



Genotypic Response of Canola (*Brassica Napus L.*) Accessions to Moisture Stress

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Abstract

Pakistan is an agrarian economy heavily dependent on crop production, yet it faces a substantial edible oil import burden due to low domestic oilseed yields. To address this, drought-tolerant canola (*Brassica napus* L.) varieties are essential for sustainable production. This study evaluated the genotypic response of 15 canola accessions to moisture stress under controlled conditions. Two experiments were conducted: (1) a germination assay using polyethylene glycol (PEG-6000) to simulate osmotic stress at four levels (0, -0.2, -0.4, and -0.6 MPa), and (2) a pot trial comparing well-watered and drought-stressed conditions. Germination percentage declined significantly with increasing stress, ranging from 62.33–100% (control) to 0–53.3% (-0.6 MPa). The range of germination stress tolerance index percentage was 18.40 - 78.56% across the treatments. The ranges of germination stress tolerance index percentages were 55.3-100%, 31-100% and 0-53.3% in T₂ (-0.2 MPa), T₃ (-0.4 MPa) and T₄ (-0.6 MPa) respectively. Accessions Dunkeld and Zn-R-7 exhibited high drought tolerance, maintaining better germination and seedling vigor, whereas Zn-M-9 and Zn-N-6 were highly sensitive. Under drought, root length increased (3.87–9.92 cm vs. 1.67–7 cm in controls), likely as an adaptive response, while shoot length (1.58–5.32 cm vs. 1.92–8.13 cm) and seedling dry weight (0.03–0.44 g vs. 0.05–0.51 g) decreased. High heritability (>90%) and strong genotypic correlations indicated that these traits were predominantly genetically controlled. Path analysis revealed that shoot length had the most significant direct positive effect on seedling dry weight, emphasizing its importance in drought resilience. The findings demonstrate substantial genetic variability among canola accessions, providing a basis for breeding programs aimed at enhancing drought tolerance. Selecting genotypes with superior stress adaptability, such as Dunkeld and Zn-R-7, could improve canola productivity in water-limited environments, reducing reliance on edible oil imports.

Keywords: Oilseed yield, Drought tolerance, Stress tolerance index, Genotypic correlation.

Introduction

Edible oil is an essential commodity in every household and a critical component of national food security (Olabisi et al., 2021). It serves as a major source of dietary energy and essential fatty acids, playing a vital role in human nutrition and health. Globally, the demand for vegetable oils has been rising steadily, driven by population growth, urbanization, and

changing food habits (Mannucci et al., 2023). Among oilseed crops, canola (*Brassica napus* L.) has emerged as one of the leading sources of high-quality edible oil due to its low saturated fat content and favorable omega-3 and omega-6 fatty acid profile (Sachan et al., 2024). In Pakistan, edible oil consumption has increased significantly over the years, yet domestic production remains alarmingly low (Hussain et al., 2023). The country meets nearly 80–85% of its edible oil requirements through imports, primarily palm oil from Malaysia and Indonesia, resulting in a huge financial burden on the national economy (Goh & Potter, 2022). According to the Pakistan Bureau of Statistics (2023), the edible oil import bill crossed USD 4.5 billion annually, making it one of the major contributors to the trade deficit (Mustafa & Iqbal, 2021). Despite having suitable agro-climatic conditions and substantial arable land, Pakistan produces only about 0.5–0.7 million tons of edible oil annually, largely from cottonseed, sunflower, and canola. Among these, canola holds significant promise due to its adaptability, high oil yield (40–45%), and potential for cultivation in both irrigated and rainfed areas (Hameed & Azeem, 2017). Canola (*Brassica napus* L.), a prominent member of the Brassicaceae family, has gained global importance as a leading oilseed crop due to its high oil content, favorable fatty acid profile, and broad agronomic adaptability (Goyal et al., 2020). To reduce dependency on imports and achieve self-sufficiency, there is an urgent need to enhance local oilseed production, particularly canola (Sinha et al., 2020). However, one of the major constraints limiting canola productivity in Pakistan is moisture stress, especially in rainfed regions such as Potohar, Thal and parts of southern Punjab and Balochistan (Rana et al., 2022). The erratic rainfall pattern, coupled with the increasing frequency of droughts due to climate change, severely affects crop establishment, flowering, and seed development, resulting in substantial yield losses (Dietz et al., 2021). Moisture stress is one of the most devastating abiotic stresses affecting canola growth, physiology, and productivity. It alters various physiological processes such as photosynthesis, nutrient uptake, water relations, and hormonal balance (Sabagh et al., 2019). The impact of drought varies depending on the intensity, duration, growth stage, and most importantly, the genotype of the plant. Different genotypes of canola respond differently to water-deficit conditions some exhibit tolerance by maintaining higher relative water content, root growth, and osmotic adjustment, while others are more susceptible (Mirzaei et al., 2013). Understanding the genotypic variation in response to moisture stress is crucial for identifying drought-tolerant canola accessions suitable for cultivation under limited irrigation or rainfed systems in Pakistan (Nadem et al., 2024). Genotypes that can sustain physiological and agronomic performance under moisture stress can serve as valuable resources for breeding programs aiming to develop resilient varieties (Cooper & Messina, 2023). In this context, evaluating diverse canola accessions under water-deficit conditions can help in screening for important traits such as early vigor, deeper rooting ability, chlorophyll retention, efficient water use, and stable seed yield under drought. In Pakistan, research efforts on canola have primarily focused on agronomic management and hybrid development, with relatively limited attention to drought physiology and genotypic screening under moisture stress. This creates a research gap, especially in identifying and utilizing locally adaptable, stress-resilient germplasm. Given the increasing water scarcity and shrinking irrigation resources, the success of canola expansion in Pakistan's marginal areas will depend heavily on the identification and promotion of genotypes that can withstand moisture-limited environments. The current study is therefore designed to investigate the genotypic response of diverse canola accessions to moisture stress under local agro-climatic

conditions. The objectives of this research are to (i) evaluate morphological, physiological, and yield-related traits under controlled and drought conditions, (ii) quantify the degree of drought tolerance among genotypes, and (iii) identify promising accessions for future breeding and commercial cultivation. By conducting this research in the context of Pakistan's agricultural challenges, the findings would directly contribute to increasing domestic oilseed production, reducing the import bill, and strengthening national food security. This work will provide valuable insights into the adaptive mechanisms of canola under water stress and contribute to a more targeted and efficient breeding strategy for drought resilience. Ultimately, promoting drought-tolerant canola genotypes will help improve the sustainability of oilseed cropping systems in Pakistan's water-scarce environments, thereby aligning with national priorities for climate-smart agriculture and economic stability.

