www.ajlifesciences.com / ISSN: 2663-1040 *AJ Life Sci. 2024, 8 (1):16-30* **Research Article**

Abasyn Journal of Life Sciences

Open Access

DOI: 10.5281/zenodo.1538889

Screening of Mustard (*Brassica juncea*) Genotypes for Growth, Physiological, and Yield Traits Under Water Deficit Conditions

Saima Bano[1], Sajid Hussain Rao[1*], Abdul Wahid Baloch[2]

[1]*Oilseeds Research Institute, Agriculture Research Sindh, Tandojam*
[2]*Department of Plant Breeding & Genetics, SAU, Tandojam*

Abstract

Water stress is the primary constraint for environmental crop development. Water scarcity can severely affect growth, physiology, and yield traits of mustard varieties. The aim of the study is to evaluate drought resistant cultivars for genetically potential seed yield and oil content. In this context, the current research was carried out in randomized complete block design with factorial setup having twenty mustard genotypes, four replications and three treatments in growing season 2017-18. The treatments given as, T_1 control with well water (Watered at stem growth, flowering, silique formation and maturity stages), T_2 water stress at maturity stage (Watered at stem growth, flowering and silique formation stages) and T_3 water stress at silique formation (Watered at stem growth and flowering stages). Based on obtained results, the majority of the morphological (Plant height, branch plant^{-1}, siliqua plant^{-1} and seed siliqua^{-1}), yield (yield plant^{-1} and seed weight of 1000 grains), physiological (Chlorophyll and relatively water percentage), and oil (Oil and protein percentage) characteristics were statistically different ($P \leq 0.05$) for cultivars, treatments, and genotype × treatment collaboration, indicating that the breeding materials utilized in this study has worth using in future mustard breeding programs. Under field screening, almost half of the evaluated genotypes (AARI-Canola, Galaxy and Super Raya, Khanpur Raya, K-J-1104, Coral-432, MS-2, Dhoom-1, HUM-322 and MS-4) showed tolerance against water stresses hence utilizing these genetic resources for water stress breeding would likely enhance the seed productivity under less irrigated areas.

KEYWORD: Mustard, water stress, field screening, yield traits, oil traits, Physiological traits.

Article Info:
Received:
November 10, 2024
Received Revised:
May 05, 2025
Accepted:
May 08, 2025
Available online:
May 12, 2025

**Corresponding author's email:*
sajidrao100100@gmail.com

1. INTRODUCTION

Mustard (*B. junceae* L.) is known as the adaptable oilseed crop; it is one of the earliest crops to be domesticated. Because of its great nutritional and commercial value, it is considered as the third-largest source of vegetable oil in the world[1]. For centuries, mustard has been eaten as a vegetable, besides its byproducts have been used to make industrial and edible oils as well as sauces. Oil is frequently used in cooking and to give food a fiery, spicy taste. There are many names for *Brassica juncea* (L.), including big red, Sarepta, Asian, oriental, Chinese, Indian, leaf, brown, wild Brazilian and green mustard[2]. Mustard additionally serves as one of the best plants for producing oil and protein[3]. The seeds of enhanced mustard have been 40 to 44% oil content, however less than 2% of erucic acid is retained, which is within an internationally acceptable range[4]. Although Indian mustard (*Brassica juncea* L.) is typically self-pollinating crop, out-crossing often occurs, varying as of 5 to 30%, depends on the random conditions like climate and insects' pollinators as well. According to cytological research, mustard is an amphidiploid (2n=36) that results in spontaneous chromosomal duplication after mating two distinct species, such as *B. campestris* and *B. nigra* (2n=20 and 2n=16)[5]. During 2018-19, 586 million acres cultivated with 337 million tonnes production of mustard and its related species including rapeseed[6]. During 2019-20, a total of 860 million acres cultivated with production of 458 million tonnes of mustard and other *brassica* species. However, this production only provides 12% of Pakistan's edible oil requirements, while 88% of the same is imported[7]. In Pakistan, there is a large disparity between consumption and production, which continues to expand year after year. Pakistan is unable to produce sufficient edible oil due to increased demand and a fast-growing population[8]. Water scarcity is regarded among the fundamental causes responsible for declining agricultural production because of its links to other key abiotic factors like salt and heat stresses[9]. Drought tolerance is a complicated characteristic and determining the level of drought resistance of various cultivars is vital. It is believed that many markers may be used to phenotype drought tolerance since plants' physiological reactions to severe drought vary according to the stage of development. A variety of indicators are being employed in research and breeding methods, such as the comparative vigour index, stress resistance index, water-use efficiency, and leaves wilt index[10]. *Brassica junceae* cultivars outperform *Brassica napus* cultivars in production, especially in low rainfall and marginal growth conditions. *Brassica junceae* surpasses *Brassica napus* in terms of seedling vigor, resilience to high temperatures and dryness, as well as resilience to pod-shattering[11,12]. Although a crop's specific requirements in terms of climate, soil, and cultivation techniques are essential, the production of certain oilseed crops is mostly determined by the crop's genetic stability, yield potential, and marketable product quality[13]. Water scarcity has a more significant negative effect on seed yield during the flowering stage as compared to other stages of plants growth, because of the sensitivity of pollen development, anthesis, and fertilization, which leads to reduced seed yield[14]. The effects of water stress vary based on genotype, the intensity and period of the stress, climate and the growth and development stages of Brassica[15]. According to[16], in brassica species water deficit at flowering stage causes decreases in seed yield and dry matter, indicating that the stage of reproductive is the most susceptible to stress. Reportedly[17], under water deficit environment the quantity of silique and seed per silique reduced of brassica species, whereas stress resistant verities showed no discernible loss. The no of silique per plant, no of seeds per silique, grain index, grain yield and oil yield of five brassica napus genotypes reduced due to water stress[18].

2. MATERIALS AND METHODS

This research sets out to identify the drought resistance genotypes on genetic basis in 20 distinct mustard genotypes under water deficit environments at Botanical Garden, Sindh Agriculture University, Tandojam, during the rabi season 2017-18. Through this experiment physical, yield and maturing characteristics were examined. The seeds of each cultivar were cultivated in randomized complete block design with factorial arrangements having three treatments and four replications. Treatments: (T_1) normal condition; given four irrigation (at stem growth, flowering, silique formation and maturity stages) (T_2) water stress at maturity stage; with three irrigation (at stem growth, flowering, and silique formation) and (T_3) water stress at silique formation; with two irrigations (stem growth and flowering). The following characteristics were investigated, such as plant height (cm), branches per plant, silique per plant, seeds per silique, seed yield per plant, seed index, SPAD chlorophyll, relative water content (%), oil content (%) and protein content (%). All cultural practices were done timely, such as plant to plant and row to row distances, fertilizer doses and interculture. To perform the LSD test and analysis of variance, the software program Statistics Ver. 8.1 was used.

2.1 Characterization of Agro-morphology and physiology of mustard

For data collection, ten plants from each genotype were chosen from each replication. The scale of centimeters was used to measure the plant height, and that is done from base to tip of longest inflorescence, when it reached at maturity. The data for number of branches, silique plant^{-1} and seeds silique^{-1} were observed after harvesting the plants, whereas the length of silique was measured in centimeters from base to tip. In grams, the seed yield from each silique was weighed from its obtained seeds. Similarly, the seed yield of each selected individual plant was observed in grams, hence the seed index noted in grams after 1000 seeds weighed. The relative water content in percentage were verified using the[19] techniques. According to this technique the sample fresh leaf was weighed (FW), the turgid weight (TW) was noted using the soaked of leaf till 4 hours in distilled water. Then the soaked leaves were dried at 72 °C for 24 hours and observed the dry weight (DW). Finally calculate the relative water content using the following formula.

$$\text{Relative Water Content \%} = [(\text{Fresh Weight-Dry Weight}) / (\text{Turgid Weight-Dry Weight})]\times 100$$

Whereas for observing the SPAD chlorophyll used the SPAD meter 502 and noted the data.

