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Evaluation of mustard genotypes under irrigated and rainfed conditions

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Abstract
A field experiment was conducted during the 2023-24 cropping season at the Experimental Farm of the All India Coordinated Research Project on Linseed and Mustard and the Agricultural Botany Section, College of Agriculture, Nagpur, to evaluate the morpho-physiological responses and yield performance of Indian mustard genotypes under contrasting moisture conditions. Sixteen genotypes were evaluated under two sowing environments irrigated and rainfed using a factorial randomized block design (FRBD) with three replications. The findings revealed that genotype ACN-237 demonstrated superior performance across both conditions in key morpho-physiological parameters such as plant height, root-shoot length ratio, number of branches plant^{-1}, and leaf area. Yield related attributes, including siliquae density, number of siliquae plant^{-1}, 1000-seed weight, seed yield plant^{-1}, and seed yield plot^{-1}, were generally higher under irrigation. However, ACN-237 consistently outperformed others even under rainfed conditions, highlighting its broad adaptability to moisture stress.

Keywords: Indian mustard, genotypes, sowing conditions, seed yield and factorial randomized block design (FRBD)

Introduction
Mustard [*Brassica juncea*] is an important oilseed crop belonging to the Brassicaceae family (formerly known as Cruciferae). Indian mustard, commonly referred to as brown mustard, is a natural amphidiploid with a total chromosome count of (2n=36). It primarily reproduces by self-pollination, though insects and other factors contribute to an estimated 2-15% of pollination. The oil content in rapeseed-mustard crops ranges from 33% to 46%, with an average oil recovery of approximately 32% to 38% (Dhaliwal *et al.*, 2022) [1]. Oil cake remaining after oil extraction is used as animal feed and manures (Gopale *et al.*, 2022) [2]. The lack of water is a significant environmental limitation to the survival, growth, and productivity of plants (Yang *et al.*, 2021) [3]. Generally, drought stress situations trigger a series of morphological, physiological, biochemical, and molecular reactions that influence plant metabolism. To address the effects of water scarcity, plants have developed various adaptive strategies, which encompass mechanisms for stress avoidance and stress tolerance. Deficit irrigation (DI) and irrigation scheduling are critical irrigation management techniques that are gaining traction to save water and maintain crop yields in areas facing water shortages. A reduced volume of irrigation water, less than the complete water requirements of the crop, is supplied at different stages of crop growth or occasionally throughout the entire growing season (Nasir *et al.*, 2022) [4].

Different mustard genotypes may respond differently to water availability, with some performing better under irrigated conditions while others excel in rainfed environments. By evaluating genotypes under both conditions, researchers can pinpoint the varieties that offer the highest yields under each scenario, thus optimizing production. Excessive water application leads to wastage, while limited water application may result in decreased yield (Jat *et al.*, 2018) [5].

Considering the economic and agronomic importance of Indian mustard as a major oilseed crop, the present investigation was conducted to evaluate suitable sowing environments and genotypes based on morphological traits, yield, and yield-contributing parameters for achieving higher productivity and profitability.

Materials and Methods
A field experiment was conducted at experimental farm of All India Co-ordinated Research Project on Linseed and Mustard and Agricultural Botany Section, College of Agriculture, Nagpur during *Rabi* 2023-24 under the research study entitled "Evaluation of mustard genotypes under irrigated and rainfed conditions". The experiment was laid out in a Factorial Randomized Block Design (FRBD) comprising sixteen Indian mustard genotypes ACN-231, ACN-237, ACN-248, ACN-258, ACN-264, ACN-281, ACN-285, ACN-294, ACNMM-32, ACNMM-40, ACNMM-55, ACNMM-62, TM 308-1(YS), Kranti, BIO-902, and TAM-108-1 under two distinct sowing conditions irrigated and rainfed. Each treatment was replicated thrice. The gross plot size was 5.00 m × 2.70 m, while the net plot size was maintained at 4.80 m × 1.80 m, with a spacing of 45 cm × 10 cm. Sowing was carried out using a seed rate of 5 kg ha^{-1}. For the assessment of morpho-physiological parameters, five plants were randomly selected from each plot. Observations on plant height were recorded in centimeters at harvest using a measuring scale. Measurements were taken from the base to the tip of the highest leaf or the terminal flower of the main shoot in flowering plants. The root-shoot length ratio was calculated by dividing root length by shoot length. The number of primary branches $plant^{-1}$ was determined by counting the branches on the main stem of the five selected plants and calculating the average. Leaf area was measured at 45 and 75 DAS using a leaf area meter. Leaves from five randomly selected plants per plot were used, and the values recorded in cm^2 were later converted to dm^2. At harvest, key yield and yield-attributing traits were recorded, including siliquae density, number of siliquae $plant^{-1}$, 1000-seed weight, seed yield $plant^{-1}$, and seed yield $plot^{-1}$.

Results and Discussions
Plant height
At harvest, irrigated conditions resulted in significantly higher plant height compared to rainfed conditions. The height of plants at harvest was significantly greater under irrigated conditions (184.40 cm) compared to rainfed conditions. Overall reduction percentage between irrigated and rainfed conditions was 23.56%. Result revealed by Rani *et al.* (2024) [6] revealed that decreasing irrigation water significantly decreased plant height of the crop. Significant genotypic variation was observed in plant height across irrigated (A1) and rainfed (A2) conditions at harvest. ACN-237 consistently recorded the highest plant height under both conditions with the lowest percent reduction 17.70% at harvest. ACN-294 followed closely with reductions of 19.98% and remained statistically at par with ACN-237 across harvest. In contrast, genotypes like ACN-248 and TM 308-1(YS) showed the highest reductions, exceeding 30% at harvest, suggesting greater sensitivity to moisture stress. Similar findings reported by, Sodani *et al.* (2017) [7] that the tallest plants were observed in the genotype NRCDR-02 under control conditions (196.2 cm) and RGN-219 under drought conditions (176.5 cm). Interaction between sowing conditions and genotypes for plant height was found non-significant at all stages of observations.

