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Genetic Variability Studies on Drought Tolerance using Agro-Morphological and Yield Contributing Traits in Rapeseed-Mustard

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ABSTRACT

A study was conducted during *rabi* season (October-May), 2018–2019 at the Experimental Farm of Department of Genetics and Plant Breeding, CSK HPKV, Palampur (HP), India to develop reliable selection criteria for drought tolerance. 25 advanced breeding lines of different *Brassica* species were used to determine their mean performance, components of variability, heritability and genetic advance under moisture stress conditions created at rosette stage, flower initiation stage and siliqua formation stage using various agro-morphological and yield contributing traits. Sufficient genetic variability was found for almost all the characters except for 1000-seed weight under non-stress stage conditions. Estimates of parameters of variability revealed that phenotypic coefficients of variation were higher than their respective genotypic coefficients of variation. Under moisture stress conditions, high heritability coupled with high genetic advance was observed for number of secondary branches plant^{-1} in non-stress and all the moisture-stress stages. Siliqua formation stage was found most susceptible to moisture stress conditions which also led to maximum reduction in seed yield. Using drought susceptibility index, the genotypes HPBS-1 followed by HPKM-04-1 were found to be moderately drought tolerant as these exhibited the lowest drought susceptibility index value in Stage-I and Stage-III while in Stage-II, RCC-4×Varuna followed by HPBS-1 exhibited lowest drought susceptibility index value. Therefore, systematic characterization of differences in physiological responses to drought stress among elite lines is helpful in understanding mechanisms of drought resistance. Hence, traits like primary branches plant^{-1}, secondary branches plant^{-1}, siliquae plant^{-1}, seeds siliqua^{-1}, seed yield plant^{-1} and 1000-seed weight can be further used in selection criteria for future breeding programme aimed for enhancing drought tolerance.

KEYWORDS: Drought susceptibility index, genetic advance, heritability, moisture-stress, selection

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1. INTRODUCTION

Oilseeds are the most important crops in World's agricultural economy. Globally, India has the world's fifth biggest vegetable oils economy contributing up to 10% of the world's oilseeds production next only to Brazil, United States, China and Argentina (Anonymous, 2021). Among oilseeds, the family Brassicaceae (cruciferae) consists of about 350 genera and 3500 species with the genus *Brassica* being one of the most economically important genera (Rakow, 2004). The genus consists of diverse group of species including major vegetables and oilseed crops (Love et al., 2005). In India, 8 different species of oilseeds viz., Indian mustard [*Brassica juncea* (L.) Czern & Coss], gobhi *sarson* (*Brassica napus* L.), three ecotypes of Indian rapeseed {*toria*, brown *sarson* and yellow *sarson* (*Brassica campestris* L. ssp. *oleifera*)}, Ethiopian mustard/karan rai (*Brassica carinata* A. Braun), taramira (*Eruca sativa* Mill.) and black mustard are cultivated under rapeseed-mustard group. Rapeseed-mustard group of crops is primarily used for human consumption as edible oil. Apart from being a significant element of the human diet, oils and fats are also used in the production of soaps, paints and varnishes, hair oils, lubricants, textiles, auxiliaries and medicines. data India needs to produce 17.84 mt of vegetable oils to meet the nutritional fat demand of projected population of 1685 million by 2050. These crops are also grown for vegetables, fodder, condiments, cakes and green manure purposes.

Rapeseed-mustard throughout the world is grown over an area of 36.24 mha with 73.16 mt production. In India, it occupies approximately 8.20 mha acreage with a total of 8.50 mt production (Anonymous, 2021). This crop suffers both in terms of acreage and production (Biswas et al., 2019) chiefly due to lack of varieties for different ecosystems, fluctuating weather environments, marginal and sub-marginal cultivation with low input conditions as well as and prevalence of various biotic and abiotic stresses. Moreover, growing vulnerabilities and insufficient efforts to offset the negative effects of climate change, sustainable food production has proven to be a difficult problem for many developing countries (Ali et al., 2017). To achieve these rising demands, it has become important to narrow down yield losses occurring due to biotic as well as abiotic stresses to realize exploitable yield (Chauhan et al., 2020). Among all environmental stresses, moisture stress is considered as one of the foremost causes responsible for reduced crop productivity, because it is often linked to other abiotic stresses like salinity, heat, etc. (Mahmood and Ashraf, 2009, Kumari et al., 2020). Variation in precipitation levels and temperature fluctuations seems to be 2 important factors influencing moisture stress (Ijaz et al., 2021, Langridge and Reynolds, 2021). Globally, more than 1.2 bha of area under rainfed cultivation faces severe moisture stress conditions (Kijni, 2006, Passioura, 2007). The sensitivity of drought due to climate change varies with different growth stages of the crop species (Qiang et al., 2016). Under drought stress, plant growth is affected by a number of morpho-physiological disorders that cause reduction in nutrient uptake, impairs active transport of photosynthates (Yuncai and Schmidhalter, 2005) and cause a sharp decrease in plants productivity (Pan et al., 2002). It also affects stomatal conductance, photosynthetic activity, pigment content, plant water relations and overall plant growth (Praba et al., 2009). Such plants consequently have poor plant growth and low seed yield (Kumari et al., 2019). Drought stress does not occur suddenly but slowly compared to many stresses, so time dimension plays an important role in terms of survival in drought stress conditions (Gunes et al., 2008). As *Brassica* is mostly grown on light textured soils in India, it suffers from moisture stress during its reproductive stage inevitably as all water stored from monsoon rains gets depleted till then (Kumar and Singh, 1998).