2.2 Method to Extract the oil content as well as protein content (%):

For extracting the oil content Soxhlet extract techniques were used, first take the 6 to 12g sample of seeds and put them in the oven for drying. Then take the dried sample of seeds 3 to 4g and make the packets individually, then keep the dried packets in a Soxhlet device. After that taken the chemical petroleum ether in a chemical flask and kept into Soxhlet apparatus. After that the testers were taken away from the Soxhlet device when extract comes to be visible and put in oven after drying in the fresh air. In the last, according to (AOCS, 1990) methods readings were calculated using following formula.

$$\text{I.Reading} - \text{F.Reading} / \text{I.Reading}\times 100$$

The protein content was measured by the authorized technique of the American Oil Chemists' Society (AOCS), commonly referred to as the combustion technique for determining crude protein, which was reaffirmed in 1997. With this technique, a grain sample was ground and heated to an extremely high temperature (900°C) in the presence of oxygen. The combustion releases carbon dioxide, water, and nitrogen as in product. The determined nitrogen amount was converted to crude protein amounts using the 6.25 factor. The findings were presented as a percentage, where 6.25 indicated an oilseed component and N indicated nitrogen.

2.3 Soil analysis

2.3.1 Soil texture

The soil texture (distribution of partial sizes) was determined using the Bouyoucos water meter method[20], soil grains were dispersed using the sodium hexameta phosphate $(NaPO_3)_6$ on 10%. For alone clay and silt+clay and the suspension of soil density was calculated by the hyderometer. The silt was classified as clay loam after the soil texture it was assessed using the standard triangle (Table 1).

2.3.2 Soil EC (Electrical conductivity)

The electric conductivity filtrate was measured through EC meter by soil water extract according to[21] at 1:2 purified water extract (soil: filtered water) (Table 1). The results are shown in dSm^{-1}.

2.3.3 pH of the Soil

The response of the soil was determined by pH meter using soil water extract at a 1:2 ratio of distilled water, stated by[21] (Table 1).

2.3.4 Organic matter in soil

The matter of organic in the soil was found through determining soil carbon using the chromic acid titration or Walkley and Black method as reported by[22] (Table 1).

2.3.5 Soil water content

The water content in soil was measured by method of gravimetric reported through[23]. Using an Auger, the samples of soil were obtained from the experimental field and promptly moved to crucibles, these were pre-weighed with a tight-fitting cover for the observations. Immediately, the weight of the soil moisture with crucibles was recorded. After removing the cover, the soil crucibles were left in oven at 105°C until they reached an endless weightiness (forty-eight hr). After that, immediately remove crucibles into the oven, cover it with a closure cap and chill the desiccator. Then, cooling the crucibles holding oven dry soil weight with cover was weighed. The data was recorded in (Table 1) by following formula.

Weight of can + lid = Wc (g)
Weight of wet soil + can + lid = Wcws (g)
Weight of oven dry soil + can +lid = Wcds (g)
Weight of water loss during drying = Wcws - Wcds = Ww (g)
Weight of oven dry soil = Wcds – Wc = Wods (g)
Moisture by weight = (Ww/Wods) × 100 = Θ_w (%)

2.3.6 Water holding capacity

The percolation method was used to determine the amount of water in the soil. A bucket auger was used to collect soil samples from the experimental field and then the air-dried soil was crushed with a grinder and passed into a 2.0 mm sieve for observation. Filter sheets were used in three funnels, which were labelled with alphabet letters a, b, and c. After labelling the funnels were placed on measuring cylinders. Then, 50g dried samples of soil were placed in funnels a, b, and c. After that, in each funnel pour 50 ml of water. After the water halted dripping from the funnel, the volume of filtered water in the measuring cylinder was noted. Finally, results were calculated (Table 1) with formula as given below.

Weight of soil = (X)
Volume of water poured = (Y)
Volume of water collected in measuring cylinder = (Z)
Volume of water retained by the soil = (Y-Z)
Water holding capacity of the soil in percentage = (Y-Z) / X × 100

Table 1. Investigation of soil in the experimental field

Sampling	Intensity (Inches)	Physical appearance of soil	Electrical conductivity dSm^{-1}	Potential of hydrogen	Biological substance	Water content %	Water holding capacity%
a	0-12	Loam of Silty Clay	0.60	7.8	0.50	21.24	48.8
b	0-12	Loam of Silty Clay	0.68	7.9	0.63	21.66	50.6
c	0-12	Loam of Silty Clay	0.60	7.8	0.42	21.40	49.6

2.4 Statistical analysis

It was conducted following the method of[24], with the least significant difference (LSD) test employed to assess the superiority of the treatment means.

2.5 Cluster analysis

The clustering was observed using the Ward's metho and dendrogram with the help of SPSS (Version 21).

3. RESULTS AND DISCUSSION

3.1 Morphological Characters

According to agriculturists, plant yield, or the economical production of biomass, is very important for feeding the world's rapidly expanding population. One of the main factors affecting the production of all the major crop varieties, including mustard, is water stress[25]. Present experiment reported that the mostly characters studied in genotypes, treatments and their interaction has significantly differed ($P \leq 0.05$) for mean squares (Table 2a and 2b). This represents the range of breeder studies that the mustard verities have considerable capability to be used for genetic enhancements. Numerous morphological traits, including plant height, are adversely affected by water deficit, according to[26]. In current research the mean performance for the plant height is shown in (Figure 1) at distinct stages. The highest plant heights at maturing and siliques levels were recorded in Galaxy (192.45cm), while Khanpur Raya showed (184.70 cm), however the lowest plant height was observed by the genotype S-9 (159.15cm) and HUM-321 (159.15cm) at maturity and silique stages under control condition. The majority of genotypes, however, shrank in height as a result of the water stress. The minimum plant height in *brassica* species in water stress condition stated by[27]. Irrigation intervals were substantially impacted by the yield’s components of mustard genotypes for branches per plant, siliques per plant, seeds per silique and seed yield per silique. Nonetheless, several genotypes performed for each yield contributing traits in water deficits at (maturing and siliques) stages. The findings indicated that the range within 7.30 - 5.65 in control, 7.15 - 5.05 at maturity and 7.05 - 4.05 at siliques stage for branches per plant indicated in (Figure 1). The average data as 6.33, 5.89 and 5.23 for branches per plant under all three conditions (control, maturing and siliques) shown in (Table 2a). The siliques per plant ranged from 622.35 (AARI-Canola) to 292.00 (K-J-221) in well water (Table 2a). At maturity stage, it varied from 508.50 (AARI- Canola) to 288.20 (K-J-230) with average 330.37 siliques per plant. The range for siliques per plant between (AARI-Canola) 459.00 to (Early Raya) 234.05 and the average was 292.07 at silique stage displayed in (Table 2a). The reduction % at the stages of maturing and siliques due to water scarcity differed by 34.68% (Coral-432) to 0.55% (HUM-322) and 43.00% (Dhoom-1) to 4.43% (K-J-221), respectively (Figure 2). The data regarding the trait seeds per silique is summarized in (Figure 2). The genotype AARI-Canola in all three treatments including control (16.50), maturity stage (15.48) and silique stage (15.13) produced the maximum seeds per silique. While the genotypes S-9 at normal (13.27) and silique (11.85) and HUM-322 at maturity stages (12.92) produced the minimum seeds per silique, respectively. These mustard genotypes offer valuable genetic diversity in terms of water stress resistance. In usual terms, the number of siliques per plant due to water scarcity decreased[28]. The number of branches, silique per plant and seeds per plant was noted in various brassica genotypes grown in drought stress & also recorded countless reductions for seed yield while applied the drought at the time of flowering[17,18]. A variety of variables, including the number of branches and siliques per plant, the size of the seed, the quantity of seeds and yield of mustard genotypes affected due to combination of factors.