Root shoot length ratio
Root shoot ratio was significantly influenced by the sowing conditions (A), while the genotypic differences and interaction were found non-significant. The overall mean root shoot ratio was higher under rainfed conditions (A2: 0.126) compared to irrigated conditions (A1: 0.082), indicating an adaptive response towards moisture stress. Similar results revealed by, JIA *et al.* (2021) [8] that the root shoot ratio of plants under three drought levels increased by 56.70%, 99.65%, and 48.05% compared with controls.

Number of branches $plant^{-1}$
The number of branches $plant^{-1}$ was significantly affected by sowing conditions. Under irrigated conditions, the average number of branches was 3.35, which declined to 2.40 under rainfed conditions, reflecting a reduction of 28.35%. These findings align with those of Gupta *et al.* (2021) [9], who also reported a noticeable decline in the number of primary branches under moisture-stressed environments compared to irrigated ones. However, the genotypic differences in branch number at harvest were statistically non-significant. Furthermore, the interaction between sowing conditions and genotypes did not show a significant effect, indicating a uniform response pattern across genotypes.

Leaf area
Leaf area was significantly affected by sowing conditions at both 45 and 75 DAS, as confirmed by the F-test. At 45 DAS, the average leaf area under irrigated conditions was 7.04 dm^2, which declined to 5.69 dm^2 under rainfed conditions. A similar pattern was observed at 75 DAS, with mean leaf area decreasing from 6.37 dm^2 (irrigated) to 5.22 dm^2 (rainfed). This indicates that sufficient water availability under irrigated conditions supports enhanced leaf expansion. These results are in agreement with the findings of Rani *et al.* (2024) [6], who reported that leaf area was maximized under well-watered conditions compared to drought stress.

Significant genotypic differences in leaf area were observed at both stages. At 45 DAS, ACN-237 exhibited the largest leaf area and the lowest percent reduction (12.67%), followed by ACN-294 and ACNMM-55. In contrast, TM 308-1(YS) had the smallest leaf area and the highest reduction (22.96%), indicating greater sensitivity to water deficit. This trend continued at 75 DAS, where ACN-237 was highest and followed by ACN-294 maintained superior leaf development, while TM 308-1(YS) remained the lowest. These observations are consistent with Rani *et al.* (2024) [6], who noted that the cultivar RH-749 showed maximum leaf area at the fruiting stage, followed by RH-725. The interaction between sowing conditions and genotypes was non-significant at both growth stages, suggesting a uniform genotypic response to moisture regimes.

Table 1: Plant height of Indian mustard and root shoot length ratio as affected by sowing conditions and genotypes

Genotypes	Plant height (cm) At harvest			Root shoot length ratio At harvest		
	A1	**A2**	**Reduction (%)**	**A1**	**A2**	**Reduction (%)**
(B1) ACN 231	204.40	147.53	27.82	0.070	0.110	36.36
(B2) ACN-237	223.33	183.80	17.70	0.087	0.132	33.68
(B3) ACN-248	182.33	126.47	30.64	0.080	0.150	46.76
(B4) ACN-258	168.60	131.07	22.26	0.087	0.132	34.15
(B5) ACN-264	163.47	128.07	21.66	0.080	0.122	34.65
(B6) ACN 281	163.40	129.33	20.85	0.081	0.117	30.53
(B7) ACN 285	162.53	128.67	20.84	0.081	0.115	29.40
(B8) ACN 294	209.33	167.50	19.98	0.078	0.119	34.06
(B9) ACNMM-32	181.67	136.87	24.66	0.084	0.127	33.90
(B10) ACNMM-40	188.07	141.96	24.52	0.085	0.129	33.88
(B11) ACNMM-55	176.27	137.20	22.16	0.082	0.128	35.50
(B12) ACNMM-62	177.60	138.35	22.10	0.092	0.140	34.13
(B13) TM 308-1(YS)	135.87	91.10	32.95	0.084	0.125	32.66
(B14) Kranti (C)	202.40	153.93	23.95	0.077	0.119	34.88
(B15) BIO-902 (C)	203.73	148.93	26.90	0.077	0.118	34.78
(B16) TAM-108-1 (C)	207.47	164.27	20.82	0.083	0.131	37.08
Mean (A)	184.40	140.94		0.082	0.126	36.36
	A	B	I	A	B	I
SEm±	2.146	6.070	10.514	0.0026	0.0073	0.0126
CD at 5%	6.067	17.160	NS	0.0073	NS	NS

Note: A1:-Irrigated, A2:-Rainfed, A:-Sowing conditions, B:-Genotypes, C:-Check and NS:-Non-significant

Table 2: Number of branches plant^{-1} and Leaf area of Indian mustard as affected by sowing conditions and genotypes