For planning an effective selection breeding programme (Meena et al., 2017, Manjunath et al., 2017, Kumar et al., 2018, Sharma et al., 2022), the knowledge of variability estimates is crucial to the plant breeders. The utilization of any species in breeding programmes depends upon genetic diversity and its adaptability in different environments (Rai and Jat, 2022). Variability parameters such as phenotypic and genotypic coefficients of variation measures the amount of variability which is actually under genetic control. Moreover, heritability estimates are helpful in studying the degree of inheritance of quantitative characters with desired degree of expected genetic progress. To obtain higher genetic gain, both high heritability with high genetic advance are crucial. Thus, evaluation and identification of drought tolerant genotypes becomes essential in all breeding programmes concerning moisture stress (Cattivelli et al., 2008). Moreover, drought indices are used to screen such drought tolerant genotypes base on yield reduction due to drought conditions (Kumari et al., 2020). Keeping this in view, the present investigation was undertaken with the aim to study the genetic variation for drought tolerance through morpho-physiological and yield contributing traits in rapeseed-mustard.

2. MATERIALS AND METHODS

2.1. Study sites

The experimental material for the present study comprised of 25 advanced breeding lines including released varieties of different *Brassica* species grown under moisture stress conditions during *rabi* season (October-May), 2018–2019 at the Experimental Farm of Department of Genetics and Plant Breeding, CSK HPKV, Palampur (HP), India (Table 1). All breeding lines were laid out in completely randomized design (CRD) using pots with two replications and moisture stress was created at three stages viz., rosette formation (Stage-I), flower initiation (Stage-II) and siliqua formation (Stage-III). Lifesaving amount of water was given at the crucial stage of wilting at each stress stage.

2.2. Method of data collection

Observations were recorded on five randomly selected plants in each genotype for agro-morphological and yield contributing characters viz., days to 50% Flowering (50% F), days to 75% Maturity (75% M), plant height (PH), number of primary branches plant^{-1} (PB), number of secondary branches plant^{-1} (SB), siliquae plant^{-1} (SQ), seeds siliqua^{-1} (SSQ), 1000-seed weight (1000-SW), biological yield plant^{-1} (BY), harvest index (HI) and seed yield plant^{-1} (SY). Analysis of variance for each trait was done as per Panse and Sukhatme (1984). Estimates of variability viz., phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (h^2_{bs}) in broad sense and expected genetic advance (GA) expressed as % of mean resulting from the selection of 5 % superior individuals was calculated as per Burton and De Vane (1953) and Johnson et al., (1955). Drought Susceptibility Index (S) was calculated from grain yield data recorded under non stress and moisture stress environments (Fischer and Maurer 1978) which was used to characterize the relative drought tolerance of the genotypes, based on minimization of yield losses under stress environment.

Table 1: Details of the experimental material along with source used in the study

S. No.	Genotype	Species	Source
1.	HPBS-1	*Brassica campestris*	Released variety of H.P.
2.	HPKM-04-01	*Brassica campestris*	Local cultivar of H.P.
3.	KDH-B5-06 × 03-472	*Brassica campestris*	Department of Genetics and Plant Breeding
4.	03-473 ×03-472	*Brassica campestris*	Department of Genetics and Plant Breeding
5.	03-472 × 02 KLM-6	*Brassica campestris*	Department of Genetics and Plant Breeding
6.	HPBS-1 × 02-KLM-6	*Brassica campestris*	Department of Genetics and Plant Breeding
7.	Jayanti	*Brassica carinata*	Released variety of H.P.
8.	P(4)2a (80KR)	*Brassica carinata*	Mutant line
9.	P(4)2b (0.3% EMS WPS)	*Brassica carinata*	Mutant line
10.	P13a (100KR)	*Brassica carinata*	Mutant line
11.	P13b (0.4% EMS WPS)	*Brassica carinata*	Mutant line
12.	P(11)2 (0.3 EMS WPS)	*Brassica carinata*	Mutant line
13.	P(3)2 (0.3% EMS WPS)	*Brassica carinata*	Mutant line
14.	P22 (0.3% EMS WPS)	*Brassica carinata*	Mutant line
15.	P36 (0.5% EMS WPS)	*Brassica carinata*	Mutant line
16.	Sheetal (HPN-1)	*Brassica napus*	Released variety of H.P.
17.	Neelam (HPN-3)	*Brassica napus*	Released variety of H.P.
18.	ONK-1	*Brassica napus*	Released variety of H.P.
19.	ONK-1 × CAN-130	*Brassica napus*	Department of Genetics and Plant Breeding
20.	ONK-1 × HPN-1	*Brassica napus*	Department of Genetics and Plant Breeding
21.	RCC-4	*Brassica juncea*	Released variety of H.P.
22.	TM-172	*Brassica juncea*	BARC, Mumbai
23.	TM-204	*Brassica juncea*	BARC, Mumbai
24.	TM-215	*Brassica juncea*	BARC, Mumbai
25.	RCC-4 × Varuna	*Brassica juncea*	Department of Genetics and Plant Breeding

$$S = \{1-(Yd / Yp)\} / D \qquad \text{………………(1)}$$

$$D=1\text{-Mean } Y_d \text{ of all the genotypes/Mean } Y_P \text{ of all the genotypes} \qquad \text{………(2)}$$

where, Y_d is the mean yield of a genotype under moisture stress environment, Y_p is the mean grain yield under non stress environment and D is drought intensity.