MATERIAL AND METHODS

Experimental Conditions

The present study on canola (*Brassica napus* L.) was carried out in the laboratory and wire house of the Department of Crop Physiology, University of Agriculture, Faisalabad. The material for the study consisted of 15 accessions of canola (*Brassica napus* L.) i.e. Zn-R-5, Zn-M-9, Zn-M-18, Po-9-5F, DGL, KN-256, Dunkeld, Zn-R-7, Zn-N-6, Durr-e-Niffa, Punjab Sarson, Cyclone, Excel, Zn-R-2 and KN-258 This material was obtained from the germplasm maintained by the Oilseed Research Program of the Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan.

Experiment No. 1: Screening in Petri Plates

This study was carried out in the Laboratory of the Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan. The experiment was conducted under laboratory conditions ($20\pm 5^{\circ}\text{C}$) to determine the germination response of fifteen canola accessions to drought stress. Experiment was laid out in completely randomized design (CRD) in factorial arrangements with three repeats in petri plates. Fifteen seeds of each accession were placed on top of filter paper moistened with PEG-6000 solutions for the germination. Before planting, seeds were surface sterilized in 10% sodium hypo-chlorite solution for 5 minutes and then washed three times with distilled water and air dried. Polyethylene glycol (PEG-6000) at 5, 10, and 15 g was dissolved separately in 100 ml of distilled water to develop water stress levels of -0.2 MPa, -0.4 MPa, -0.6 MPa respectively. Distilled water was used as control. These solutions were prepared in doubled deionized water by using magnetic heating stirrer (Model #78-1). The designated treatment solution of 10 ml was applied daily in each petri plate after washing out the previous solution with the help of pipette. The data were recorded daily till ten days for following traits.

1. **Germination Percentage (%)**: Germination of the plants were recorded for every accessions from each replication at each stress level of the polyethylene glycol (PEG-6000) on daily basis till ten days and percentage of germination was calculated for further analysis.

2. **Germination stress tolerance index (GSI %)**

The promptness index was calculated by using the formula given by (Sapra et al., 1991).

$$P.I = nd_2 (1.00) + nd_4 (0.75) + nd_6 (.50)$$

Where

nd₂= No of seed germinated on day two

nd₄= No of seed germinated on day four

nd₆= No of seed germinated on day six

On the basis of promptness index seed germination stress tolerance index was calculated by using following formula given by Bouslama and Schapauga (1984).

GSI= (Promptness index of stressed seed / Promptness index of control seed) ×100

3. Mean emergence time (MET)

On the basis of data recorded regarding emergence, mean emergence time was calculated by using formula given by Ellis and Roberts (1981)

$$MGT/MET = \sum Dn / \sum n$$

Where

n = Number of seeds newly germinated at that day (time D)

D = Days from the beginning of the germination test

$\sum n$ = Final germination

Experiment No. 2: Screening in Plastic Cups

This study was carried out in wire house of Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan. This experiment was laid out in triplicate completely randomized design (CRD) in factorial arrangement. Five seeds of each accession were sown at 100% field capacity in plastic pots containing 550 g of sterilized sand. After germination two treatments were applied; one treatment was control (100% FC) and the second treatment no water was applied. The amount of water evaporated was calculated daily and control treatment was re-watered with that amount. After two weeks two plants were uprooted from each entry by replication for data recording on the following traits.

1. Root length (cm)

Root length of the seedlings was measured in centimeters (cm) using metric scale when seedlings were 15 days old. The root length from radical to root tip of two randomly selected plants were measured in each replication of every accessions and their average was calculated for further analysis.

2. Shoot length (cm)

The shoot length of these seedlings was also measured in centimeters (cm) by using metric scale from polumel to shoot tip. Averages were calculated for further analysis.

3. Seedling dry weight (g)

After 3 days of oven dried dry weight of these seedlings were recorded in grams (g). For drying oven (Eyela, windy oven WFO-6000ND) was used and for dry weight electrical balance (Petit, MK-500C) was used.

4. Root length stress tolerance index (%)

The following formulae given by Ashraf et al. (2006) were used for the calculation of root length stress index RLSI= (Root length of stressed plant/ Root length of control plant) × 100

5. Plant height stress tolerance index (%)

The following formulae given by Ashraf et al. (2006) were used for the calculation of plant height stress tolerance index (PHSI)

$$\text{PHSI} = (\text{Plant height of stressed plant} / \text{Plant height of control plant}) \times 100$$

6. Dry matter stress tolerance index (%)

The following formulae given by Ashraf et al. (2006) were used for the calculation of dry matter stress index

$$\text{DMSI} = (\text{Dry matter of stressed plant} / \text{Dry matter of control plant}) \times 100$$

Statistical analysis

Using the Statistix-8.1 software, an ANOVA was performed on the gathered data (Statistix, 2006). Tests were used when needed to evaluate the effectiveness of various treatments.