Genotypes	Number of branches plant^{-1} At harvest			Leaf area (dm^2) 45 DAS			Leaf area (dm^2) 75 DAS		
	A1	**A2**	**Reduction (%)**	**A1**	**A2**	**Reduction (%)**	**A1**	**A2**	**Reduction (%)**
(B1) ACN 231	2.83	2.13	24.71	6.67	5.22	21.83	6.00	4.98	17.10
(B2) ACN-237	4.68	2.73	41.55	10.58	9.24	12.67	9.16	7.99	12.74
(B3) ACN-248	3.13	2.20	29.79	6.41	4.98	22.26	5.92	4.54	23.41
(B4) ACN-258	3.00	2.33	22.22	6.20	5.01	19.25	5.58	4.66	16.44
(B5) ACN-264	3.07	2.13	30.43	6.70	5.37	19.86	5.90	4.93	16.50
(B6) ACN 281	2.73	2.47	9.76	6.84	5.44	20.38	5.80	4.91	15.35
(B7) ACN 285	3.13	2.33	25.53	6.55	5.31	18.93	5.71	4.86	14.78
(B8) ACN 294	3.80	2.47	35.09	8.58	7.39	13.86	8.14	6.85	15.81
(B9) ACNMM-32	3.40	2.53	25.49	6.52	5.05	22.55	5.85	4.89	16.31
(B10) ACNMM-40	3.53	2.40	32.08	6.97	5.38	22.73	6.42	5.19	19.21
(B11) ACNMM-55	3.73	2.27	39.29	7.65	6.09	20.43	6.68	5.33	20.16
(B12) ACNMM-62	3.43	2.55	25.68	6.56	5.40	17.59	5.79	4.69	19.04
(B13) TM 308-1(YS)	2.73	2.40	12.20	5.91	4.55	22.96	5.03	3.57	29.05
(B14) Kranti (C)	3.53	2.40	32.08	6.65	5.34	19.66	6.27	4.92	21.54
(B15) BIO-902 (C)	3.41	2.57	24.80	6.62	5.26	20.59	6.26	4.89	21.87
(B16) TAM-108-1(C)	3.43	2.47	28.16	7.22	6.03	16.44	7.46	6.38	14.43
Mean (A)	3.35	2.40		7.04	5.69		6.37	5.22	
	A	B	I	A	B	I	A	B	I
SEm±	0.078	0.221	0.383	0.096	0.272	0.471	0.084	0.238	0.413
CD at 5%	0.221	NS	NS	0.272	0.770	NS	0.238	0.674	NS

Note: A1:-Irrigated, A2:-Rainfed, A:-Sowing conditions, B:-Genotypes, C:-Check and NS:-Non-significant

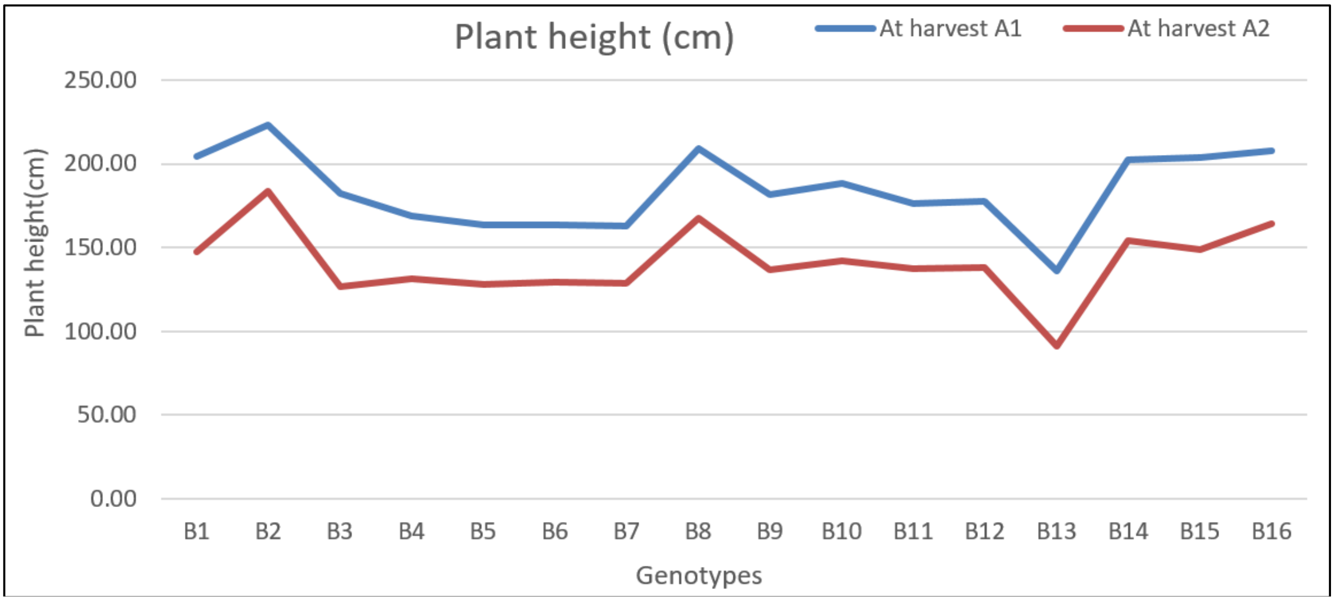

Fig 1: Plant height of Indian mustard as affected by sowing conditions and genotypes