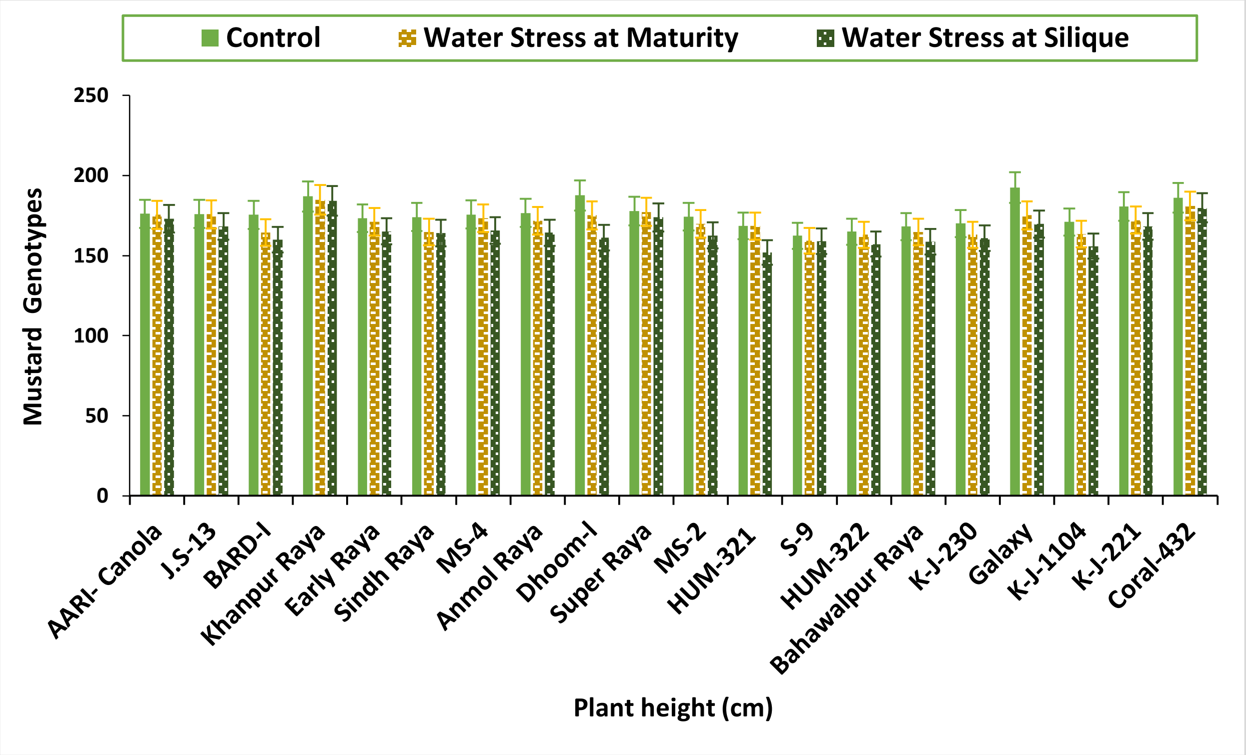
Table 2 (a): **Source of variances and mean squares of morphological, yield physiological and oil traits**

SOV	DF	Height of plant	Branch per plant	Silique per plant	Seed per silique	Seed yield per plant
Replication	3	1175.07	1.5418	42914	1.2193	248.010

Genotypes	19	578.26^{**}	2.5006^{**}	34638^{**}	5.7601^{**}	99.610^{**}
Treatments	2	2299.03^{**}	24.2887^{**}	177695^{**}	27.6380^{**}	975.145^{**}
G x T interaction	38	52.40^{ns}	0.6281^{ns}	3998^{ns}	0.5324^{ns}	19.657^{ns}
Error	177	129.96	0.9393	8216	2.0316	32.654
LSD at 5% (G)	19	4.654	0.3957	37.005	0.5819	2.3329
LSD at 5% (T)	2	1.8025	0.1532	14.332	0.2254	0.9035
LSD at 5% (G x T)	38	8.061	0.6853	64.094	1.0079	4.0407
Average	Control	175.89	6.33	385.81	14.54	22.55
	W.S at Maturity	170.69	5.89	330.37	13.94	18.86
	W.S at Silique	165.17	5.23	292.07	13.36	15.57
Range	Control	162.40-192.45	5.65-7.3	292.00-622.35	13.27-16.50	16.90-32.57
	W.S at Maturity	159.15-184.70	5.05-7.15	288.20-508.50	12.92-15.48	14.52-26.28
	W.S at Silique	151.95-184.15	4.05-7.05	234.05-459.00	11.85-15.13	12.28-23.52

Table 2 (b): Source of variances and mean squares of morphological, yield physiological and oil traits

SOV	DF	Seed index	RWC	Chlorophyll SPAD	Content in oil	Content in protein
Replication	3	0.0380	208.22	1.114	2.487	0.0257
Genotypes	19	4.9243^{**}	42.96^{*}	19.450^{*}	54.308^{**}	41.5824^{**}
Treatments	2	11.8184^{**}	1306.95^{**}	325.237^{**}	421.552^{**}	76.3846^{**}
G x T interaction	38	0.1926^{ns}	23.54^{ns}	3.938^{ns}	6.700^{**}	0.1998^{**}
Error	177	0.6296	23.57	9.924	0.268	0.0195
LSD at 5% (G)	19	0.3239	1.2861	1.9818	0.2112	0.057
LSD at 5% (T)	2	0.1255	0.4981	0.7676	0.0818	0.0221
LSD at 5% (G x T)	38	0.5611	2.2276	3.4326	0.3659	0.0987
Average	Control	4.85	68.13	44.75	44.14	26.67
	W.S at Maturity	4.54	66.25	39.94	42.54	25.84
	W.S at Silique	4.09	64.10	36.72	39.61	24.72
Range	Control	3.67-5.98	65.54-71.75	40.00-51.36	37.47-46.13	21.93-29.52
	W.S at Maturity	3.55-5.88	64.13-68.83	36.38-45.54	37.39-45.19	21.17-28.32
	W.S at Silique	3.18-5.70	61.38-67.08	30.29-42.87	34.27-43.44	20.10-27.16



