical traits under irrigated and utera conditions

(A)Sowing Conditions (B) Genotypes	Plant height (cm)		Leaf Area Index		Total Dry Matter Accumulation		Leaf Relative Water Content	
	Irrigated (A1)	Utera (A2)	Irrigated (A1)	Utera (A2)	Irrigated (A1)	Utera (A2)	Irrigated (A1)	Utera (A2)
	Mean	Mean	Mean	Mean	Mean	Mean	Mean	Mean
NL-510	64.29	55.40	1.17	0.76	10.12	7.33	73.13	56.21
NL-513	57.55	46.50	1.16	0.76	9.63	6.93	72.08	56.28
NL-426	61.96	52.20	1.39	0.98	10.82	7.83	67.05	57.46
NL-429	55.04	45.96	1.33	0.95	9.95	7.13	65.25	56.31
NL-527	71.52	61.07	1.77	1.22	11.43	8.45	75.02	60.94
NL-353	53.74	47.13	1.45	0.89	9.13	6.53	76.16	60.64
NL-378	59.53	48.60	1.82	1.23	10.33	7.53	72.35	53.48
NL-386	67.98	56.46	1.33	0.83	10.02	7.23	64.98	56.37
NL-390	61.24	52.59	1.46	0.92	11.03	8.05	73.99	61.43
NL-391	55.63	46.55	1.38	0.86	9.77	7.03	64.58	54.24
NL-403	74.00	62.76	1.49	0.95	10.53	7.64	71.35	55.69
NL-511	60.02	52.26	1.69	1.14	11.28	8.30	64.17	54.06
NL-512	60.88	51.40	1.13	0.73	9.33	6.67	63.61	54.52
NL-517	69.39	60.72	1.50	1.07	10.07	7.28	72.41	51.62
NL-529	69.63	59.53	1.73	1.17	10.93	7.94	71.81	62.28
NL-519	63.31	51.95	1.84	1.27	9.83	7.08	75.48	66.02
NL-522	54.86	48.00	1.73	1.18	11.18	8.19	74.95	62.20
NL-521	59.85	50.06	1.41	0.96	9.23	6.57	72.87	53.14
PKV NL-260 (C)	64.01	53.58	1.72	1.18	10.23	7.43	72.65	61.46
LSL-93 (C)	51.68	43.95	1.57	1.05	11.38	8.39	71.95	59.14
Mean (A)	61.81	52.33	1.50	1.01	10.31	7.48	70.79	57.68
F test	**	**	**	**	**	**	**	**
SEm ±	0.147	0.465	0.0083	0.0262	0.0048	0.0151	0.2102	0.6647
CD at 5%	0.414	1.309	0.0233	0.0737	0.0135	0.0426	0.5918	1.8713

Table 2. Performance of different linseed genotypes for morpho-physiological and phenological traits under irrigated and utera conditions

(A)Sowing Conditions (B) Genotypes	Primary branches plant ⁻¹			Secondary branches plant ⁻¹			Days to 50 % flowering			Days to maturity		
	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean
NL-510	7.67	6.67	7.17	11.00	9.67	10.33	53.00	51.33	52.17	126.33	120.33	123.33

(continued on next page)