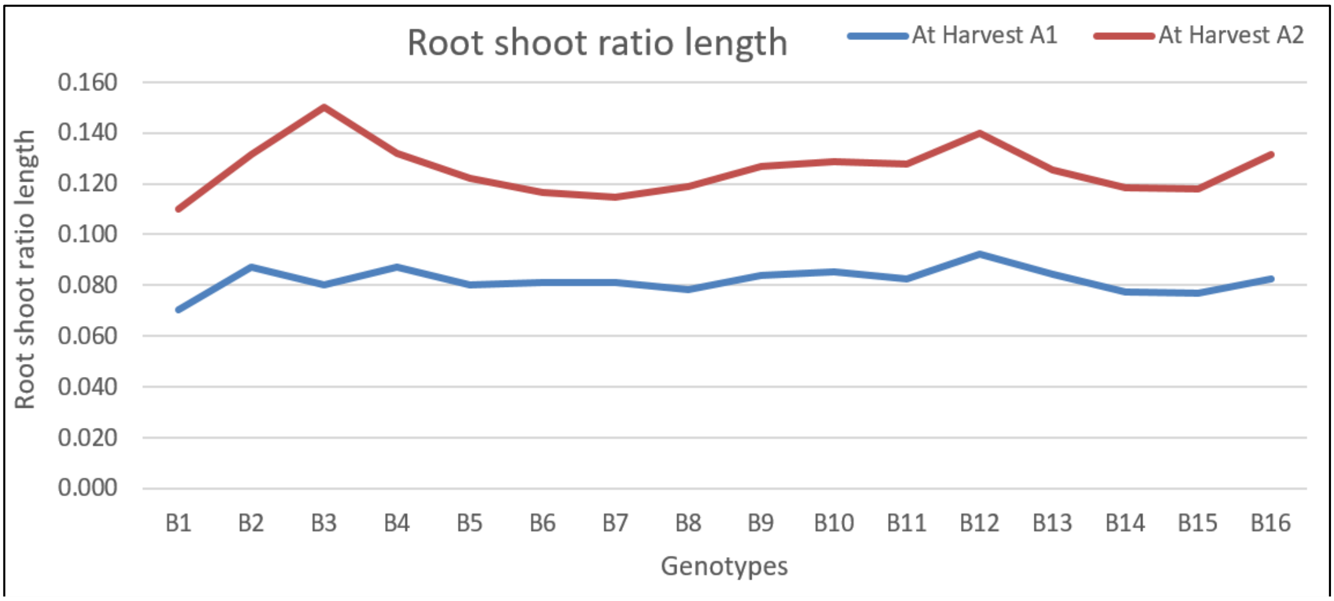

Fig 2: Root shoot length ratio as affected by sowing conditions and genotypes

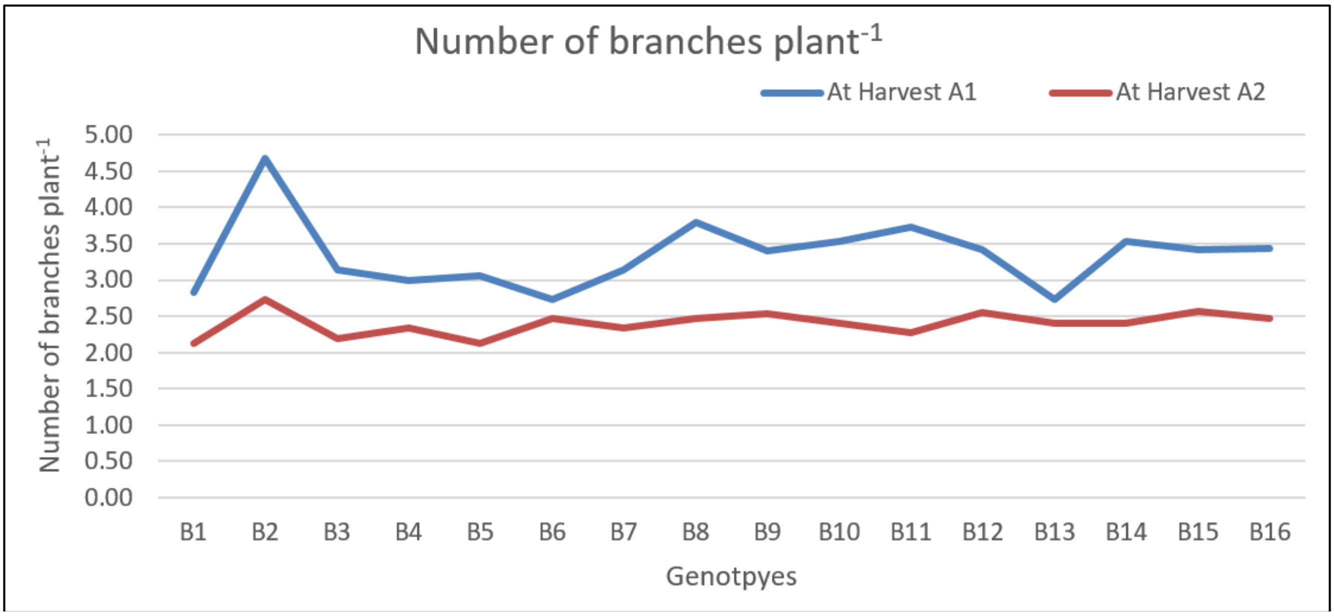

Fig 3: Number of branches plant^{-1} of Indian mustard as affected by sowing conditions and genotypes

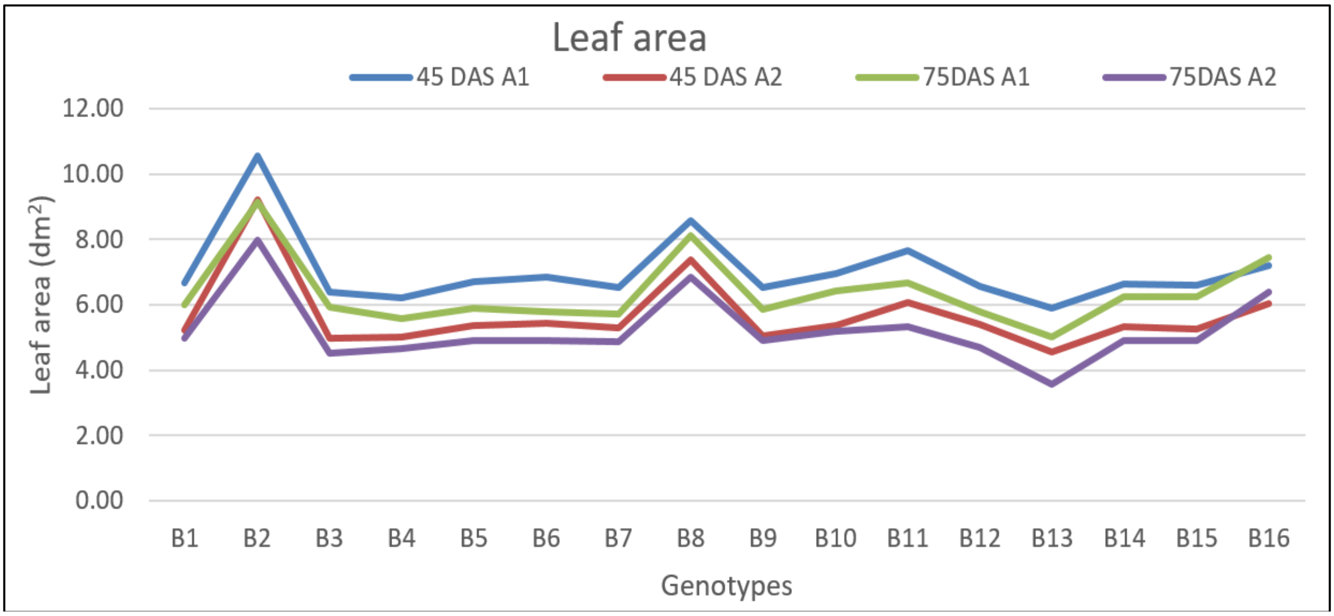

Fig 4: Leaf area of Indian mustard as affected by sowing conditions and genotypes