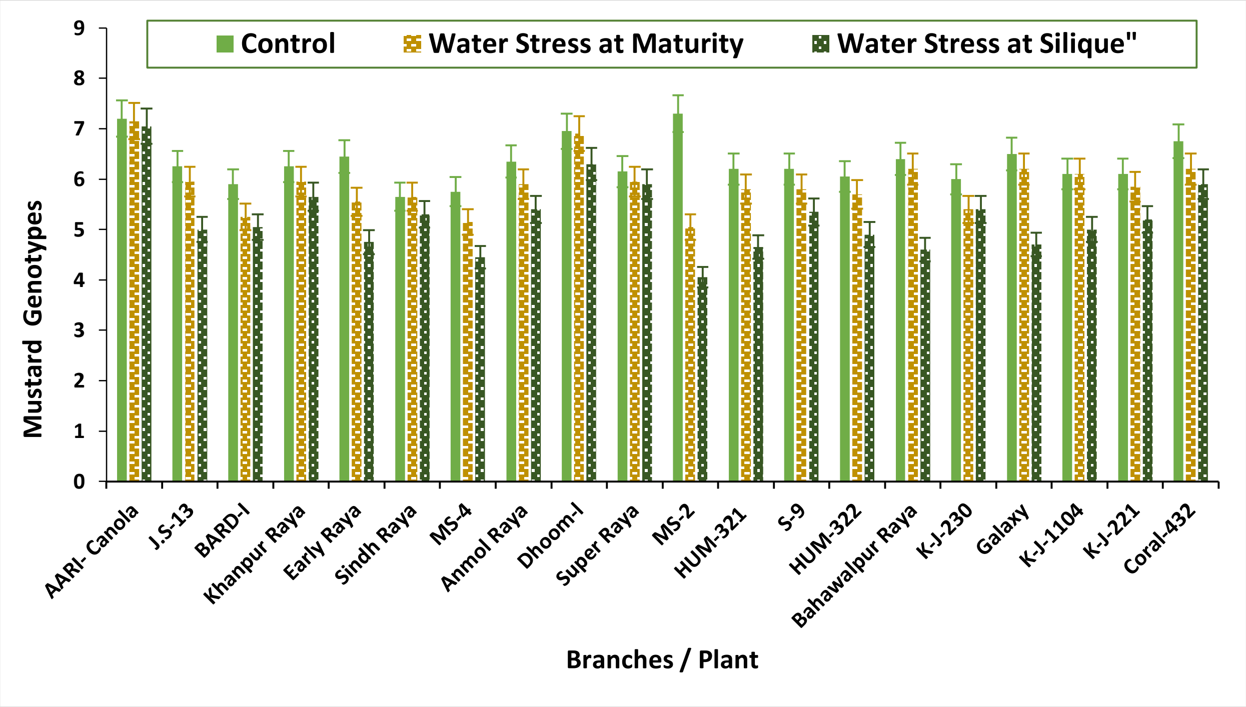


Figure 1: Average of plant height (cm) and branches per plant, in normal, water deficit at maturing and siliques stages

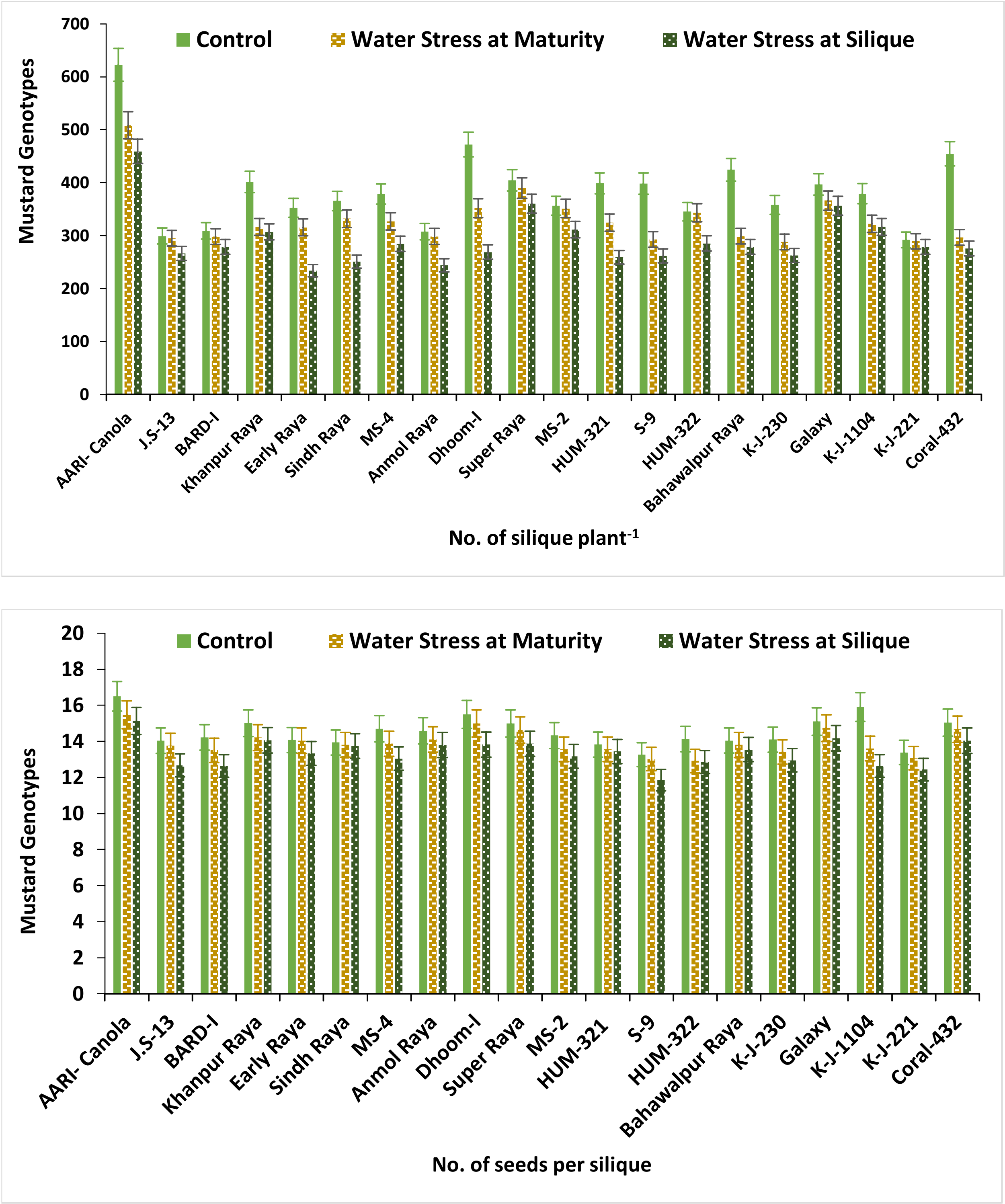
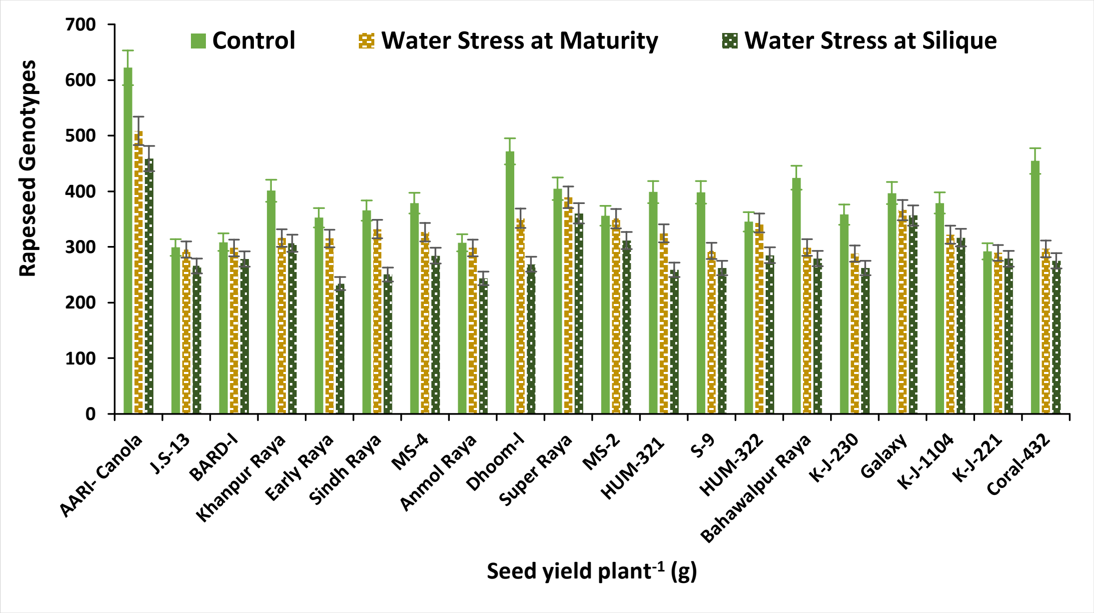


Figure 2: Average silique per plant and seeds per silique in normal, water deficit at maturing and siliques stages