(A)Sowing Conditions		Primary branches plant ⁻¹			Secondary branches plant ⁻¹			Days to 50 % flowering			Days to maturity		
(B) Genotypes		Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean
NL-513		7.33	6.33	6.83	15.33	14.33	14.83	61.67	58.00	59.83	121.00	119.00	120.00
NL-426		7.00	6.00	6.50	14.67	12.00	13.33	64.00	56.67	60.33	123.67	114.33	119.00
NL-429		7.33	6.00	6.67	13.67	12.33	13.00	64.33	62.33	63.33	109.00	105.00	107.00
NL-527		7.33	6.00	6.67	14.67	13.00	13.83	53.33	50.67	52.00	118.00	114.33	116.17
NL-353		7.33	5.33	6.33	15.33	13.33	14.33	64.33	61.67	63.00	122.33	108.67	115.50
NL-378		8.33	6.67	7.50	15.33	14.00	14.67	57.67	52.67	55.17	119.67	114.67	117.17
NL-386		7.67	6.33	7.00	12.67	10.67	11.67	64.00	61.00	62.50	126.67	118.67	122.67
NL-390		8.00	6.67	7.33	13.33	12.00	12.67	58.33	52.33	55.33	109.67	105.00	107.33
NL-391		7.67	6.00	6.83	13.33	12.33	12.83	65.33	54.67	60.00	116.33	112.67	114.50
NL-403		7.00	5.33	6.17	13.33	11.00	12.17	54.33	53.67	54.00	110.33	106.67	108.50
NL-511		7.67	5.67	6.67	14.33	12.00	13.17	64.67	52.00	58.33	124.00	113.67	118.83
NL-512		7.00	5.67	6.33	13.67	12.00	12.83	54.33	51.33	52.83	119.00	110.00	114.50
NL-517		8.00	7.00	7.50	14.33	11.67	13.00	64.00	59.67	61.83	120.67	111.00	115.83
NL-529		8.00	7.00	7.50	14.33	12.00	13.17	62.33	52.00	57.17	123.00	114.67	118.83
NL-519		7.67	6.00	6.83	13.67	12.33	13.00	60.33	52.67	56.50	114.67	104.67	109.67
NL-522		6.67	5.67	6.17	13.33	12.00	12.67	65.00	60.33	62.67	126.00	112.33	119.17
NL-521		8.67	6.67	7.67	14.00	11.67	12.83	56.67	52.33	54.50	124.33	113.00	118.67
PKV NL-260 (C)		8.33	7.33	7.83	12.33	10.67	11.50	62.00	55.33	58.67	111.00	108.67	109.83
LSL-93 (C)		6.67	5.33	6.00	12.33	10.67	11.50	57.67	47.67	52.67	113.67	107.00	110.33
Mean (A)		7.57	6.18		13.75	11.98		60.37	54.92		118.97	111.72	
F test		**	**	NS	**	**	NS	**	**	**	**	**	**
SEm ±		0.0656	0.2076	0.3595	0.1157	0.3659	0.6337	0.2016	0.6374	1.1040	0.2185	0.6910	1.1968
CD at 5%		0.1848	0.5844	1.0122	0.3258	1.0301	1.7842	0.5675	1.7946	3.1083	0.6152	1.9455	3.3696

Table 3. Performance of different linseed genotypes for biochemical traits under irrigated and utera conditions

(A)Sowing Conditions (B) Genotypes	Total chlorophyll content (mg g ⁻¹)			Seed oil content (%)		
	Irrigated (A1)	Utera (A2)	Mean	Irrigated (A1)	Utera (A2)	Mean
NL-510	2.19	1.17	1.68	41.59	40.55	41.07
NL-513	2.10	1.66	1.88	39.84	38.47	39.16
NL-426	2.65	1.65	2.15	42.31	41.27	41.79
NL-429	2.65	1.55	2.10	41.45	40.96	41.21
NL-527	2.12	1.86	1.99	40.95	39.16	40.06
NL-353	1.77	1.34	1.56	41.18	40.17	40.68
NL-378	1.76	1.30	1.53	40.72	39.50	40.11
NL-386	2.10	1.54	1.82	41.97	40.49	41.23
NL-390	1.74	1.43	1.58	39.82	38.80	39.31
NL-391	1.71	1.37	1.54	40.00	39.81	39.91
NL-403	2.27	1.93	2.10	39.91	38.95	39.43
NL-511	2.19	1.76	1.97	40.77	39.43	40.10
NL-512	2.13	1.73	1.93	41.37	40.07	40.72
NL-517	1.95	1.70	1.83	42.73	41.11	41.92
NL-529	1.81	1.52	1.67	40.55	39.77	40.16
NL-519	2.32	1.94	2.13	42.54	41.54	42.04
NL-522	1.80	1.63	1.72	41.30	40.96	41.13
NL-521	1.79	1.44	1.62	42.15	41.33	41.74
PKV NL-260 (C)	1.87	1.75	1.81	39.20	38.54	38.87
LSL-93 (C)	1.42	1.28	1.35	39.35	37.72	38.54
Mean (A)	2.02	1.60		40.99	39.93	
	Sowing Conditions	Genotypes	Interaction	Sowing Conditions	Genotypes	Interaction
F test	**	**	**	**	**	**
SEm ±	0.0054	0.0171	0.0296	0.1242	0.3928	0.5555
CD at 5%	0.0152	0.0482	0.0835	0.3497	1.1060	1.5641

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