Siliquae density

Sowing conditions had a significant influence on silique density, with higher mean values observed under irrigated (0.638) compared to rainfed (0.492) conditions, reflecting the negative impact of moisture stress on reproductive development. These findings align with Singh *et al.* (2018) [10], who reported greater main shoot length and silique number under irrigated conditions. Genotypic variation was also significant. ACN-237 recorded the highest silique density with the lowest reduction (17.10%), followed closely by ACN-294 (17.35%) and ACNMM-55 (17.62%), all statistically at par. Conversely, TM 308-1(YS) showed the lowest silique density and the highest reduction (34.59%), indicating sensitivity to drought stress. The interaction between sowing conditions and genotypes was non-significant, suggesting a consistent genotypic response across environments.

Number of siliquae plant^{-1}

Sowing conditions had a highly significant impact on the number of silique plant^{-1}, as shown by the mean values of 316.32 under irrigated and 220.43 under rainfed conditions. Similar findings were reported by Rani *et al.* (2024) [6], where the highest number of siliquae was observed in plants that received two irrigations (control), followed by those with single irrigation, while the lowest number was noted in plants with no irrigation. Genotypic differences were also highly significant. ACN-237 recorded the highest silique count with the lowest reduction (24.17%), followed by ACN-294 (26.93%) and ACNMM-55 (27.95%) both statistically at par. In contrast, TM 308-1(YS) showed the lowest silique number and highest reduction (40.04%), indicating poor performance under moisture stress. Rani *et al.* (2024) [6] found that the cultivar RH-749 produced a significantly greater number of siliquae compared to RH-725. The interaction between sowing conditions and genotypes was non-significant.

1000 seed weight

Sowing conditions had a significant effect on 1000 seed weight, with higher values under irrigated (4.88 g) compared to rainfed conditions (4.46 g). Similar reductions under moisture stress were reported by Ali *et al.* (2022) [11]. Genotypic differences were also significant, with ACN-237 showing the highest seed weight and lowest reduction (3.31%), followed by ACN-294 (3.62%) and ACNMM-55(4.66%), all statistically at par. TM 308-1(YS) had the lowest weight and highest reduction (20.98%), indicating poor drought tolerance. These findings are consistent with Rani *et al.* (2024) [6], who reported greater seed weight in RH-749 than RH-725. The interaction was non-significant, indicating stable performance across conditions.

Seed yield plant^{-1} (g)

Seed yield plant^{-1} was significantly influenced by sowing conditions, with higher yield under irrigated (14.02 g) than rainfed conditions (9.43 g). Similar yield declines under moisture stress were reported by Sujata *et al.* (2023) [12]. Genotypic variation was also significant; ACN-237 recorded the highest yield with the lowest reduction, followed by ACN-294 and ACNMM-55, all at par. TM 308-1(YS) showed the lowest yield and highest reduction, indicating poor drought tolerance. These findings align with Kumari *et al.* (2019) [13], who observed wide variability in seed yield under both moisture regimes. The interaction was non-significant, indicating stable genotypic performance across conditions.

Seed yield plot^{-1} (kg)

Sowing conditions had a significant impact on seed yield per plot, with a mean yield of 0.93 kg under irrigated conditions, which declined to 0.61 kg under rainfed conditions. Sharma *et al.* (2022) [14] similarly reported a 12.7% reduction in seed yield under moisture deficit. Genotypic differences were also significant ACN-237 recorded the highest yield with the least reduction, followed by ACN-294 and ACNMM-55, with ACN-294 statistically at par with ACN-237. TM 308-1(YS) showed the lowest yield and greatest reduction, reflecting sensitivity to drought. These results are in line with Sharma *et al.* (2022) [14], who noted the highest yield loss in JC 210-335 and the least in PBR 357. The interaction was non-significant, indicating consistent genotypic performance across moisture regimes.

Table 3: Siliquae density, Number of siliquae plant^{-1} and 1000 seed weight of Indian mustard as affected by sowing conditions and genotypes

Genotypes	Siliquae density			Number of siliquae plant^{-1}			1000-seed weight (g)		
	A1	A2	Reduction (%)	A1	A2	Reduction (%)	A1	A2	Reduction (%)
(B1) ACN 231	0.592	0.466	21.28	306.90	213.80	30.34	4.77	4.05	15.15
(B2) ACN-237	0.833	0.691	17.10	385.37	292.22	24.17	5.94	5.74	3.31
(B3) ACN-248	0.574	0.451	21.40	314.27	214.88	31.62	4.31	4.02	6.80
(B4) ACN-258	0.621	0.477	23.20	314.77	213.87	32.06	4.94	4.64	6.14
(B5) ACN-264	0.617	0.483	21.73	308.63	218.60	29.17	4.73	4.45	5.99
(B6) ACN 281	0.619	0.495	20.02	306.03	191.67	37.37	4.85	3.88	19.99
(B7) ACN 285	0.593	0.425	28.35	263.17	184.98	29.71	4.53	4.22	6.70
(B8) ACN 294	0.769	0.635	17.35	363.33	265.50	26.93	5.62	5.41	3.62
(B9) ACNMM-32	0.679	0.521	23.29	294.87	199.10	32.48	4.87	3.94	18.97
(B10) ACNMM-40	0.572	0.441	22.94	318.40	218.73	31.30	4.41	4.13	6.42
(B11) ACNMM-55	0.707	0.582	17.62	361.83	260.70	27.95	5.58	5.32	4.66
(B12) ACNMM-62	0.662	0.447	32.38	315.33	223.63	29.08	5.01	4.70	6.32
(B13) TM 308-1(YS)	0.388	0.254	34.59	258.00	154.70	40.04	4.02	3.18	20.98
(B14) Kranti (C)	0.625	0.486	22.19	318.38	224.33	29.54	4.62	4.25	7.94
(B15) BIO-902 (C)	0.692	0.481	30.53	312.33	221.63	29.04	4.86	4.55	6.45
(B16) TAM-108-1(C)	0.671	0.537	19.90	319.48	228.50	28.48	5.08	4.81	5.31
Mean (A)	0.638	0.492		316.32	220.43		4.88	4.46	
	A	B	I	A	B	I	A	B	I
SEm±	0.016	0.047	0.081	4.088	11.562	20.026	0.054	0.152	0.264
CD at 5%	0.047	0.132	NS	11.556	32.685	NS	0.152	0.431	NS