3. RESULTS AND DISCUSSION

Analysis of variance revealed significant genotypic variation for all the traits in all the stages except for 1000-SW in non-stress stage which indicated the presence of substantial variability for all the traits in different *Brassica* species (Table 2). Khan et al. (2013) also reported presence of significant variation among all the genotypes for all the traits except for 1000-SW in *Brassica campestris*. Zare and Sharafzadeh (2012) also reported highly significant differences for 50% F and 75% M, SB, PH, 1000-SW, SY and HI. Similar significant differences were also reported in earlier studies for 50% F, 75% M, PB, PH, SQ, SSQ, 1000-SW and SY (Monalisa et al., 2005, Rameeh, 2015, Pawar et al., 2018), Jat et al. (2019) while Abideen et al. (2013) reported non-significant differences for PB. Hence, traits under investigation are adequate for studying drought tolerance in *Brassica* species.

Table 2: Analysis of variance for different traits in different Brassica species

S. No.	Characters	Non-Stress Stage		Stage-I		Stage-II		Stage-III	
	Source	Genotypes	Error	Genotypes	Error	Genotypes	Error	Genotypes	Error
	df	24	24	24	24	24	24	24	24
1.	50% F	73.953*	0.403	120.788*	0.792	72.287*	0.667	75.928*	0.488
2.	75% M	170.897*	1.047	169.03*	0.417	178.458*	0.695	169.128*	1.072
3.	PH (cm)	144.655*	10.016	106.885*	5.563	131.574*	3.318	172.263*	6.049
4.	PB	0.473*	0.093	0.300*	0.038	0.561*	0.03	0.840*	0.114
5.	SB	4.271*	0.030	1.815*	0.088	2.510*	0.032	2.457*	0.054
6.	SQ	114.772*	2.030	99.318*	1.958	85.128*	0.92	124.551*	1.924
7.	SSQ	2.034*	0.069	2.081*	0.095	3.584*	0.048	2.188*	0.061
8.	1000-SW (g)	0.243	0.078	0.073*	0.003	0.027*	0.003	0.036*	0.004
9.	BY (g)	0.445*	0.003	0.704*	0.113	0.574*	0.005	0.538*	0.009
10.	HI (%)	3.569*	0.170	11.236*	0.832	3.646*	0.144	5.769*	0.173
11.	SY (g)	0.047*	0.002	0.208*	0.001	0.108*	0.001	0.124*	0.001

*Significant at $p \leq 0.05$

3.1. *Mean performance*

The comparison of mean values indicated that there was significant reduction in mean performance for almost all the traits (Table 3 and 4). In stage-I, 50% F and 75% M were delayed in *Brassica campestris* and *Brassica carinata* while earliness was seen in *Brassica napus* and *Brassica juncea.* Maximum reduction in PH was observed in stage-I while all the other characters showed variable trend. Maximum reduction in SY was observed in *Brassica napus* followed by *Brassica campestris, Brassica juncea* whereas, *Brassica carinata* showed minimum reduction. In stage-II, maximum reduction in SY was observed in *Brassica napus* followed by *Brassica campestris* and *Brassica carinata* whereas, *Brassica juncea* had the minimum reduction in yield. In stage III, maximum reduction in seed yield was again observed in *Brassica napus* followed by *Brassica carinata* and *Brassica campestris* while minimum reduction was observed in *Brassica juncea*. The comparison of mean values of SY in three stages revealed that stage-III (siliqua formation stage) had the maximum reduction in SY and was most susceptible to moisture stress conditions.

3.2. *Estimates of parameters of variability*

3.2.1. *Non-stress stage*

Moderate PCV (10%–30%) was recorded for PH, PB, SB, SQ and 1000-SW while low estimates were recorded for rest of the characters (Table 3). Moderate GCV (10%–30%) was observed for PH, PB, SB and SQ while low GCV (<10%) was recorded for characters such as 50% F, 75% M, SSQ, SY, 1000-SW, BY and HI. In general, PCV values were found to be higher than their corresponding GCV values. Similar findings in respect of PCV and GCV have been reported by Mahla et al. (2003), Kumar and Mishra (2007) and Alma et al. (2010) in Indian mustard. However, higher estimates of PCV and GCV for the characters such as SQ and 1000-SW were reported by Singh and Singh (1996) and lower estimates were observed for 50% F and 75% M (Pawar et al., 2018). Earlier, Lekh and Singh (1998) also reported high PCV and GCV estimates for 50% F in *Brassica juncea, Brassica napus and Brassica campestris*.