3.2 Yield Characters

The research has shown that drought reduces yield by interfering with photosynthesis of leaf and relations of plant water[29], relations of nutrients, partitioning of dry matters[30], biological products, seeds and the amount of oil in brassica[31]. According to the current findings, the genotype AARI-Canola was high in production at maturity stage for seed yield per plant, under control (32.57 g) and water deficit (26.28 g) (Figure 3). At silique stage, the genotype Galaxy produced greater (23.52 g) seed yield per plant. Early Raya in normal (16.90 g) and same had also remained in production of lower seed yield (12.28 g) at silique water stress, while BARD-1 was low in seed yield per plant (14.52 g) at maturity stage. The genotypes K-J-230 (37.86%) and AARI-Canola (50.01%) depicted maximum reduction at two water stresses (maturity and silique, respectively) when compared with control. However, the range between 32.57 to 16.90g (at control); 26.28 to 14.52g (at maturing) and 23.52 to 12.28g (at silique) stages were observed for seed yield per plant (Table 2a). Due to the water deficit during reproductive phase, flowers and fruits drop off quickly, therefore resulting in a decrease in the seed development[32]. The agronomical characteristics and production of seeds decreased significantly due to high and medium water stress[33]. [25] On the other hand, found good seed production with appropriate watering. When compared to less irrigated treatments, proper irrigation can improve seed production in brassica from 41.7% to 62.9% [34]. The seed index showed an increased genetic diversity in all water treatments. The genotype Galaxy formed the heavier seed index with mean values of 5.98 g (normal), 5.88 g (maturity stress) and 5.70 g (silique stress) (Figure 3). In contrast, the lighter seeds were noticed in Anmol Raya under control (3.67 g) and at maturity stage (3.18 g), while BARD-1 at silique stage (3.18 g). It demonstrates the worth of these genotypes possess for water stress, at the phases of water stress (maturity and silique). Seed index had negative effects due to irrigation periods according to the[35]. Brassica genotypes are also sensitive to water stress, which results in a significant decline in seed index[18].



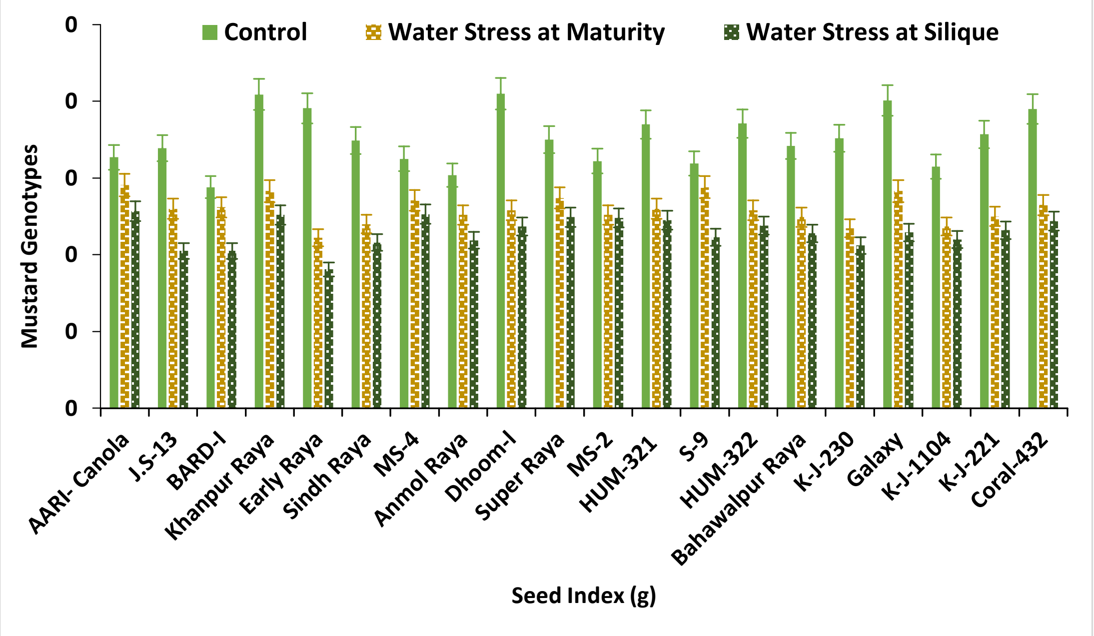
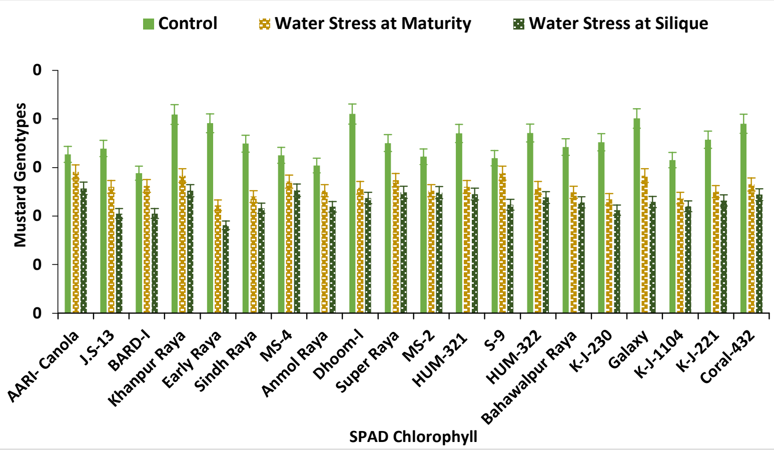


Figure 3: Average of seed yield per plant and seed index in normal, water deficit at maturing and siliques stages

3.3 Physiological Characters

According to[36] the key component of plant photosynthesis is in leaf chlorophyll, it also influences the photosynthesis rate, and the quantity of dry matter generated. Variations in chlorophyll content and respiration could restrict plant development under water scarcity[37]. The present study's results clearly revealed that water stress tended to have negative impacts on chlorophyll. The result regarding SPAD Chlorophyll at control, maturity and silique stages are given in (Figure 4). The maximum chlorophyll was noted in Anmol Raya (51.36) under control, Coral-432 (45.54) at maturity and AARI-Canola (42.87) at siliques, whereas in all three stages (normal, maturing and silique) the lowest values of 40.00, 36.38 and 30.29 were recorded in S-9, MS-2 and Anmol Raya for chlorophyll. Genotypes of mustard showed a varying response to water deficit, it had distinct genetical potential for stress tolerance. It is estimated that in agriculture, the water deficit caused numerous physical issues, like chlorophyll content, photosynthesis, and respiration reduction[38]. When compared to control, total chlorophyll content reduced considerably in all mustard genotypes and at all stages of development in reaction to water deficit[39]. Relative water content is a vital scale by which the condition of water in plants determines[40]. It has been proven that relative water content to be excellent and stable scale than water potential in leaf, it is very helpful in changing climatic conditions to indicate the respond of plants[41]. The genotypes Dhoom-1 (71.75%) under full irrigation observed the maximum relative water content, whereas Khanpur Raya produced the maximum relative water content of 68.83% and 67.08% at maturity water stress and silique water stress, respectively (Figure 4). The minimum relative water content of 65.54% resulted by Bahawalpur Raya under control, 64.13% by J-S-13 at maturity water stress, whereas K-J-221 (61.38%) produced minimum relative water content at silique water stress. These genotypes would be used as selected materials in future breeding efforts to enhance physiological traits. [42], reported that water scarcity decreases the numerous trait's performance as compared to normal, like potassium content, relative water content and osmotic potential. Water stress sensitive cultivars, on the other hand, showed a higher decrease[43].