Note: A1:-Irrigated, A2:-Rainfed, A:-Sowing conditions, B:-Genotype, C:-Check and NS:-Non-significant

Table 4: Seed yield plant^{-1} and seed yield plot^{-1} of Indian mustard as affected by sowing conditions and genotypes

Genotypes	Seed yield plant^{-1} (g)			Seed yield plot^{-1} (kg)		
	A1	A2	Reduction (%)	A1	A2	Reduction (%)
(B1) ACN 231	13.27	8.82	33.55	0.87	0.56	35.51
(B2) ACN-237	17.84	12.85	27.98	1.28	0.91	28.45
(B3) ACN-248	13.35	8.98	32.73	0.90	0.56	37.31
(B4) ACN-258	13.87	9.28	33.05	1.01	0.64	36.61
(B5) ACN-264	13.60	9.20	32.33	0.93	0.59	36.31
(B6) ACN 281	13.00	8.60	33.85	0.73	0.47	35.19
(B7) ACN 285	14.79	9.64	34.84	0.96	0.62	35.53
(B8) ACN 294	16.60	11.81	28.84	1.12	0.80	28.99
(B9) ACNMM-32	12.87	8.57	33.39	0.91	0.59	35.53
(B10) ACNMM-40	12.05	8.09	32.86	0.93	0.60	35.36
(B11) ACNMM-55	15.81	11.12	29.65	1.02	0.66	35.12
(B12) ACNMM-62	11.90	8.02	32.58	0.69	0.44	36.01
(B13) TM 308-1(YS)	11.70	6.43	45.01	0.64	0.40	38.22
(B14) Kranti (C)	14.47	9.68	33.12	0.91	0.57	37.45
(B15) BIO-902 (C)	14.28	9.63	32.56	0.97	0.63	35.25
(B16) TAM-108-1(C)	14.95	10.14	32.19	1.06	0.69	34.88
Mean (A)	14.02	9.43		0.93	0.61	
	A	B	I	A	B	I
SEm±	0.335	0.947	1.640	0.023	0.066	0.115
CD at 5%	0.947	2.677	NS	0.066	0.187	NS

Note: A1:-Irrigated, A2:-Rainfed, A:-Sowing conditions, B:-Genotype, C:-Check and NS:-Non-significant

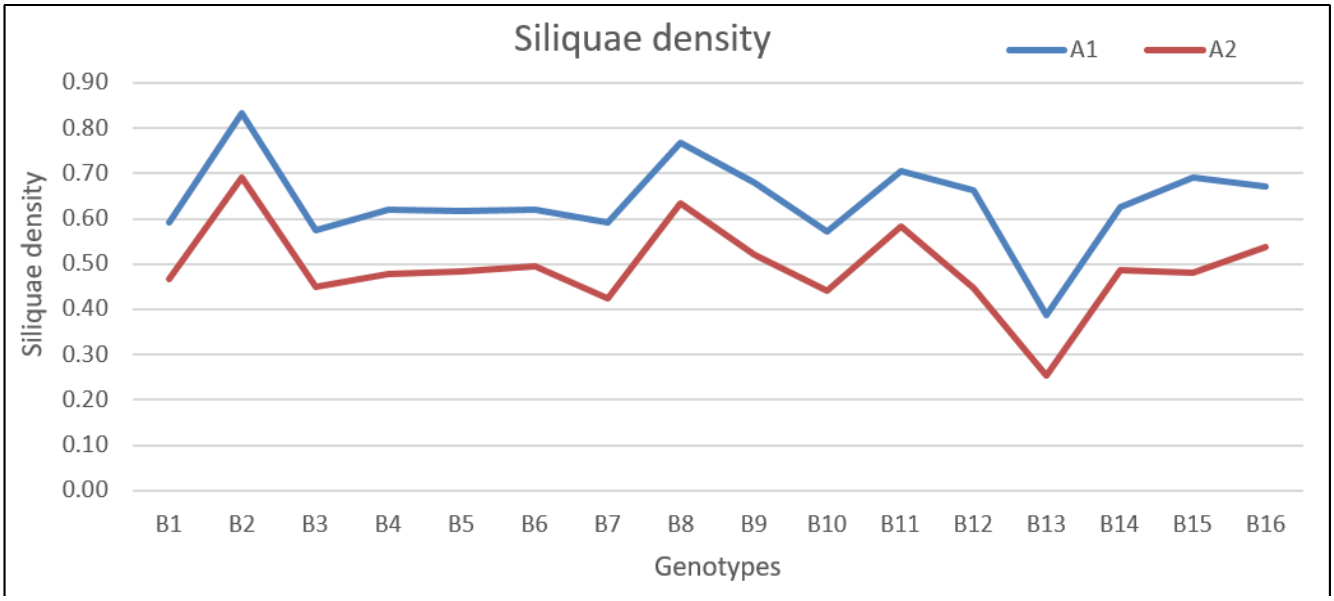

Fig 5: Siliquae density of Indian mustard as affected by sowing conditions and genotypes