RESULTS AND DISCUSSION

Experiment No. 1: Screening in Petri Plates

Germination percentage

Table 4.1(a) presents the analysis of variance of canola accessions for germination percentage across different levels of moisture stress. Mean comparisons of canola accessions for germination presented in Fig. 4.1. The Analysis of variance showed that there were significant differences in germination percentages of the accessions, treatments and their interaction across the treatments. Subedar et al. (1997), Mohammadi and Amiri (2010), Shahverdikandi et al. (2011). Jamian et al. (2014) also indicated the significant differences among the accessions and treatment. Germination percentage of the accessions ranged from 28.50 to 83.89% in present breeding material. The accession Dunkeld showed maximum germination and is significantly different from the accessions Po-9-5F, KN-256, Cyclone, Zn-R-2 and KN-258. Minimum germination was observed for the accession Zn-R-2 which was significantly different from all the other accessions except Cyclone and KN-258. Mean comparisons indicated that the germination percentage was decreased by increasing the concentration of PEG (6000). The treatment T1 (control) showed 92% germination and significantly different from all other treatments except T2 (-0.2 MPa). The T2 (-0.2 MPa), T3 (-0.4 MPa) and T4 (-0.6 MPa) treatment showed germination 87.19, 74.67 and 9.32% respectively and significantly different from each other. Mean squares values from the analysis of variance for germination under different moisture stress levels are presented in Table 4.1(b). Accessions showed significant differences in all the treatments except T₁ (control) treatment. In treatment T₁ (control) germination percentage ranged from 62.33 to 100%. All the accessions showed 100% germination except Zn-N-6, Cyclone, Zn-R-2 and KN-258. The germination percentage of the accessions in T2 (-0.2 MPa) treatment ranged from 40 to 100%. In T2 (-0.2 MPa) treatment all the accessions showed 100% germination except Dunkeld, Zn-N-6, Cyclone, Zn-R-2 and KN-258. While the accession KN-258 showed minimum germination percentage and significantly different from all other accessions except the accession Zn-R-2 in T2 (-0.2 MPa) treatment. The germination percentage of the accessions in T3 (-0.4MPa) ranged from 0 to 100%. The accession Zn-R-2

did not germinate in T3 (-0.4MPa) moisture stress level. The accessions KN-256, Zn-R-7, Durr-e-Niffa, Punjab Sarson and Excel showed maximum germination in treatment T3 (-0.4 MPa), and significantly different Po-9-5F, Zn-N-6, Cyclone, Zn-R-2 and KN-258. Minimum germination percentage was observed for KN-258 and it was significantly different from all the other accessions except Zn-R-2. The range of germination percentage of T4 (-0.6MPa) from 0 to 53.33%. All the accessions showed the lowest germination percentage in T4 (-0.6 MPa) treatment as compared to other treatments. The accessions Zn-R-2 and KN-258 did not germinate in T4 (-0.6 MPa) treatment. Dunkeld showed maximum germination and significantly different from all the other accessions. While Zn-M-9, Zn-N-6, Cyclone and Excel had minimum germination and significantly different from all the other accessions. Germination and seedling growth are generally the most sensitive stages in plant life (Ashraf et al., 1986). PEG is frequently used to simulate drought stress. Drought causes osmotic stress in Nandawal et al. (2000) which reduces inhibits bit of seed germination and seedling growth (Chen et al., 2010). PEG is an inert osmotic in germination tests and is a non-penetrating solute, which results in osmotic stress that inhibits seed germination through the prevention of water uptake. Subedar et al. (1997), Jie et al. (2007), Torabi and Ardestani (2013), (Jamian et al., 2014; Bahari and Bighdilu 2014) and Razaji et al. (2014) also found significant differences among accessions for germination percentage at different concentrations of PEG levels. The range for germination in moisture stress was recorded from 11 to 89% in literature (Xie et al. 2013). So, our material falls according to the literature.

Mean emergence time (MET)

Mean emergence time of the canola accessions presented in Fig. 4.2. Different accessions of canola showed differential behavior to mean emergence time under different levels of moisture stress. It increased by increasing the moisture stress levels. Subedar et al. (1997), Jie et al (2007), Torabi and Ardestani (2013) and (Jamian et al., 2014; Bahari and Bighdilu 2014) also found that mean emergence time of accessions was increased by increasing the moisture stress levels so our material falls according to the literature.

Table 4.1(a) Analysis of variance of canola accessions for germination percentage across different moisture stress levels

Sources of variations	Degrees of freedom	Sum of squares	Mean squares	F-value
Treatment (T)	3	195543	65181.2	347.05**
Accessions (A)	14	55655	3975.4	21.17**
AXT	42	28521	679.1	3.62**
Error	115	21599	187.8	
Total	174			

** =Significant at 1% probability level

Table 4.1(b) Mean squares values from analysis of variance of canola accessions for germination percentage under different moisture levels

Sources of variations	of Degrees freedom	Treatments				
		T1 (Control)	T2 (MPa)	(-0.2 T3 (0.4MPa)	(- T4 (MPa)	(-0.6
Accessions	14	629.07	1118.87**	3740**	540.473	
Error	25	334.78	53.83	247.62	92.706	

** Significant at 1% probability level

Fig. 4.1 Germination percentage of canola accessions at different moisture levels

