Analysis of Drought Susceptibility Index in Indian Mustard
[Brassica juncea (L.) Czern and Coss]

Akanksha, K. Srivastava, Ayushi Srivastava, B. Sinha

ABSTRACT

Background: Climatic variations such as drought have high level of impingement on the yield of rain-fed crops like mustard. A drought is an extended period of months or years when region notes a deficiency in its water availability. Water stress causes heavy yield losses in Indian mustard (17-94%). Low water availability during stem elongation, flowering and pod development causes reduction of pods per plant leading to reduction in grain yield. Very meagre efforts have been made towards improving drought tolerance of this crop. Hence there is an urgent need for, development of water use efficient genotypes. Drought Susceptibility Index (DSI) is a measure of drought, based on loss of yield under drought conditions in comparison to the yield under normal conditions. It expresses the separate effects of yield potential and drought susceptibility on yields under drought. In these terms, lower DSI is considered synonymous with higher drought tolerance. In view of above facts, present study is aimed at investigating the effects of drought on yield attributing traits with, the objective of identifying Indian mustard genotypes and their hybrids which can withstand water stress with minimum loss in yield.

Methods: Nine Indian mustard genotypes and their F₁s were evaluated under irrigated and rainfed conditions to study the effect of drought by calculating DSI, on yield and yield traits and to characterize their relative tolerance against drought at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during Rabi 2017-18 season. Observations were made for different yield and yield related traits.

Result: Genotype RB-50 was found as tolerant for seed yield per plant with DSI 0.38 while hybrids RB-50×RH-749 and RB-50×Giriraj were exhibiting tolerant DSI values for siliqua per plant, 1000 seed weight, seed yield per plant and oil content. These parents and F₁s would serve as useful donors and hybrids respectively, in mustard breeding programmes for improving drought tolerance.

Key words: DSI, Indian mustard, Rainfed, Yield.

INTRODUCTION

Indian mustard (Brassica juncea L. Czern and Coss, AABB 2n = 36), a major oilseed crop of Indian subcontinent is a natural amphidiploid combining the genomes of two species, B. campestris (AA, 2n = 20) and B. nigra (BB, 2n = 16) (Nagaharu, 1935). In India, the production of rapeseed–mustard is around 8.43 million tonnes (2.47 million tonnes oil) from an area of 6.02 million hectare (Agricultural Statistics at a Glance, 2018). India ranks third in terms of acreage (19.29%) after Canada (24.55%) and China (20.58%), however, it accounts for only 11.27% of total production next to China and Canada which contributes nearly 22.08% and 21.77% of total production, respectively (www.dmr.res.in).

A drought is an extended period of months or years when region notes a deficiency in its water supply, whether surface or underground water because of consistent below average precipitation. It is a global phenomenon which causes significant damage due to stochastic nature in occurrence and severity (Karthika et al., 2017). Climatic variations such as drought have high level of impingement on the yield of rain-fed crops (Kumar and Upadhyay, 2019). Indian mustard is grown under diverse agro-ecological conditions such as timely sown/late sown, rain fed/irrigated, sole and/or mixed crop with cereals (wheat, barley, etc.) and, pulses (chick pea, lentil, etc.) during Rabi (Oct-April). Nearly 76.6% of the total rapeseed-mustard area is irrigated while, 30% is under rainfed conditions (DES, GOI). This crop is severely affected by seasonal droughts resulting in, acute yield losses particularly in the drought-prone areas of eastern and western India. Water stress causes heavy yield losses in Indian mustard (17-94%) (Sharma and Kumar, 1989). Low water availability during stem elongation, flowering and pod development causes reduction of pods per plant leading to, grain yield reduction (Gunasekara et al., 2006). Despite India being third largest producer of rapeseed-mustard in the world with large area under oilseed cultivation, production is not keeping pace with population (Singh et al., 2019). Limited efforts have been made towards improving drought tolerance of this crop. Hence, there is a need for, development of water use efficient genotypes urgently (Singh et al., 2014).
Analysing the effects of drought on yield and yield attributes of Indian mustard is very crucial for identifying drought-tolerant traits (Chauhan et al., 2007). Drought Susceptibility Index (DSI) is a useful tool for comparison of cultivar performances under drought and irrigated conditions and identifying tolerant genotypes for drought (Fischer and Maurer, 1978). DSI characterizes the separate effects of yield potential and drought susceptibility on yields under drought. In these terms, lower DSI is considered synonymous with higher drought resistance (Fischer and Maurer, 1978). In view of above facts, present study is aimed at investigating the effects of drought on yield attributing traits with, the objective of identifying Indian mustard genotypes and their hybrids which can withstand water stress with minimum loss in yield. We have made efforts in this direction by attempting crosses among reported high yielding tolerant genotypes for moisture stress tolerance, to identify and classify germplasms that includes parents and F<sub>1</sub> hybrids on the basis of DSI.