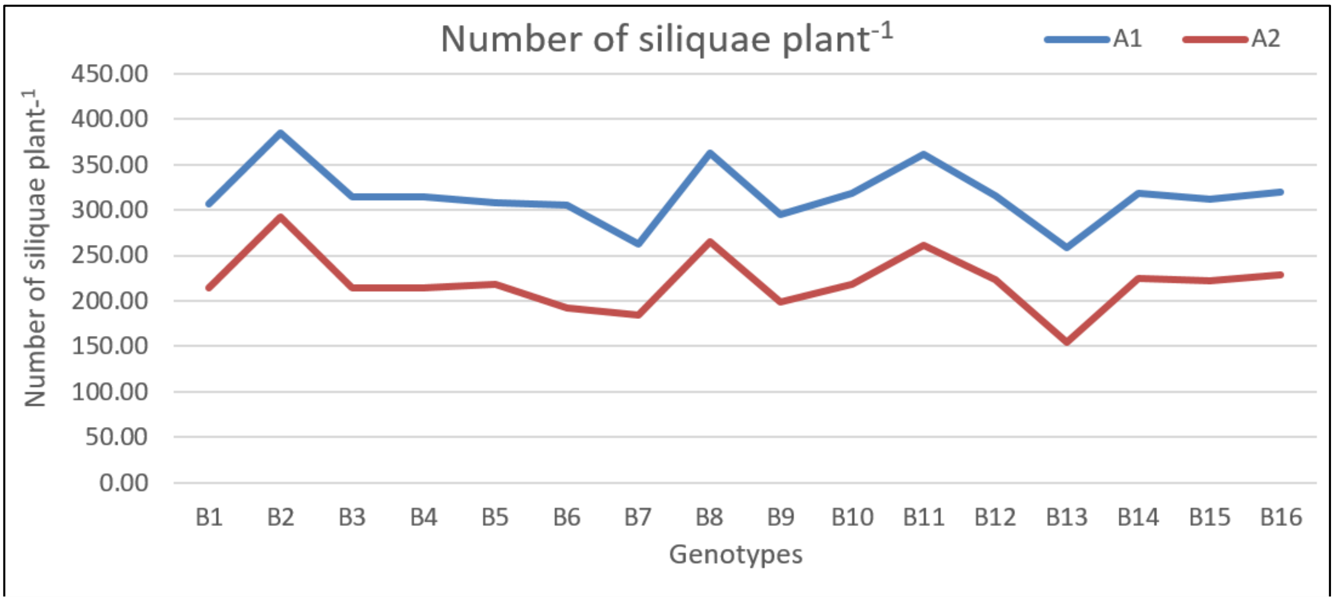

Fig 6: Number of siliquae plant^{-1} of Indian mustard as affected by sowing conditions and genotypes

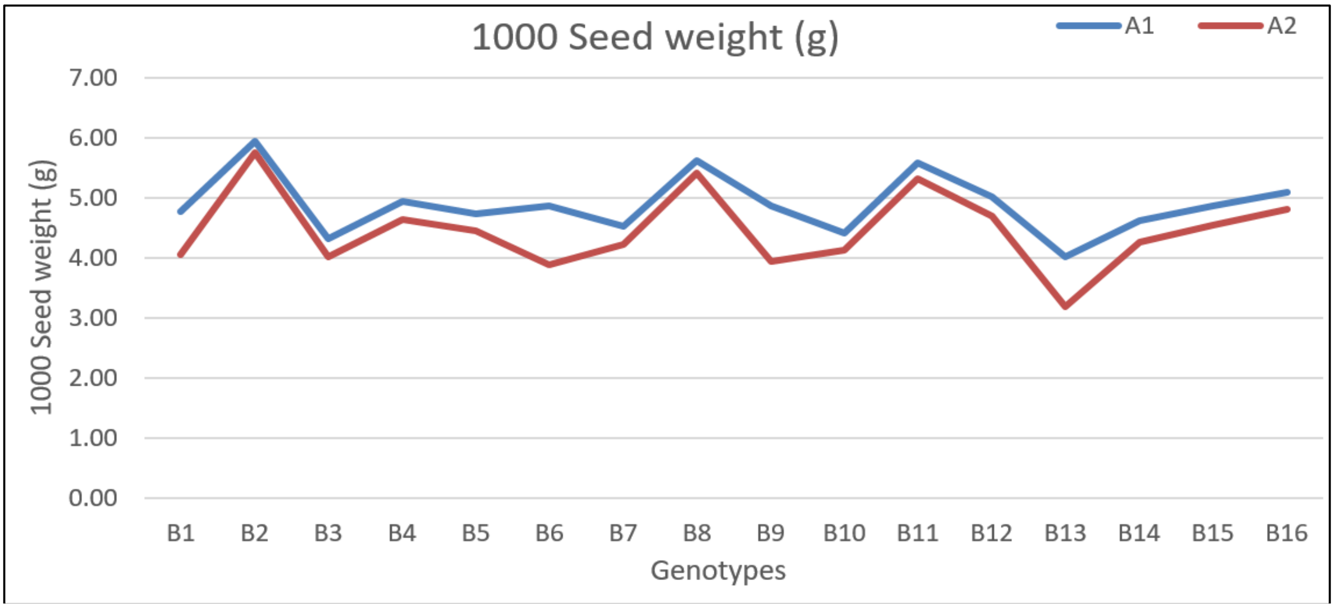

Fig 7: 1000 Seed weight of Indian mustard as affected by sowing conditions and genotypes