Heritability estimates were found high (>60%) for all the traits except 1000-SW showed moderate heritability

Table 3: Estimates of different parameters of variability for various characters (Non-stress and Stage-I)

Sl. No.	Charac-ters	Non-Stress Stage						Stage-I					
		Range	Mean	PCV (%)	GCV (%)	h^2_{bs} (%)	GA (%)	Range	Mean	PCV (%)	GCV (%)	h^2_{bs} (%)	GA (%)
1.	50% F	62.5–79	71.32	8.55	8.50	98.92	17.42	59.5–82.5	72.04	10.82	10.75	98.70	22.01
2.	75%M	133.5–159	150.64	6.16	6.12	98.78	12.53	136.5–163.5	151.34	6.08	6.07	99.51	12.47
3.	PH (cm)	62.6–93.5	76.0552	11.56	10.79	87.05	20.73	43.2–69.7	56.67	13.23	12.56	90.11	24.56
4.	PB	3–4.7	3.972	13.39	10.96	67.01	18.49	2–3.5	2.78	14.83	13.04	77.37	23.63
5.	SB	2.3–8.2	4.896	29.95	29.74	98.61	60.84	2.5–5.9	3.82	25.54	24.32	90.71	47.72
6.	SQ	40.4–67.6	52.276	14.62	14.36	96.53	29.07	28.1–52.3	35.56	20.01	19.62	96.13	39.63
7.	SSQ	14.5–17.5	15.778	6.50	6.28	93.45	12.51	9.9–15.4	12.01	8.63	8.24	91.25	16.22
8.	1000-SW (g)	3.11–4.5	3.52	11.39	8.14	51.14	12.00	2.98–3.64	3.26	6.00	5.74	91.55	11.31
9.	BY (g)	11.5–13.4	12.378	3.82	3.80	98.85	7.79	10.03–11.9	10.91	5.86	4.98	72.28	8.72
10.	HI (%)	23.6–28.4	26.324	5.19	4.95	90.92	9.73	14.42–24.18	20.37	12.06	11.20	86.22	21.42
11.	SY (g)	2.9–3.6	3.2576	4.78	4.62	93.27	9.18	1.57–2.69	2.19	14.79	14.71	98.84	30.12

Table 4: Estimates of different parameters of variability for various characters (Stage-II and Stage-III)

Sl. No.	Charac-ters	Stage-II						Stage-III					
		Range	Mean	PCV (%)	GCV (%)	h^2_{bs} (%)	GA (%)	Range	Mean	PCV (%)	GCV (%)	h^2_{bs} (%)	GA (%)
1.	50% F	62–78	70.82	8.53	8.45	98.17	17.25	62.5–78.5	71.12	8.69	8.64	98.72	17.68
2.	75%M	133–158.5	150.2	6.30	6.28	99.22	12.88	133.5–159	150.72	6.12	6.08	98.74	12.45
3.	PH (cm)	51.6–76.7	64.21	12.79	12.47	95.08	25.05	54.4–86.7	69.72	13.54	13.08	93.22	26.01
4.	PB	2.7–5	3.21	16.91	16.05	90.01	31.36	2–5.8	3.49	19.78	17.25	76.07	30.99
5.	SB	2–6.1	3.95	28.56	28.19	97.45	57.33	2.4–6.5	4.19	26.77	26.19	95.70	52.77
6.	SQ	31.2–56.4	40.69	16.12	15.95	97.86	32.50	31.3–61.2	42.65	18.64	18.36	96.96	37.24
7.	SSQ	11.1–17.1	13.13	10.27	10.13	97.35	20.59	10.4–14.4	11.7	9.06	8.82	94.59	17.66
8.	1000-SW (g)	2.97–3.43	3.21	3.78	3.45	83.02	6.47	2.75–3.38	3.08	4.59	4.14	81.14	7.68
9.	BY (g)	10.44–12.07	11.21	4.80	4.76	98.38	9.73	10.59–12.4	11.55	4.53	4.45	96.82	9.03
10.	HI (%)	16.65–21.76	20.07	6.86	6.59	92.40	13.06	13.57–19.11	17.02	10.13	9.83	94.17	19.65
11.	SY (g)	1.7–2.48	2.22	10.55	10.42	97.69	21.20	1.5–2.3	1.97	12.72	12.60	98.08	25.70

(30%–60%). Choudhary et al., (1999) in *Brassica juncea* also reported high heritability for siliqua traits like SQ and SSQ. Expected genetic advance expressed as percent of mean was found to be high (>30%) for SB, moderate (10%–30%) for 50% F, 75% M, PH, PB, SQ, SSQ and 1000-SW while lower estimates (<10%) were observed for remaining traits. High heritability coupled with high genetic advance was observed for SB while high heritability along with moderate genetic advance was observed for 50% F, 75% M, PH, PB, SQ and SSQ. Results were in conformation with the earlier findings of Das et al. (1998), Lodhi et al. (2014), Pawar et al. (2018) and Jat et al. (2019) in *Brassica juncea*.

3.2.2. Stage-I (Rosette formation)

Moderate PCV and GCV (10%–30%) values were recorded for 50% F, PH, PB, SB, SQ, SY and HI (Table 3). However, high estimates of PCV for PB, SY and 1000-SW were also reported by Patel et al. (2019) in Indian mustard.

Heritability estimates were high (>60%) for the characters such as 50% F, 75% M, PH, PB, SB, SQ, SSQ, SY, 1000-SW and HI. High heritability for SY was also reported by Pant and Singh (2001) in Indian mustard. Expected genetic advance expressed as percent of mean recorded was high (>30%) for SB, SQ and SY while moderate genetic advance (10%–30%) was recorded for 50% F, PH, 75% M, PB, SSQ, 1000-SW and HI. High genetic advance for SY was also observed by Bind et al. (2014) in Indian mustard. High heritability coupled with high genetic advance was observed for SB, SQ and SY whereas high heritability along with moderate genetic advance was observed for 50% F, 75% M, PH, PB, SSQ, 1000-SW and HI. High heritability coupled with high genetic advance for the characters such as SB and SQ was also reported by Afrin et al. (2011) in *Brassica napus* and high heritability coupled with high genetic advance for SY was reported by Nazzar et al., (2003) in rapeseed varieties.