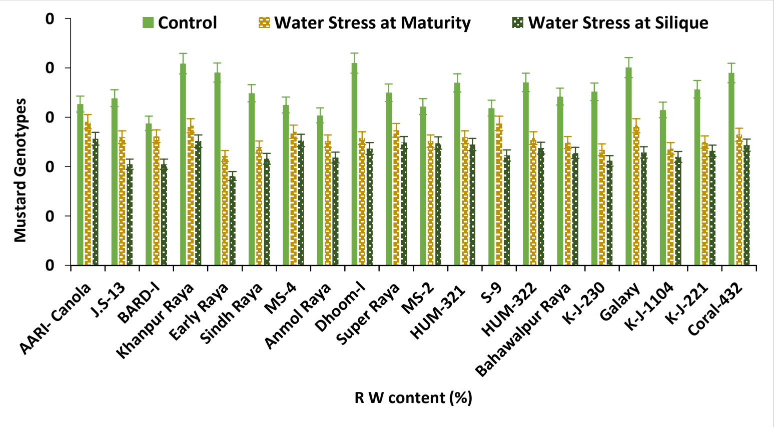
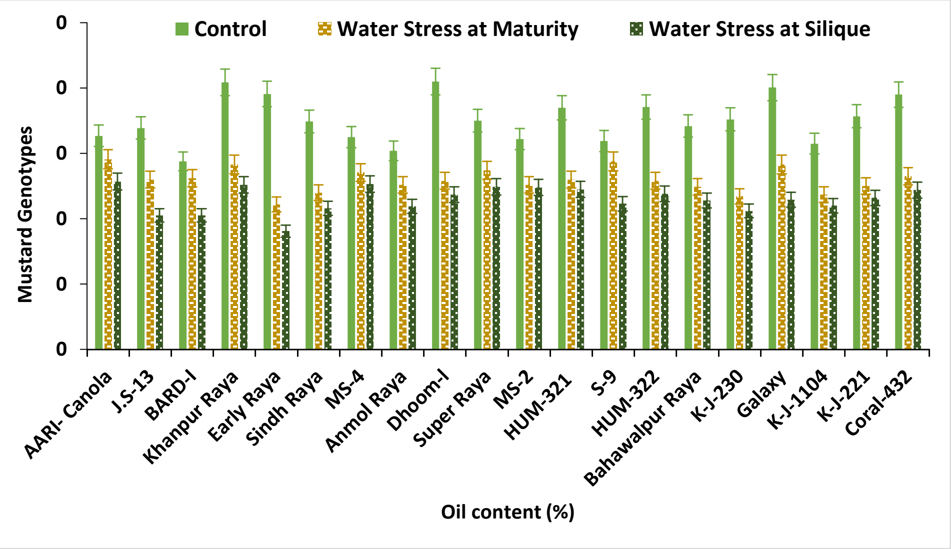


Figure 4: Average of SPAD chlorophyll and relative water content in normal, water deficit at maturing and siliques stages

3.4 Oil and Protein content (%)

The Brassica species' main quality attribute is their oil content, which is adversely affected by the water deficit[44]. According to[45], in oil seed crops the oil content shown decreased in water deficit environment. The oil content (%) was measured between 46.13 and 37.47% in normal condition; 45.19 to 37.39% at maturity water stress and 43.44 to 34.27% at silique water stress (Table 2b). The average oil content of 44.14%, 42.54% and 39.61% were noted in normal and water stresses at maturity and silique formation, respectively. In controlled and silique formation stage, the maximum oil content was noted in Dhoom-1 with mean values of 46.44% and 45.19%, respectively. At maturity water stress, genotypes such as Coral-432 (43.44%) and J.S-13 (34.27%) produced high and low oil content, respectively (Figure 5). However, in terms of oil content, these mustard genotypes would be excellent breeding resources. In two consecutive years, increasing the water deficit intensity reduced seed oil and grain yield[46]. According to[44], the primary qualitative features of brassica genotypes substantially influenced the protein and oil content due to scarcity of water. Regarding protein content of genotypes ranged between 29.52 and 21.93%, 28.32 and 21.17% and 27.16 and 20.10% in normal and water stresses at maturity and silique formation, respectively (Table 2b). The genotype Dhoom-1 recorded high protein content in all three treatments such as 29.52% (normal), 28.32% (at maturing) and 27.16% (at siliques) stages. Whereas K-J-221 produced the minimum protein content of 21.93% at control, 21.17% at maturity and 20.10% at silique water stress (Figure 5). These genotypes show the breeding worth for retained. According to[47], under drought stress, total protein synthesis decreases significantly.



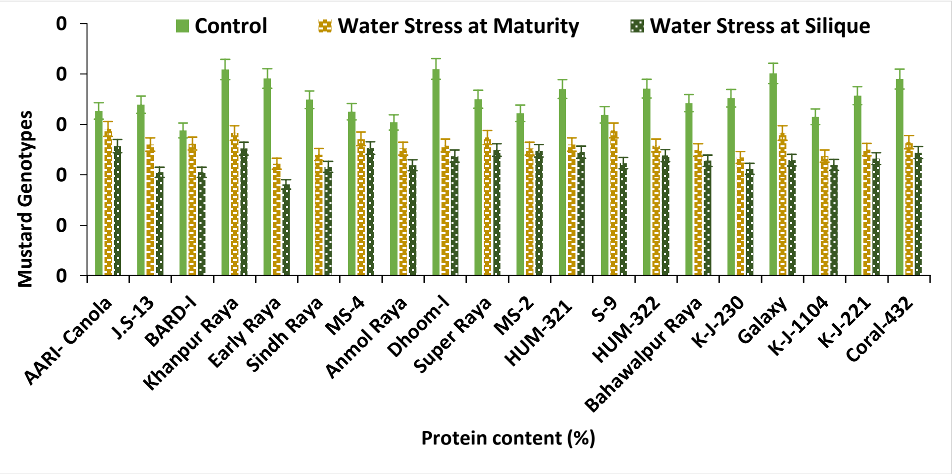


Figure 5: Average of oil content and protein content in normal, water deficit at maturing and siliques stages

3.5 Cluster analysis

The essential clustering method is used for identifying the tolerant or sensitive group of genotypes based on the performance and similarity against stress. The breeders also used these techniques to identify the distinct group of genotypes in numerous abiotic stresses in a variety of field crops. The current results discovered significant differences in performance based on cluster analysis. Three mustard genotypes (AARI-Canola, Galaxy and Super Raya) were grouped in the same cluster, which is considered as highly tolerant against water stress. Seven genotypes (Khanpur Raya, K-J-1104, Coral-432, MS-2, Dhoom-1, HMU-322 and MS-4) were combined into the second group, which is categorized as tolerant group against water scarcity. The last 3rd cluster included the ten cultivars such as Amol Raya, Early Raya, HMU-321, Sindh Raya, J.S-13, K-J-230, S-9, K-J-221, Bahawalpur Raya and BARD-1, while this group was recognized as sensitive one against water stress based on mean performance of all traits (Figure 6). Many scientists such as[48,49,50,51,52,53,54,] reported this technique used for cluster analysis in barley, maize, mustard, millet, sorghum, wheat, cotton and rice, respectively.