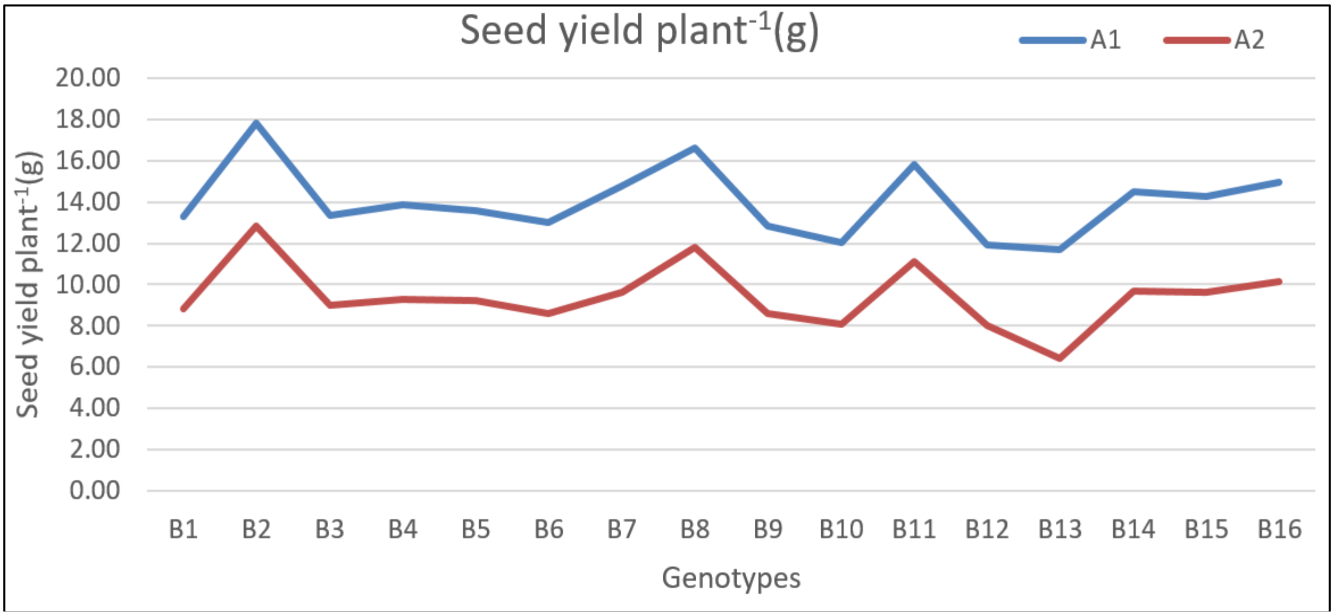

Fig 8: Seed yield plant^{-1} of Indian mustard as affected by sowing conditions and genotypes

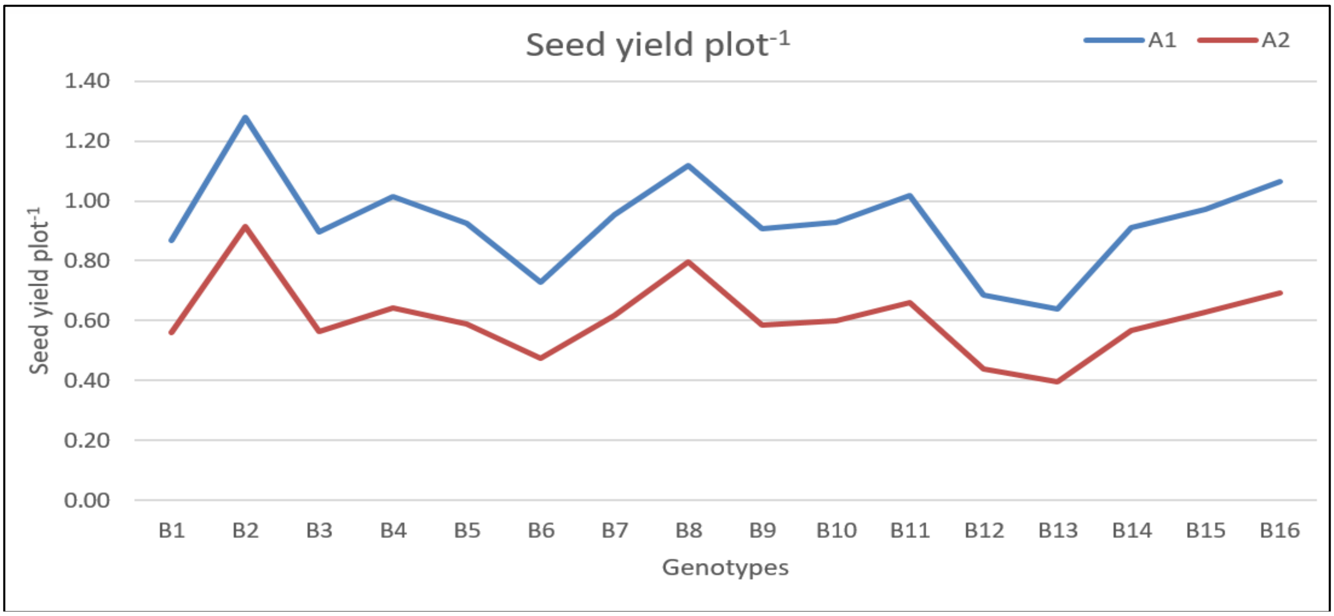

Fig 9: Seed yield plant^{-1} of Indian mustard as affected by sowing conditions and genotypes

Conclusion

The present investigation demonstrated that sowing conditions exerted a highly significant effect on key morphological and yield-related traits in mustard genotypes. Moisture deficit under rainfed conditions led to marked reductions in plant height, root shoot length ratio, number of branches plant^{-1}, leaf area, siliquae density, 1000 seed weight, and seed yield, highlighting the sensitivity of these traits to water stress. Genotypic variability was evident, with ACN-237 consistently exhibiting superior performance and minimal reduction across environments, followed closely by ACN-294 and ACNMM-55, indicating their inherent drought resilience. Conversely, TM 308-1(YS) recorded the lowest performance and highest reduction, confirming its susceptibility to stress. The non-significant interaction for most traits suggests relative stability of genotype rankings across irrigated and rainfed conditions. These findings underscore the potential of ACN-237 and ACN-294 as promising genotypes for send to multilocation trial to check performance stability.

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