3.2.3. Stage-II (Flower initiation)

The moderate PCV and GCV (10%–30%) was observed for PH, PB, SB, SQ, SSQ and SY while the estimates of PCV (<10%) were recorded low for remaining characters (Table 4).

Heritability estimates were found to be high (>60%) for all the characters such as 50% F, 75% M, PH, PB, SB, SQ, SSQ, BY, SY, 1000-SWand HI. High genetic advance (>30%) was observed for PB, SB and SQ whereas 50% F, 75% M, PH, SSQ, SY and HI exhibited moderate values (10%–30%). High heritability coupled with high genetic advance was found in PB, SB and SQ whereas high heritability along with moderate genetic advance was observed for 50% F, 75% M, PH, SSQ, SY and HI. The results were in conformation to the earlier findings of Muhammad et al. (2007) in *B. juncea*, Acharya and Patil (2008) in *B. juncea*, Aytac et al. (2008) in spring rapeseed, Singh and Singh (2010), Pawar et al. (2018) and Jat et al. (2019) in *B. juncea.*

3.2.4. Stage-III (Siliqua formation)

PCV values were found higher than their corresponding values for all the characters studied. Similar findings were earlier given by Karuppaiyan et al. (2014) in *Brassica napus*. The characters such as PH, PB, SB, SQ, SY and HI exhibited moderate PCV (10%–30%). Moderate GCV (10%–30%) was recorded by characters such as PH, PB, SB, SQ and SY while low estimates were recorded for the remaining characters (Table 4).

Heritability estimates were high (>60%) for all the characters such as 75% M, 50% F, SY, SQ, BY, SB, SSQ, HI, PH, 1000-SW and PB. Similar results were also reported by Rameeh (2011) in rapeseed genotypes; Tahira et al. (2011) in Indian mustard, Nasim et al. (2013) in *Brassica napus* and Mekonnen (2014) in *Brassica carinata*. Expected genetic advance expressed as percent of mean was recorded high (>30%) for PB, SB and SQ. Moderate estimates (10%–30%) were recorded for 50% F, 75% M, PH, SSQ, SY and HI. High heritability coupled with high genetic advance was found in PB, SB and SQ whereas high heritability along with moderate genetic advance was observed for

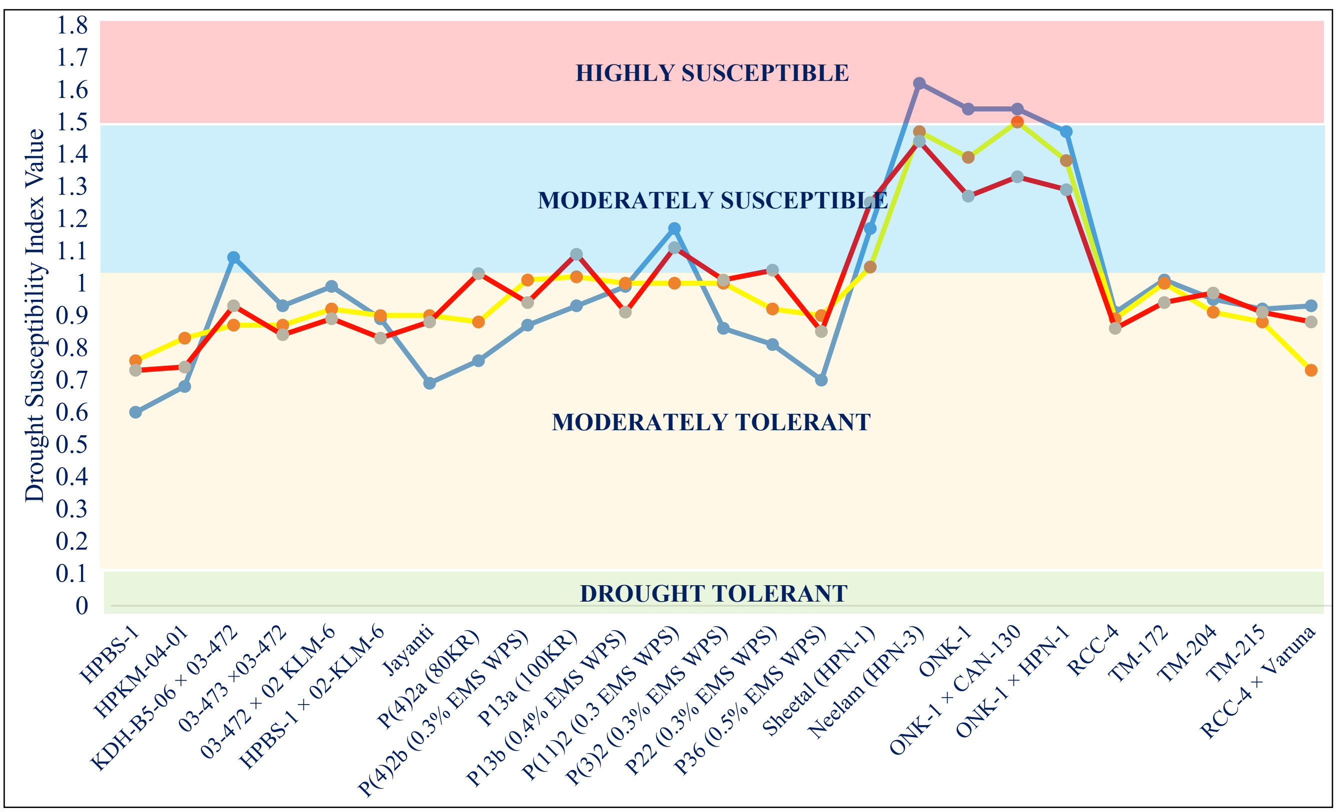

Figure 1: Classification of different genotypes based upon their Drought Susceptibility Index values (DSI) at different stages

50%F, 75%M, PH, SSQ, SY and HI. The results were in conformation to the earlier finding of Roy et al. (2011), Lodhi et al. (2014) and Jat et al. (2019) in Indian mustard.