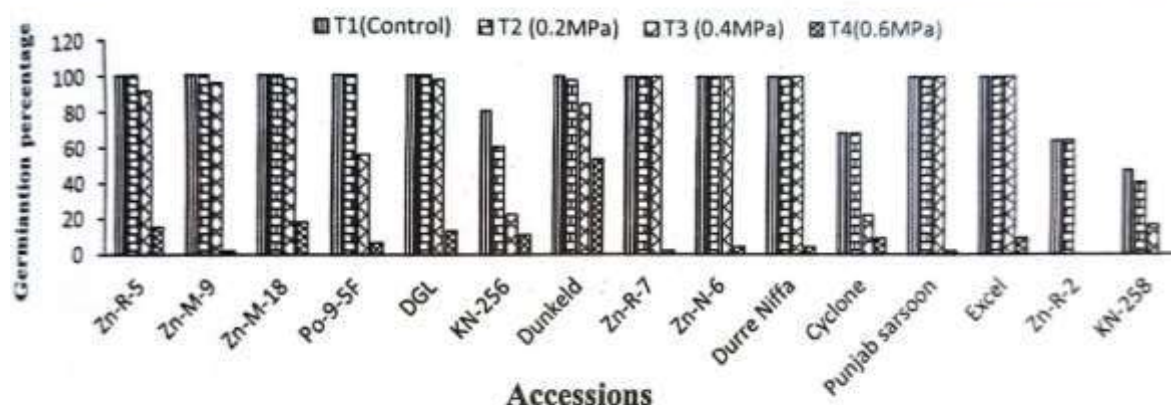


Fig. 4.2 Mean emergence time of canola accessions at different moisture levels

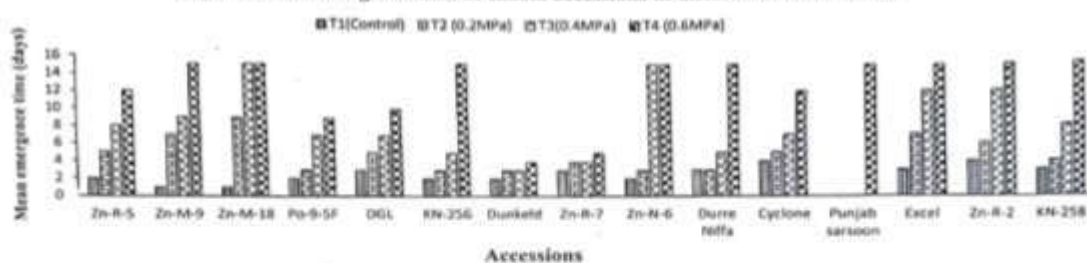
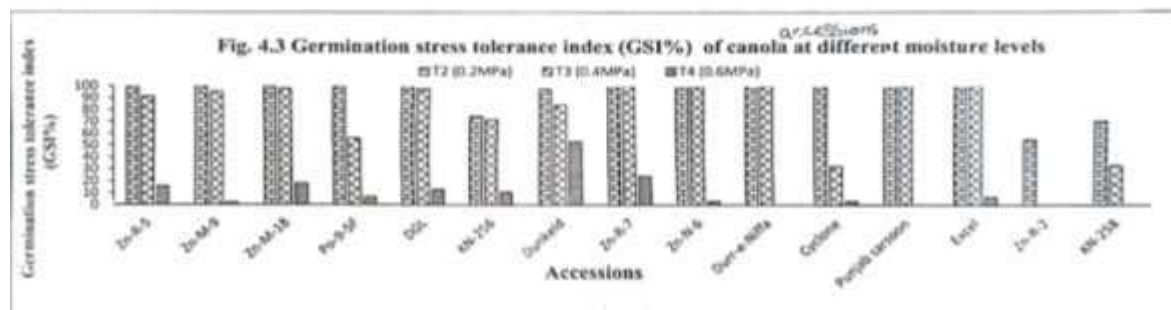


Fig. 4.3 Germination stress tolerance index (GSI%) of canola at different moisture levels



Germination stress tolerance index (GSI %)

Germination stress tolerance index presented in Fig. 4.3 and Appendix 2. Germination stress tolerance index was decreased by increasing the PEG (6000) induced water stress. The range of germination stress tolerance index was observed from 18.43 to 78.56%. The accession Dunkeld showed maximum germination stress tolerance index followed by Zn-R-7. The accessions Zn-R-2 showed minimum germination stress tolerance index percentage. The treatment T₂ (-0.2 MPa), T₃ (-0.4 MPa) and T₄ (-0.6MPa) showed 75.44 and 7% (GSI) respectively. In T₂ (-0.2MPa) treatment germination stress tolerance index ranged from 55.3 to 100% all the accessions showed 100% germination stress tolerance index except KN-256,

Dunkeld, Zn-R-2 and KN-258. The treatment T3 (-0.6 MPa) showed germination stress tolerance index ranged from 0-100%. The accession Zn -R-2 did not germinate in T3 (-0.4 MPa) treatment. The accessions Zn-R-7, Zn-N-6, Durr-e-Niffa, Punjab Sarson and Excel showed maximum germination stress tolerance index followed by DGL and Zn M-18 in T3 (-0.6 MPa). While KN-258 had minimum germination stress tolerance index percentage followed Cyclone in T3 (-0.6 MPa). Germination stress tolerance percentage ranged from 0 to 53.3% in treatment T4 (-0.6 MPa). The accessions Durr-e-Niffa, Punjab Sarson, Zn-R-2 and KN-258 did not germinate in T4 (-0.6 MPa). The accession Dunkeld showed maximum germination stress tolerance index followed by Zn-R-7 in T4 (-0.6MPa). While Zn-M-9 showed minimum germination stress tolerance index followed by Zn-N-6 and Cyclone. Dehghani et al. (2009), Xie et al. (2013) and Bahari and Bighdilu (2014) also reported that germination stress tolerance index was decreased by increasing the PEG concentration. So, our material falls according to literature and is suitable for further breeding program.

Experiment No. 2: Screening in Plastic Cups

All the accessions which were used in experiment No. 1 were shown in experiment No. 2 but the accessions Cyclone, Punjab Sarson, Zn-R-2 and KN-256 did not germinate in sand medium. So, the following traits were measured for 11 accessions.

4.2.1 Root length (cm)

Table 4.2(a) presents the analysis of variance of canola accessions for root length across different levels of moisture stress. Mean comparisons of canola accessions for root length are presented in Fig 4.4 and Appendix 3.

Table 4.2(a) Analysis of variance of canola accessions for root length across different moisture stress levels

Sources of variations	Degrees of freedom	Sum of squares	Mean squares	F-value
Treatment (T)	1		55.275	75.65**
Accessions (A)	10	155.010	15.501	21.21**
AXT	10	9.350	0.9350	1.28
Error	44	32.150	0.7307	
Total	65			

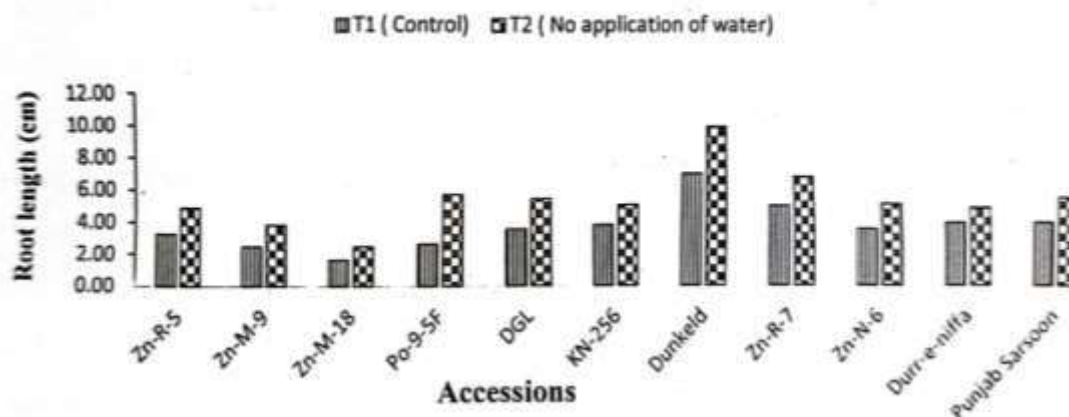
Significant at 1% probability level

Table 4.2(b) Mean Squares values from analysis of variance of canola accessions for root length under different moisture levels