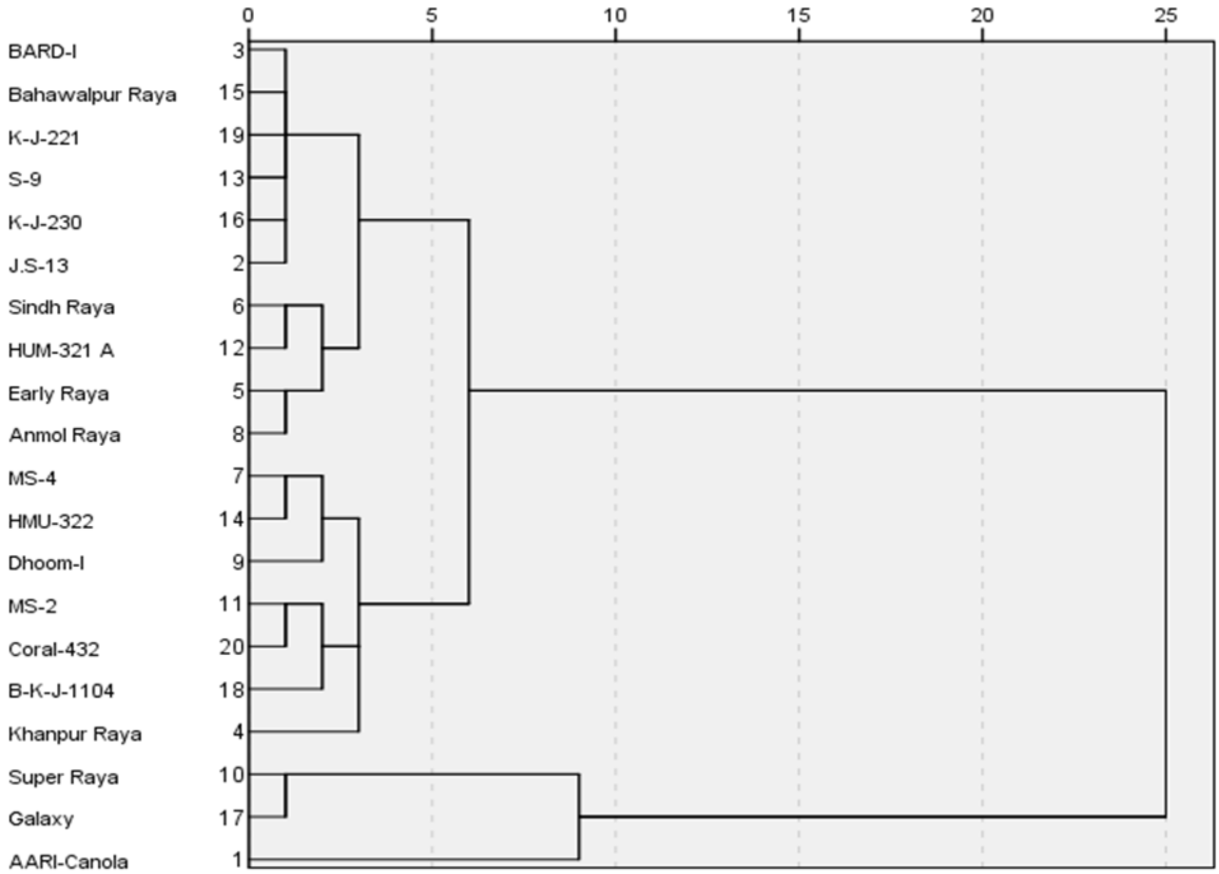


Figure 6: Clustering mustard cultivars based on mean performance under stress conditions

4. CONCLUSION

Under the field screening, the analysis of variance showed a significant difference in the characters studied. Phenotypic values of all agronomical, yield and oil traits differed significantly, showing the importance of genetic variations existing in evaluated breeding materials of mustard. AARI-Canola, Galaxy, Super Raya, Khanpur Raya, K-J-1104, Coral-432, MS-2, Dhoom-1, HMU-322 and MS-4) showed tolerance against water stresses hence utilizing these genetic resources for water stress breeding would likely enhance the seed productivity under less irrigated areas.

5. ACKNOWLEDGMENTS

I would like to extend my gratitude to all the authors and institutions whose work has significantly contributed to this research.

6. Conflict of interest

It is also declared that this Manuscript has no conflict of interest.

7. REFERENCES

1. Singh I, Kumar R, Kaur S, Singh H, Kaur R. Combining ability studies using diallel mating design in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. Indian Journal of Agricultural Research. 2019; 53(3): 366-369.
2. Rahman M, Khatun A, Liu L, Barkla BJ. *Brassicaceae* Mustards: Traditional and agronomic uses in Australia and New Zealand. Molecules. 2018; 23: 231-236.
3. Spragg J. Australian Feed Grain Supply and Demand Report 2016; JCS Solutions Pty Ltd.: North Victoria, Australia. 2016; 1–42.
4. Tomat A, Singh M. Genetic components analysis for seed yield and its contributing traits in Indian mustard (*Brassica juncea* (L.) Czern & Coss). Journal of Pharmaceutical Innovation. 2014; 6(8): 386-389.
5. Fhandsen KJ. The experimental formation of Rrassicn juncen CZERN et Coss. Ilansk Botanisk Arkiv. 1943; 11: 1-17.
6. Government of Pakistan (GOP). Pakistan Economic Survey, Ministry of Finance, Economic Advisor's Wing, Islamabad. (2018-19).
7. Government of Pakistan (GOP). Pakistan Economic Survey, Ministry of Finance, Economic Advisor's Wing, Islamabad. (2019-2020).
8. Mahmood T, Mustafa HSB, Aftab M, Ali Q, Malik A. Super Canola: Newly developed high yielding, lodging and drought tolerant double zero cultivar of rapeseed (*Brassica napus* L.). Genetics and Molecular Research. 2019; 18(2): 16039951.
9. Mehmood T, Asharf M. Does exogenous application of glycinebetaine as a pre sowing seed treatment improve growth and regulate some key adverse effects of drought stress on wheat (*Triticum aestivum* L.). Journal of Applied Botany and Food Quality. 2009; 84(2): 192-199.
10. Tuberosa R. Phenotyping for drought tolerance of crops in the genomics era. Frontiers in Physiology. 2012; 3(347): 1-26.
11. Burton W, Pymer S, Salisbury P, Kirk J, Oram R. Performance of Australian canola quality Indian mustard breeding lines. GCIRC 10th International Rapeseed Congress. Canberra. 1999.
12. Oram R, Salisbury P, Kirk J, Burton W. *Brassica juncea* breeding. 10th Int. Rapeseed Congr. Canberra, ACT, Australia. 1999; 37-40.
13. Wittkop B, Snowdon R, Friedt W. Status and perspectives of breeding for enhanced yield and quality of oilseed crops for Europe. Euphytica. 2009; 170(1/2): 131–140.
14. Faraji A, Latifi N, Soltani A, Shirani-Rad, AH. Seed yield and water use efficiency of canola (*Brassica napus* L.) as affected by high temperature stress and supplemental irrigation. Agricultural Water Management. 2009; 96(1): 132-140.
15. Reynolds M, Tuberosa R. Translational research impacting on crop productivity in drought-prone environments. Current Opinion in Plant Biology. 2008; 11(2): 171-179.
16. Gunasekera CP, Martin LD, French RJ, Siddigue KH, Walton GH. Effects of water stress on water relations and yield of Indian mustard (*Brassica juncea* L.) and canola (*Brassica napus* L.). In Proceedings of the 22th Australian Agronomy conference, Geelong. 2003.
17. Zakirullah ZA, Swati AA, Ahamd A, Raziuddin. Morpho-physiological response of selected *Brassica* lines to moisture stress. Pakistan Journal of Biological Sciences. 2000; 3(1): 130-132.