3.3. *Drought susceptibility index (DSI)*

High value of DSI indicates that genotype is less tolerant to drought or have greater drought susceptibility (Ali and Rai, 2022). On the other hand, low value of DSI indicates more tolerance capacity of a genotype to moisture stress. In the present study, drought susceptibility index was categorized into four levels viz., drought tolerant, moderately tolerant, moderately susceptible and highly susceptible genotypes. In all the three stages, none of the genotype exhibited drought tolerance (Figure 1). In Stage-I, seventeen genotypes were moderately tolerant to drought. Among these, HPBS-1 recorded lowest DSI (0.60). Five genotypes were moderately susceptible to drought having DSI value between 1–1.5. Three genotypes viz., Neelam, ONK-1×CAN-130 and ONK-1 were classified as highly susceptible to drought and had value more than 1.5. In Stage-II, fourteen genotypes were moderately tolerant and the genotype RCC-4×Varuna had the lowest DSI value (0.73). 11 genotypes were moderately susceptible and none of the genotype was highly susceptible. In Stage-III, fifteen genotypes were moderately tolerant. Among these, HPBS-1 recorded the lowest DSI value (0.73) and ten genotypes were moderately susceptible.

4. CONCLUSION

Sufficient genetic variability was found for almost all the characters except for 1000-SW while maximum reduction in SY was found in Stage-III. This stage was most susceptible to moisture stress conditions. Variability studies suggested traits like PB, SB, SQ, SSQ, SY and 1000-SW can be further used in selection criteria for future breeding programme aimed for enhancing drought tolerance. HPBS-1 in Stage-I and Stage-III while RCC-4×Varuna in Stage-II, was found to be moderately drought tolerant exhibiting lowest DSI value.

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6. REFERENCES

Abideen, S.N., Nadeem, F., Abideen, S.A., 2013. Genetic variability and correlation studies in *Brassica napus* L. genotypes. International Journal of Innovation and Applied Studies 2(4), 574–581.

Acharya, N.N., Patil, P., 2008. Genetic variability, correlation and path analysis in Indian mustard (*Brassica juncea* L.). Environment and Ecology 26(4B), 2165–2168.

Afrin, K.S., Mahmud, F., Bhuiyan, M.S., Rahim, M.A., 2011. Assessment of genetic variation among advanced lines of *Brassica napus* L. Agronomski Glasnik: Glasilo Hrvatskog agronomskog društva 73(4-5), 201–226.

Ali, S., Liu, Y., Ishaq, M., Shah, T., Ilyas, A., Din, I.U., 2017. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. Foods 6(6), 39. http://dx.doi.org/10.3390/foods6060039

Ali, Z., Rai, S.K., 2022. Drought susceptibility index analysis in Indian mustard (*Brassica juncea* L.). Journal of Oilseed Brassica 13(2), 136-142.

Alma, M.A., Nath, U.K., Malek, M.A., Rani, S., 2010. Interspecific crossability between *Brassica juncea* and *Brassica campestris* for developing short duration mustard genotype. International Journal Bioresource and Stress Management 2(10), 13–15.

Anonymous, 2021. World Agricultural Production-Foreign Agricultural Service (Circular Series). USDA, 36.

Aytac, Z., Kinaci, G., Kinaci, E., 2008. Genetic variation, heritability and path analysis of summer rapeseed cultivars. Journal of Applied Environmental and Biological Sciences 2(3), 35–39.

Bind, D., Singh, D., Dwivedi, V.K., 2014. Genetic variability and character association in Indian mustard [*Brassica juncea* (L) Czern & Cross]. Agricultural Science Digest 34(3), 183–188.

Biswas, P.K., Ferdous, L.J., Roy, T.S., Masum, S.M., 2019. Performance of rapeseed and mustard with different planting techniques. Bangladesh Agronomy Journal 22(1), 79-88.

Burton, G.M., De Vane, E.H., 1953. Estimating heritability in tall Fescue (*Festuca arundinacea*) from replicated colonal material. Agronomy Journal 45(10), 310–314.

Cattivelli, L., Rizza, F., Badeck, F.W., Mazzucotelli, E., Mastrangelo, A.M., Francia, E., 2008. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crops Research 105(1-2), 1–14. http://dx.doi.org/10.1016/j.fcr.2007.07.004.

Chauhan, J.S., Choudhury, P.R., Pal, S., Singh, K.H., 2020. Analysis of seed chain and its implication in rapeseed-mustard (*Brassica* spp.) production in India. Journal of Oilseeds Research 37(2), 71-84.

Choudhary, A.D., Barua, P.K., Duara, P.K., 1999. Siliqua traits determining seed yield in Indian rapeseed. Journal of Agricultural Science 12(1), 60–63.