Sources of variations	Degrees of freedom	Treatments	
		T1 (Control)	T2 (No application of water)
Accessions	10	6.63**	10.17**
Error	22	0.71	0.75

** Significant at 1% probability level

Fig. 4.4 Root length of canola accessions at different moisture levels



The analysis of the variance of canola for root length indicated that there were significant differences among accessions and treatments but the interaction between treatment and accessions were non-significant. Qadri et al. (2006), Qaderia et al. (2011), Cheema and Hafeez (2004), Ghaffari et al. (2007), Jie et al. (2007), Ashraf et al. (2013) and Razaji et al. (2014) also reported significant differences between accessions and treatments. Root length of canola accessions ranged from 3.18-8.46 cm. The accession Dunkeld was significantly different from all the other accessions and showed maximum root length followed by Zn-R-7. While the accessions Zn-M-9 showed minimum root length followed by Zn-N-6 and significantly different from the accessions Dunkeld and Zn R-7. Mean comparisons indicated that the root length of all canola accessions increased with increase in moisture stress levels. The treatment T1 (control) and T2 (no application of water) showed 3.60 and 5.43 cm root length respectively and significantly different from each other. Mean squares values from the analysis of variance for root length of canola seedlings under different moisture stress levels are shown in Table 4.2(b). Accessions showed significant differences in all the treatments. In T1 (control) treatment the accession Dunkeld showed maximum root length and significantly different from all the other accessions except the Zn-R-7. Minimum root length was observed for Zn-M-9 followed Zn-N-6 and significantly different from all other accessions except Punjab Sarson in T₁ (control) treatment. In T₂ (no application of water) treatment it was observed that Dunkeld showed maximum root length followed by Zn-R-7 and significantly different from all the other accessions. Minimum root length was observed for Zn-M-9 and it was significantly different from all the other accessions in T₂ (no application of water). It was observed that there was more increase in root length due to drought stress in accessions Dunkeld and Zn-R-7. So, the results indicated that root length increased by increasing the moisture stress levels. Water is essential during the whole life of plant growth from seed germination to the final growth stage. Water stress either temporarily or permanently adversely affects a number of morphological processes like shoot and root biomass and their lengths. Qadri et al. (2006), Qaderia et al. (2011), Xie et al. (2013), Cheema and Hafeez (2004), Ghaffari et al. (2007), Jie et al. (2007), Ashraf et al. (2013) and Razaji et al. (2014) also found that root length of canola accessions increased with increase in soil field capacity. So, our material falls according to the literature and is suitable for further breeding program.

Shoot length (cm)

The important agro-morphological attribute of crop plant is the shoot length and generally it displays the relative growth and vigor of crop plant. Table 4.3(a) presents the analysis of variance of canola accessions for shoot length across different levels of moisture stress. Mean comparisons of canola accessions for shoot length are presented in Fig 4.5 and in Appendix 4. The analysis of variance of canola for shoot length indicated that there were significant differences among accessions, treatments and their interaction across the treatment. Qadri et al. (2006), Qaderia et al. (2011), Cheema and Hafeez. (2004), Ghaffari et al. (2007), Jie et al. (2007), Ashraf et al. (2013) and Razaji et al. (2014) also reported significant differences among the accessions and treatments. The shoot length of the canola accessions ranged from 1.79 to 6.72 cm. The accession Dunkeld showed maximum shoot length which was significantly different from all the other accessions except Zn-R-7. Minimum shoot length was observed for Zn-N-6 followed by Zn-M-9 and significantly different from the accessions Zn-R-5, Zn-M-18, DGL, Dunkeld Zn R-7 and Punjab Sarson. Mean comparisons indicated that there was significant reduction in shoot length of all canola accessions due to the imposition of different levels of moisture stress. The treatment T1 (control) and T2 (no application of water) showed 3.87 and 2.79 cm shoot length and significantly different from each other. Mean squares values from the analysis of variance for shoot length of canola seedlings under different moisture stress levels are presented in Table 4.3(b). The accession Dunkeld showed maximum shoot length and significantly different from all the other accessions except Zn-R-7 in T. (control) treatment. While the accessions Zn-M-9 showed minimum root length followed by Zn-N-6 and significantly different from the accessions Dunkeld and Zn-R-7 in T₁ (control) treatment. It was observed that Dunkeld showed maximum shoot length followed by Zn-R-7 and significantly different from all the other accessions in T2 (no application of water). Minimum shoot length was observed for Zn-N-6 and it was significantly different from the accessions Zn-R-5, Dunkeld and Zn-R-7 in T2 (no application of water). The results indicated that Dunkeld and Zn- R-7 showed tolerance against moisture stress because there was minimum reduction in shoot length of these accessions in T2 (no application of water). The maximum reduction in shoot length was observed in accessions Zn-M-9, KN-256 and Zn-N-6 as compared with the other accessions in T2 (no application of water). So, they showed sensitivity to moisture stress. Qadri et al. (2006), Qaderia et al. (2011), Xie et al. (2013), Cheema and Hafeez, (2004), Ghaffari et al. (2007), Jie et al. (2007), Ashraf et al. (2013) and Razaji et al. (2014) also found that shoot length of canola accessions decreased with increase in soil field capacity. So our material is suitable for further breeding .