18. Nasri M, Zahedi H, Moghadam HT, Ghooshci F, Paknejad F. Investigation of water stress on macroelements in rapeseed genotypes leaf (*Brassica napus*). American Journal of Agricultural and Biological Sciences. 2008; 3(4): 669-72.
19. Bonnet M, Camares O, Veisseire P. Effect of zinc and influence of Acremonium lolii on growth parameters, chlorophyll a fluorescence and antioxidant enzyme activities of ryegrass (*Lolium perenne* L. cv Apollo). Journal of Experimental Botany. 2000; 51(346): 945-953.
20. Bouyoucos GJ. Hydrometer method improved for making particle size analysis of soils. Agronomy Journal. 1962; 54(5): 464-465.
21. Jackson ML. Soil Chemical Analysis. Prentice-Hall Inc., Englewood Cliffs, NJ, p, 498. 1958.
22. Rowell DL. The preparations of saturation extracts and the analysis of soil salinity and sodicity. Soil science methods and applications, Rowell, D.L. (Ed.). Longman Group, UK. 1994.
23. Ilyas N, Bano A, Iqbal S, Raja N. Physiological, biochemical and molecular characterization of *Azospirillum spp.* isolated from maize under water stress. Pakistan Journal of Botany. 2012; 44: 71-80.
24. Gomez KA, Gomez AA. Statistical procedures for agricultural research. John Wiley & Sons Inc. 2nd (ed.) New York U.S.A. 1984.
25. Sodani R, Singhal RK, Gupta S, Gupta N, Chauhan KS, Chauhan J. Performance of yield and yield attributes of ten Indian mustard (*Brassica juncea* L.) genotypes under drought stress. International Journal of Pure and Applied Bioscience. 2017; 5(3): 467-476.
26. Raza MAS, Shahid AM, Saleem MF, Khan IH, Ahmad S, Ali M, Iqbal R. Effects and management strategies to mitigate drought stress in oilseed rape (*Brassica napus* L.). Zemdirbyste-Agriculture. 2017; 104(1): 85-94.
27. Qaderi MM, Kurepin LV, Reid DM. Growth and physiological responses of canola (*Brassica napus*) to three components of global climate change: temperature, carbon dioxide and drought. Plant Physiology. 2006; 128: 710-721.
28. Hassanzadeh M, Naderei M, Shirani-Rad AH. Evaluation effects of drought stress on yield and yield components of autumn rapeseed cultivars in Isfahan. Journal of Agricultural Science. 2005; 1(2): 51-62.
29. Mondal SK, Khajuria MR. Genetic analysis for yield attributes in mustard. Environment and Ecology. 2000; 18(1): 1-5.
30. Ashraf M, Shahbaz M, Ali Q. Drought-induced modulation in growth and mineral nutrients in canola (*Brassica napus* L.). Pakistan Journal of Botany. 2013; (45): 93–98.
31. Ghobadi M, Bakhshandeh M, Fathi G, Gharineh MH, Alamisaeed K, Naderi A, Ghobadi V. Short and long periods of water stress during different growth stages of canola (*Brassica napus* L.): Effect on yield, yield components, seed oil and protein contents. Journal of Agronomy. 2006; 5(2): 336-341.
32. Sinaki JM, Heravan EM, Rad AHS, Mohammadi GN, Zarei G. The effects of water deficit during growth stages of canola (*Brassica napus* L.). American Eurasian Journal of Agricultural and Environmental Sciences. 2007; 2(4): 417-422.
33. Majidi MM, Rashidi F, Sharafi Y. Physiological traits related to drought tolerance in Brassica. International Journal of Plant Production. 2015; 9(4): 541-560.
34. Panda BB, Bandyopadhyay SK, Shivay YS. Effect of irrigation level, sowing dates and varieties on yield attributes, yield, consumptive water use and water-use efficiency of Indian mustard (*Brassica juncea*). Indian Journal of Agricultural Sciences. 2004; 74(6): 339-342.
35. Malekei E, Sinaki, JM. The effect of irrigation and nitrogen on yield and yield components of spring rapeseed. Journal of Agricultural Sciences. 2005; 1(1): 35-43.
36. Arjenaki FG, Jabbari R, Morshedi A. Evaluation of drought stress on relative water content, chlorophyll content and mineral elements of wheat (*Triticum aestivum* L.) varieties. International Journal of Agriculture and Crop Sciences. 2012; (4): 726-729.
37. Jaleel CA, Manivannan P, Lakshmanan GMA, Gomathi-nayagam M, Panneerselvam R. Alterations in morphological parameters and photosynthetic pigment responses of Catharanthusroseus under soil water deficits. Colloids Surfaces Biointerfaces. 2008; 61(2): 298-303.
38. Sarker BC, Hara M, Uemura M. Proline synthesis, physiological responses and biomass yield of eggplants during and after repetitive soil moisture stress. Scientia Horticulturae. 2005; 103(4): 387-402.
39. Sahoo CR, Dash M, Acharya N. Biochemical responses of Indian mustard to water stress. International Journal of Current Microbiology and Applied Sciences. 2019; 8(2): 1711-1718.

40. Lugojan C, Ciulca S. Evaluation of relative water content in winter wheat. Journal of Horticulture, Forestry and Biotechnology. 2011; 15(2): 173–177.
41. Sade N, Gebremedhin A, Moshelion M. Risk-taking plants: Anisohydric behavior as a stress-resistance trait. Plant Signaling and Behavior. 2012; 7(7): 767-770.
42. Eslam BP. Evaluation of physiological indices yield and its components as screening techniques for water deficit tolerance in oilseed rape cultivars. Journal of Agricultural Science and Technology. 2009; 11(4): 413-422.
43. Ullah F, Bano A, Nosheen A. Effects of plant growth regulators on growth and oil quality of canola (Brassica napus L.) under drought stress. Pakistan Journal of Botany. 2012; 44(6): 1873–1880.
44. Istanbulluoglu A, Arslan B, Gocmen E, Gezer E, Pasa C. Effects of deficit irrigation regimes on the yield and growth of oilseed rape (*Brassica napus* L.). Biosystems Engineering. 2010; 105(3): 388-394.
45. Zhang X, Lu G, Long W, Zou X, Li F, Nishio T. Recent progress in drought and salt tolerance studies in *Brassica* crops. Breeding Science. 2014; 64(1): 60-73.
46. Alipour A, Zahedi H. Difference in drought resistance among three Brassica species at different growing stages and application of zeolite. Indian Journal of Agricultural Research. 2016; 50(2): 193-196.
47. Hare PD. Molecular characterization of the gene encoding Æ 1-pyrroline-5-carboxylate reductase isolated from Arabidopsis thaliana (L.) Heynh. M.Sc. Thesis, Natal University, South Africa. 1995.
48. Saad FF, Ashraf A, El-Mohsen A, Mohamed A, El-Shafi A, Al-Soudan, IH. Effective selection criteria for evaluating some barley crosses for water stress tolerance. Advance in Agriculture and Biology. 2014; 2(3): 112-123.
49. Ali Q, Ahsan M, Malook S, Kanwal N, Ali F, Ali A, Ahmed W, Ishfaq M, Saleem M. Screening for drought tolerance: Comparison of maize hybrids under water deficit condition. Advancements in Life Sciences. 2016; 3(2): 51-58.
50. Hooks T, Niu G, Gunjegunte G. Seedling emergence and seedling growth of mustard and rapeseed genotypes under salt stress. Agrosystems, Geosciences and Environment. 2019; 2(1): 1-8.
51. Ponnaiah G, Gupta SK, Blummel M, Marappa M, Pichaikannu, S, Das RR, Rathore A. Utilization of molecular marker based genetic diversity patterns in hybrid parents to develop better forage quality multi-cut hybrids in pearl millet. Agriculture. 2019; 9(97): 1-21.
52. Tawfik RS, El-Mouhamady ABA. Molecular genetic studies on abiotic stress resistance in sorghum entries through using half diallel analysis and inter-simple sequence repeat (ISSR) markers. Bulletin of the National Research Centre. 2019; 43(117): 1-17.
53. Gadimaliyeva G, Akparov Z, Aminov N, Aliyeva A, Ojaghi J, Salayeva S, Serpoush M, Mammadov A, Morgounov A. Assessment of synthetic wheat lines for soil salinity tolerance. Zemdirbyste-Agriculture. 2020; 107(1): 55-62.
54. Jie Z, Wei HU, Yu-Xia, LI, Jia-Qi, HE, Hong-Hai, ZH U, Zhi-Guo, Z. Screening of drought resistance indices and evaluation of drought resistance in cotton (*Gossypium hirsutum* L.). Journal of Integrative Agriculture. 2020; 19(2): 495-508.