Das, K., Barua, P.K., Hazarika, G.N., 1998. Genetic variability and correlation in Indian mustard. Journal of the Agricultural Science Society of North East India 11, 262–264.

Fischer, R.A., Maurer, R., 1978. Drought resistance in spring wheat cultivars: Grain yield responses. Australian Journal of Agricultural Research 29(5), 897–912.
Gunes, A., Inal, A., Adak, M.S., Bagci, E.G., Cicek, N., Eraslan, F., 2008. Effect of drought stress implemented at pre-or post-anthesis stage on some physiological parameters as screening criteria in chickpea cultivars. Russian Journal of Plant Physiology 55(1), 59–67. https://doi.org/10.1134/S102144370801007X.
Ijaz, W.A., Kanwal, S., Tahir, M.H., Razzaq, H., 2021. Gene action of yield related characters under normal and drought stress conditions in *Brassica napus* L. Pakistan Journal of Botany 53(6), 1979–1985.
Jat, L., Rai, S.K., Choudhary, J.R., Bawa, V., Bharti, R., Sharma, M., Sharma, M., 2019. Phenotypic evaluation of genetic diversity of diverse indian mustard (*Brassica juncea* L. Czern and Coss) genotypes using correlation and path analysis. International Journal of Bio-resource and Stress Management 10(5), 467-471.
Johnson, H.W., Robinson, H.F., Comstock, R.E., 1955. Estimates of genetic and environmental variability in soybean. Agronomy Journal 47(7), 314–318.
Karuppaiyan, R., Kapoor, C., Gopi, R., 2014. Variability, heritability and genetic divergence in yellow sarson (*Brassica campestris* var. yellow sarson) genotypes under the mid hills of Sikkim. Indian Journal of Plant Genetic Resources 27(2), 127–132.
Khan, M.H., Bhuiyan, S.R., Rashid, M.H., Ghosh, S., Paul, S.K., 2013. Variability and heritability analysis in short duration and high yielding *Brassica rapa* L. Bangladesh Journal of Agricultural Research 38(4), 647–657.
Kijni, J.W., 2006. Abiotic stress and water scarcity: Identifying and resolving conflicts from plant level to global level. Field Crops Research 97(1), 3–18.
Kumar, A., Singh, D.P., 1998. Use of physiological indices as a screening technique for drought tolerance in oil seed *Brassica* species. Annals of Botany 81(3), 413–420.
Kumar, A., Singh, M., Yadav, R.K., Singh, P., Lallu, 2018. Study of correlation and path coefficient among the characters of Indian mustard. The Pharma Innovation Journal 7(1), 412–416.
Kumar, S., Mishra, M.N., 2007. Study on genetic variability, heritability and genetic advance in F_3 population in Indian mustard. International Journal of Plant Sciences 2, 188–190.
Kumari, A., Avtar, R., Jattan, A.N.M., Rani, B., 2019. Screening for drought tolerance in Indian mustard (*Brassica juncea* L.) genotypes based on yield contributing characters and physiological parameters. Journal of Oilseed Brassica 10(1), 1-7.
Kumari, V., Kumar, M., Kumar, V., 2020. Assessment of drought tolerance using drought tolerance indices and their inter relationships in mustard [*Brassica juncea* (L.)]. Journal of Oilseed Brassica 11(2), 134–138.
Langridge, P., Reynolds, M., 2021. Breeding for drought and heat tolerance in wheat. Theoretical and Applied Genetics 134(6), 1753–1769. https://doi.org/10.1007/s00122-021-03795-1.
Lekh, R., Hari, S., Singh, V.P., Raj, L., Singh, H., 1998. Variability studies in rapeseed and mustard. Annals of Agricultural Research 19(1), 87–88.
Lodhi, B., Thakral, N.K., Avtar, R., Singh, A., 2014. Genetic variability, association and path analysis in Indian mustard (*Brassica juncea*). Journal of Oilseed Brassica 1(1), 26–31.
Love, C.G., Robinson, A.J., Lim, G.A., Hopkins, C.J., Batley, J., Barker, G., Spangenberg, G.C., Edwards, D., 2005. *Brassica* ASTRA: An integrated database for *Brassica* genomic research. Nucleic Acids Research 33(suppl_1), 656–659.
Mahla, H.R., Jambhulkar, S.J., Yadav, D.K., Sharma, R., 2003. Genetic variability, correlation and path analysis in Indian mustard [*Brassica juncea* (L) Czern. & Coss.]. Indian Journal of Genetics and Plant Breeding 63(2), 171–172.
Mahmood, T., Ashraf, M. and Shahbaz, M., 2009. Does exogenous application of glycinebetaine as a pre-sowing seed treatment improve growth and regulate some key physiological attributes in wheat plants grown under water deficit conditions. Pakistan Journal of Botany 41(3), 1291–1302.
Manjunath, H., Phogat, D.S., Kumari, P., Singh, D., 2017. Genetic analysis of seed yield and yield attributes in Indian mustard [*B. juncea* (L.) Czern and Coss.]. Electronic Journal of Plant Breeding 8(1), 182–186.
Meena, H.S., Kumar, A., Singh, V.V., Meena, P.D., Ram, B., Kulshrestha, S., 2017. Genetic variability and interrelation of seed yield with contributing traits in Indian mustard (*B. juncea*). Journal of Oilseed Brassica 81(2), 131–137.
Mekonnen, T.W., 2014. Phenotypic variability of Ethiopian mustard *(Brassica carinata* A. Braun) genotypes in South Gondar, Ethiopia. Advanced Research Journal of Plant and Animal Sciences 2(5), 42–48.
Monalisa, P., Singh, N.B., Singh, N.G., Laishram, J.M., 2005. Genetic divergence and combining ability in relation to heterosis in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] for seed yield, its attributes and oil yield. Indian Journal of Genetics and Plant Breeding 65(4), 302–304.
Muhammad, A., Usman, S., Muhammad, T.Y., Iqbal, N.,

2007. Utilization of genetic variability, correlation and path analysis for seed yield improvement in mustard (*Brassica juncea*). Journal of Agricultural Research 45, 25–31.