Table 4.3 (a) Analysis of variance of canola accessions for shoot length across different moisture stress levels

Sources of variations	Degrees of freedom	Sum of squares	Mean squares	F-value
Treatment (T)	1	14.467	14.4668	21.55**
Accessions (A)	10	133.965	13.3965	19.96**
AXT	10	15.030	1.5030	2.24*
Error	44	29.532	0.6712	
Total	65	192.994		

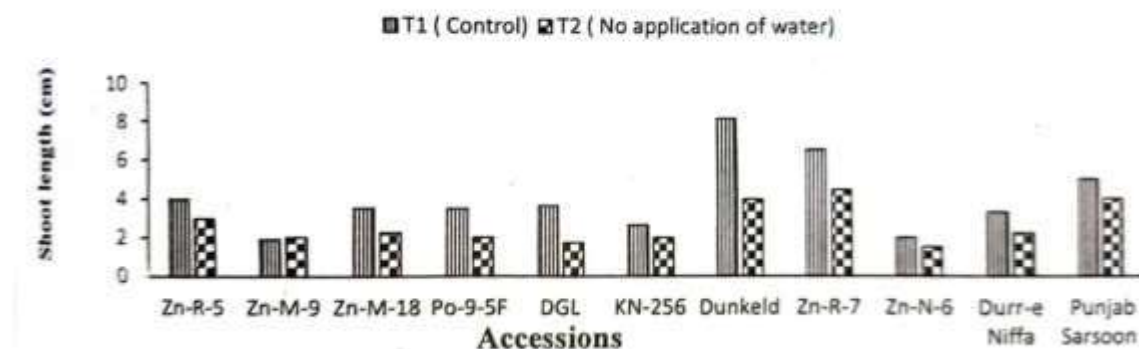
Significant at 1% probability level = Significant at 5% probability level

Table 4.3(b) Mean Squares values from analysis of variance of canola accessions for shoot length under different moisture levels

Sources of variations	Degrees of freedom	T (Control)	T2 (No application of water)
Accessions	10	10.88**	4.03**
Error	22	0.88	0.46

**Significant at 1% probability level

Fig 4.5 Shoot length of canola accessions at different moisture levels



Seedling dry weight (g)

Table 4.4(a) presents the analysis of variance of canola accessions for seedlings dry weight across different levels of moisture stress. Mean comparisons of canola accessions for dry weight are presented in Fig 4.6 and Appendix 5. The analysis of the variance of canola for seedling dry weight indicated that there were significant differences among accessions and treatments but the interaction between treatment and accessions were non-significant. Dry weight of the canola accessions ranged from 0.04 to 0.47g. The accession Dunkeld showed maximum dry weight and significantly different from all the other accessions except Zn-R-7. While Zn-N-6 showed minimum dry weight followed by Zn-M-9 and significantly different from all the other accessions.

Mean comparisons indicated that the dry weight of all canola accessions decreased when increased in water stress. The treatment T1 (control) and T2 (no application of water) showed 0.29 and 0.22 g dry weight and significantly different from each other. Mean squares values from the analysis of variance for dry weight of canola seedlings under different moisture stress levels presented in Table 4.4(b). Accessions showed significant differences in all the treatments. The accession Dunkeld showed maximum dry weight and was significantly different from all the other accessions except DGL and Zn-R-7 in T1 (control) treatment. Minimum dry weight was observed for Zn-N-6 followed by Zn-M-9 and significantly different from all the other Dunkeld showed maximum dry weight followed by Zn-R-7 and significantly different from effects of drought stress on seedling dry weight are due to inhibited cell expansion (Arshad et al., 2008). This differential response of different canola accessions to different levels moisture stress on plant dry weight might be due to their differential genetic potential to drought stress at different growth stages. Such variations in plant dry weight production under drought stress have already been reported in different accessions of oilseed rape Qadri et al. (2006), Qaderia et al. (2011), Xie et al. (2013), Cheema and Hafeez (2004), Ghaffari et al., 2007; Jie et al. 2007), Ashraf et al. (2013) and Razaji et al.

(2014) also found that seedling dry weight of canola accessions decreased with increase in soil field capacity. So our material is suitable for further breeding .

Table 4.4(a) Analysis of variance of canola accessions for seedling dry weight across different treatments

Sources of variations	Degrees of freedom	Sum of squares	Mean squares	F-value
Treatment (T)	1	0.06275	0.06275	16.56**
Accessions (A)	10	1.03881	0.10388	27.42**
A x T	10	0.03284	0.00328	0.87
Error	44	0.16672	0.00379	
Total	65	1.36619		

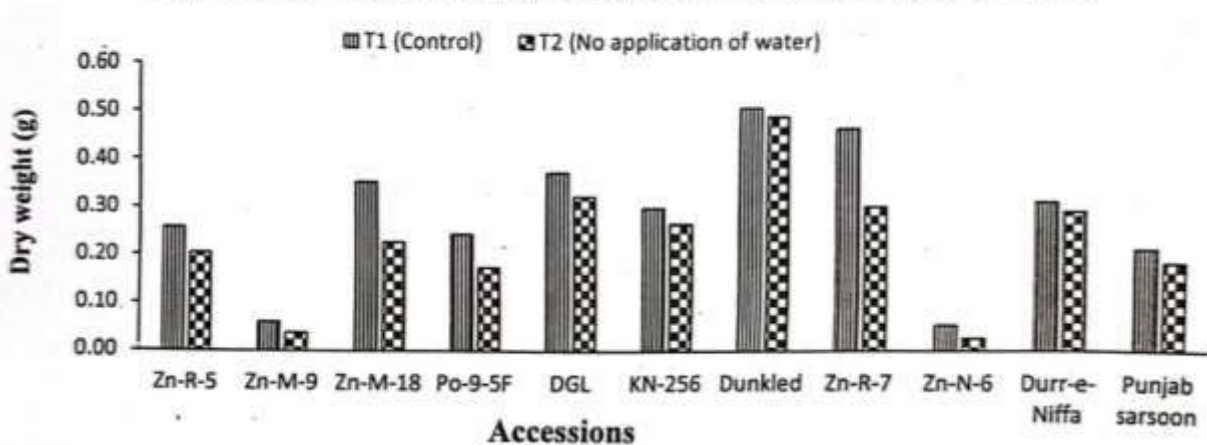
**= Significant at 1% probability level

Table 4.4(b) Mean Squares values from analysis of variance of canola accessions for seedling dry weight under different moisture levels

Sources of variations	Degrees of Freedom	T1 (Control)	T2 (No application of water)
Accessions	10	0.061**	0.045**
Error	22	0.005	0.003

**Significant at 1% probability level

Fig. 4.6 Dry weight of canola accessions at different moisture levels



Root length stress tolerance index (%)

Fig 4.7 presents the root length stress tolerance index (RLSI) for different canola accessions, All the accession showed differential behavior for RLSI. Dehghani et al. (2009). Yarnia et al. (2011) reported that root length stress index increased by increasing the drought stress, Ahmad et al. (2009) stated that RLSI off sunflower were increased by increasing the PEG 6000 levels.

Plant height stress tolerance index (%)

Fig 4.8 presents the plant height stress tolerance index (PHSI) for different canola accessions. All the accession showed different results for PHSTI. Dehghani et al. (2009), Yarnia et al.

(2011) reported shoot length stress tolerance index. Ahmad et al. (2009) stated that PHSTI of sunflower were decreased by increasing the PEG 6000 levels.

Dry matter stress tolerance index (%)

Fig 4.9 presents the plant height stress tolerance index (DMSI) for different canola accessions. All the accession showed different results for DMSI. Dehghani et al. (2009) and Yarnia et al. (2011) studied dry matter stress tolerance index. Ahmad et al. (2009) stated that DMSTI of sunflower were increased by increasing the PEG 6000 levels.

Genotypic and phenotypic coefficients of variability and heritability

Study of genetic behavior such as genetic variability, heritability and correlations etc. of the germplasm is a key step for initiation of any breeding program. Genotypic and phenotypic coefficients of variability and heritability for various traits studied are presented in Table 4.5. Genotypic and phenotypic coefficients of variability revealed the extent of differences among the accessions, due to the genetic factors and their response to environmental condition of the experiment. The magnitude of phenotypic coefficients of variability (PCV) values for all the traits were higher than genotypic coefficients of variability (GCV). Shehzad and Farhatullah (2012) also reported that higher phenotypic coefficient of variability than their corresponding genotypic coefficients of variability. It indicated that higher contribution of genotypes than environment. Phenotypic coefficients of variability (PCV) ranged from 12.51 to 52.34% and genotypic coefficients of variability (GCV) ranged between 11.42% for germination percentage and 50.89% for seedling dry weight. The shoot length had highest phenotypic and genotypic coefficients of variability followed by root length.

The broad sense heritability as a ratio of genetic variance to the phenotypic one was estimated to determine the probable transmission of the variation of traits to the progenies. Broad sense heritability estimates exceeded 90% for all traits except germination percentage (83%). Higher magnitudes of broad sense heritability were also found by Shehzad and Farhatullah (2012). The results stated that shoot length, root length and seedling dry weight could be useful traits for improvement of Brassica spp. in further breeding strategies. It indicates that environmental effects had some effects on phenotypes.

Correlation analysis

Genotypic and Phenotypic correlations are presented in Table 4.6(a) and 4.6(b) respectively. Results showed that genotypic correlations were higher in magnitudes than phenotypic ones. This indicated that the correlations among different traits under investigation are due to genetic factors rather than environmental effects in all combinations.

Correlations of germination percentage with other traits

The genotypic and phenotypic correlations of germination percentage with shoot length were positive and significant. While it (germination percentage) had non-significant correlations with seedling dry weight at both genotypic and phenotypic levels. The genotypic correlations of