Narayan, P., 2016. Recent demand-supply and growth of oilseeds and edible oil in India: an analytical approach. International Journal of Advanced Engineering Research and Science 4(1), 32–46.

Nasim, A., Iqbal, S., Shah, S., Azam, S.M., Farhatullah, Dr., 2013. Genetic variability and correlation studies for morphological traits in *Brasssica napus* L. Pakistan Journal of Botany 45(4), 1229–1234.

Nazzar, A., Javidfar, F., Elmira, J.Y., Mirza, M.Y., 2003. Relationship among yield components and selection criteria for yield improvement in winter rapeseed (*Brassica napus*). Pakistan Journal of Botany 35(2), 167–174.

Pan, X.Y., Wang, Y.F., Wang, G.X., Cao, Q.D., Wang, J., 2002. Relationship between growth redundancy and size in equality in spring wheat populations mulched with clear plastic film. Acta Ecologica Sinica 26(2), 177–184.

Panse, V.G., Sukhatme, P.V., 1984. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi, 359.

Pant, S.C., Singh, P., 2001. Genetic variability in Indian mustard. Agricultural Science Digest 21(1), 28–30.

Passioura, J., 2007. The drought environment: Physical, biological and agricultural perspectives. Journal of Experimental Botany 58(2), 113–117.

Patel, J.R., Prajapati, K.P., Patel, P.J., Patel, B.K., Patel, A.M., Jat, A.L., Desai, A.G., 2019. Genetic variability and character association analysis for seed yield and its attributes in Indian mustard (*Brassica juncea* (L.) Czern and Coss.). The Pharma Innovation Journal 8(4), 872–876.

Pawar, P.D., Nair, B., Charjan, S.U., Manojkumar, D., 2018. Evaluation of induced genetic variability, heritability and genetic advance in Indian mustard (*Brassica juncea* L.). Journal of Soils and Crops 28(1), 115-120.

Praba, M.L., Cairns, J.E., Babu, R.C., Lafitte, H.R., 2009. Identification of physiological traits underlying cultivar differences in drought tolerance in rice and wheat. Journal of Agronomy and Crop Science 195(1), 30-46.

Qiang, C., Yantai, G., Cai, Zhao., Hui-Lian, Xu., Reagan, M.W., Yining, N., 2016. Regulated deficit irrigation for crop production under drought stress. A review. Agronomy for sustainable development 36(1), 3. http://dx.doi.org/10.1007/s13593-015-0338-6

Rai, S.K., Jat, L., 2022. Genetic diversity studies for drought tolerance among various genotypes of *Brassisa juncea* L. using SSR markers. The Pharma Innovation Journal 11(6), 1627–1630.

Rakow, G., 2004. Species origin and economic importance of *Brassica*. Biotechnology in Agriculture and Forestry 54, 3–11. https://doi.org/10.1007/978-3-662-06164-0_1

Rameeh, V., 2011. Correlation and path analysis in advanced lines of rapeseed (*Brassica napus*) for yield components. Journal of Oilseed Brassica 1(2), 56–60.

Rameeh, V., 2015. Genetic variability and interrelationships among quantitative traits in rapeseed (*Brassica napus* L.) advanced lines. The Journal of Agricultural Sciences 10(3), 158–167.

Roy, S.K., Haque, S., Kale, V.A., Asabe, D.S., Dash, S., 2011. Variability and character association studies in rapeseed-mustard (*Brassica* sp.). Journal of Crop and Weed 7(2), 108–112.

Sharma, A., Kumari, V., Rana, A., 2022. Early Generation selection parameters for genetic improvement using morpho-physiological and seed yield components in Brassica species. International Journal of Plant & Soil Science 34(2), 43–53. https://doi.org/10.9734/IJPSS/2022/v34i230835

Singh, M., Singh, G., 1996. Evaluation of yellow *sarson* germplasm at mid hills of Sikkim. Journal of Hill Research 9(1), 112–114.

Singh, S.K., Singh, A.K., 2010. Inter-relationship and path analysis for seed yield in Indian mustard. Indian Journal of Ecology 37(1), 8–12.

Tahira, Mahmood, T., Tahir, M.S., Saleem, U., Hussain, M., Saqip, M., 2011. The estimation of heritability associated and selection criteria for yield components in mustard (*Brassica juncea*). Pakistan Journal of Agricultural Sciences 48(4), 251–254.

Yuncai, H., Schmidhalter, U., 2005. Drought and salinity, A comparison of the effects of drought and salinity. Journal of Plant Nutrition and Soil Science 168(4), 541–549.

Zare, M., Sharafzadeh, S., 2012. Genetic variability of some rapeseed (*Brassica napus* L.) cultivars in Southern Iran. African Journal of Agriculture Research 7(2), 224–229.