Fig. 4.7 Root length stress tolerance index of canola accessions

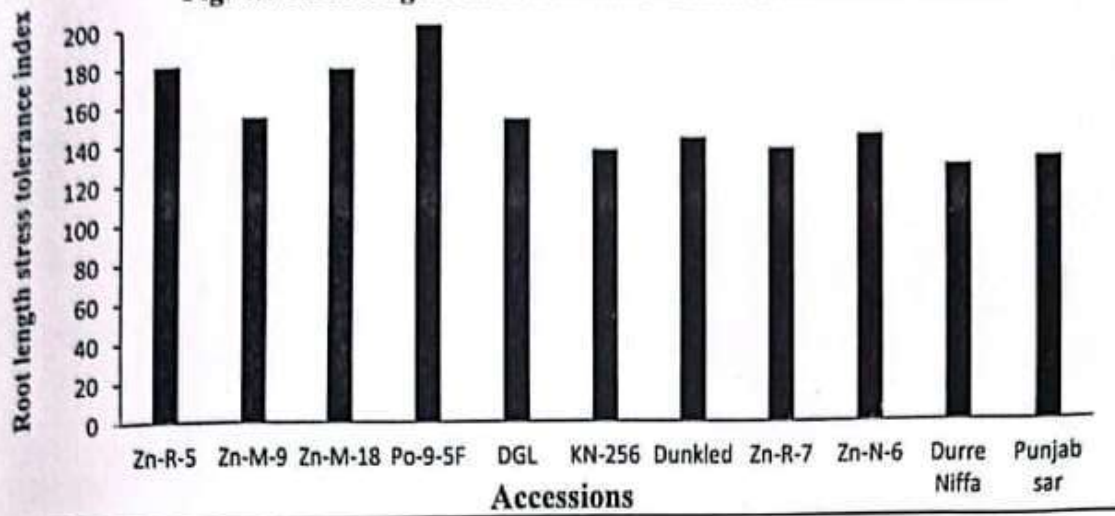


Fig. 4.8 Plant height stress tolerance index of canola accessions

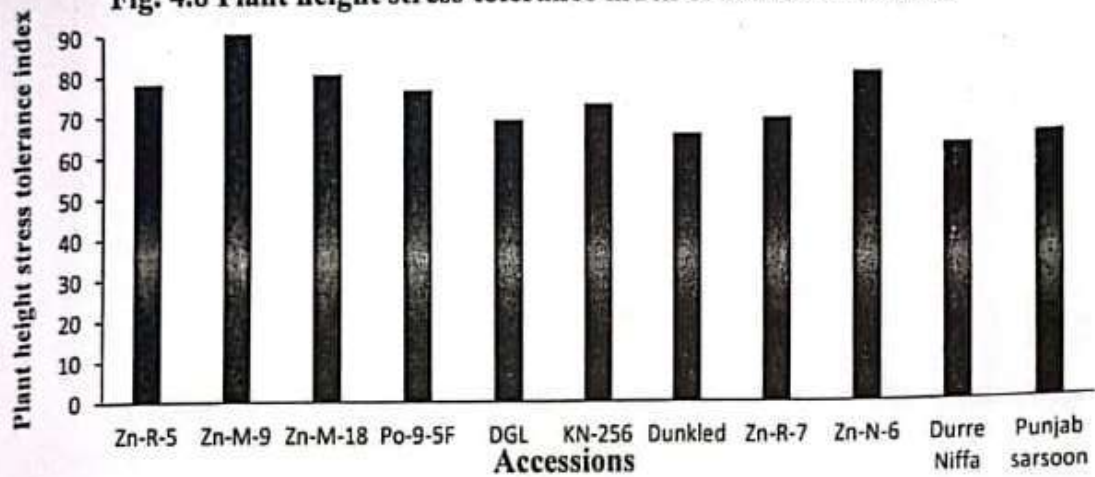
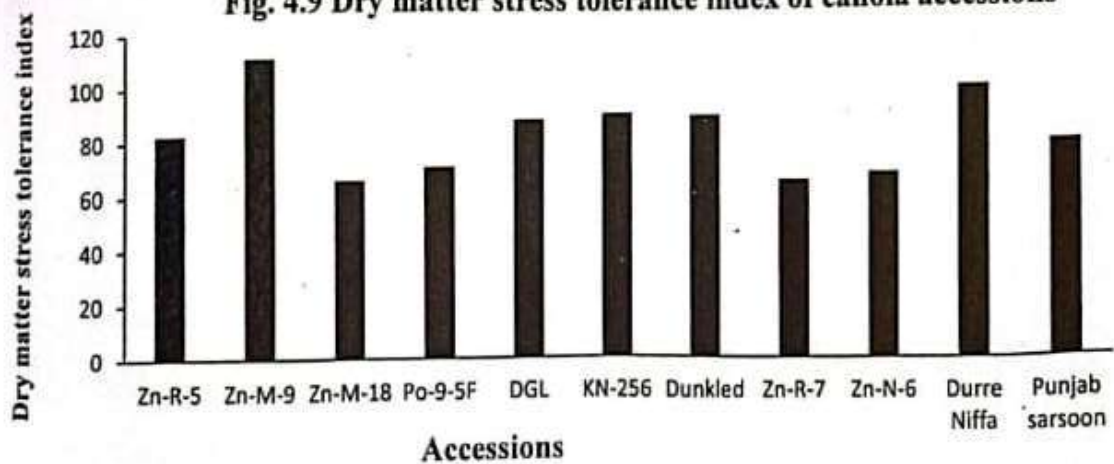


Fig. 4.9 Dry matter stress tolerance index of canola accessions



Germination percentage with root length was also positive and significant. Germination percentage was non-significantly correlated with root length at phenotypic level. The findings revealed that if there is an increase in germination than there will be an increase in those traits which are positively and significantly correlated with germination. Cheema et al. (2004) were also found these results.

Correlations of shoot length with other traits

Genotypic and phenotypic correlations of shoot length with root length and seedling dry weight were positive and significant. The findings revealed that if there is an increase in shoot length than there will be an increase in those traits which are positively and significantly correlated with germination. Naderi and Emam (2010) found these results for canola.

Correlations of root length with other traits

Correlations of root length with seedling dry weight was positive and significant at both genotypic and phenotypic level. The findings revealed that if there is an increase in root length than there will be an increase in those traits which are positively and significantly correlated with root length. Cheema and Sadaqat (2004) also reported that there was positive association between these traits in canola.

Path coefficient analysis

Only genotypic correlations were used in path analysis which partitioned and quantified the genetic correlations into direct and indirect effects to rank the traits according to their magnitude of the effect on seedlings dry weight of canola to evolve an effective selection criterion and to select lines on the basis of possessions of traits having high to high contribution towards the moisture stress tolerance. Direct and indirect effects of various traits on dry matter of canola seedlings are present in Table 4.7.

Direct and indirect effects of germination percentage on seedling dry weight

Germination percentage had negative direct effects on seedling dry weight. Germination percentage had positive indirect effect via shoot length while negative indirect effects via root length on seedling dry weight. The highest positive indirect effects of germination percentage on seedlings dry weight through shoot length.

Direct and indirect effects of shoot length on seedling dry weight

Shoot length had positive direct effects on seedling dry weight. Shoot length had negative indirect effects on seedling dry weight via germination and root length. Shoot length had maximum negative indirect effect via germination percentage. Aytac et al. (2008) found positive direct effect of shoot length.

Direct and indirect effects of root length on seedling dry weight

Root length had negative direct effects on seedling dry weight. Root length had positive indirect effects through shoot length, while root length had negative indirect effect through germination percentage. The highest positive indirect effect of root length on seedling dry weight through shoot length.

Table 4.5 Genotypic and phenotypic coefficients of variability and heritability estimate for various traits of canola accessions

Trait	σ^2_g	σ^2_p	GCV	PCV	h^2 (BS)
Germination percentage	72.16	86.59	11.42	12.51	0.83
Shoot length	2.39	2.47	46.34	47.11	0.96

Trait	σ^2_g	σ^2_p	GCV	PCV	h^2 (BS)
Root length	2.67	2.83	35.72	36.76	0.94
Seedling dry weight	0.02	0.02	50.89	52.34	0.95

σ^2_g = Genotypic variance, σ^2_p = Phenotypic variance, GCV = Genotypic coefficient of variability, PCV = Phenotypic coefficient of variability, h^2 (B.S) = Heritability in broad sense

Table 4.6(a) Genotypic correlation coefficients of various traits among canola accessions

Traits	Shoot length	Root length	Dry weight
Germination %	0.50*	0.25*	0.25
Shoot length		0.84*	0.86*
Root length			0.67**

**Significant at 1% probability level, * Significant at 5% probability level

Table 4.6(b) Phenotypic correlation coefficients of various traits among canola accessions

Traits	Germination percentage	Shoot length	Root length
Germination %	0.46*	0.22	0.20
Shoot length		0.80**	0.81*
Root length			0.61**

**Significant at 1% probability level, * Significant at 5% probability level

Table 4.7 Direct (diagonal) and indirect (off-diagonal) effects of various traits on seedling dry weight of canola

Features	Germination percentage	Shoot length	Root length
Germination percentage	-0.333	0.676	-0.092
Shoot length	-0.169	1.333	-0.304
Root length	-0.084	1.116	-0.362

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