**MATERIALS AND METHODS**

**Plant material, experimental design and location**

Nine genotypes of Indian mustard, specifically four testers: RGN-73, Kranti, RH-749 and Giriraj and five lines: RH-406, RB-50, RH-119, RGN-298 and Vardan were crossed in line × tester fashion during Rabi 2016-17, to develop 20 F<sub>1</sub>s. The whole experimental material was evaluated at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during Rabi 2017-18 season in two separate trials viz., rainfed and irrigated. Rain-fed and irrigated trials were separated by at least 3 m raised bund to avoid interference. In each trial, a total of 29 treatments (genotypes) consisting of 9 parents (5 lines + 4 testers) and 20 crosses (F<sub>1</sub> hybrids) were grown in the Randomized Block Design with three replications. Within each replication, parents and crosses were randomly assigned and sown in two rows each (3 m length) having row to row and plant to plant distance of 45 cm and 10 cm, respectively. All recommended agronomic package of practices were followed to raise a healthy crop in both the trials except the irrigation in rainfed condition. Pre-sowing irrigation was given in both the conditions to ensure the germination. Furthermore, the irrigated trials received two irrigations at 40 and 80 days after sowing. The temperature regime during the cropping season was ranged between 24.9°C (maximum) to 10.8°C (minimum). The total precipitation during the above period was recorded to be 9.4 mm.

**Observations and evaluation**

Observations were recorded on five randomly selected plants of each genotype from each replication for plant height, number of primary branches per plant, number of secondary branches per plant, number of siliqua per plant, 1000-seed weight, seed yield per plant and oil content (%). The effect of drought was assessed as percentage reduction in mean performance of a trait under rain-fed conditions relative to, its performance under irrigated conditions. Accordingly, DSI for yield and its traits was calculated using, the following formula (Fischer and Maurer 1978): 

\[
\text{DSI} = \frac{(1 - Y_s/Y_i)}{(1 - X_s/X_i)}
\]

Where, 

\(Y_s = \text{mean seed yield of a genotype in a water stress environment, } Y_i = \text{mean seed yield of same genotype in a stress free environment (irrigated), } X_s = \text{mean seed yield of all genotypes in water stress environment and } X_i = \text{mean seed yield of all genotypes in stress free environment (irrigated).}\)

In the present study, DSI values for different traits were calculated and genotypes were classified into four different categories: Drought tolerant (DSI < 0.50), moderately drought tolerant (DSI 0.51 to 1.0), moderately drought susceptible (DSI 1.0 to 1.50) and highly drought susceptible (DSI > 1.50) (Yang et al, 2002).

**RESULTS AND DISCUSSION**

**Performance of genotypes**

Significant differences among genotypes for all studied traits were revealed by statistical analysis. Performance of all the agro-morphological characteristics, were reduced under rainfed condition when compared with irrigated conditions in both, parents and F<sub>1</sub> s (Tables 1-4). There is a substantial

| Entry | Plant height (cm) | Primary branches | Secondary branches |
|-------|------------------|------------------|-------------------|
|       | I* | R* | DSI* | I | R | DSI | I | R | DSI |
| RH-406 | 201.34 | 188.97 | 0.79 | 6.87 | 5.80 | 0.83 | 18.60 | 13.82 | 0.94 |
| RB-50 | 199.02 | 190.79 | 0.53 | 6.67 | 5.91 | 0.61 | 18.53 | 15.27 | 0.65 |
| RH-119 | 205.50 | 193.46 | 0.81 | 7.00 | 5.33 | 1.27 | 12.87 | 12.60 | 0.08 |
| RGN-298 | 222.60 | 207.48 | 0.76 | 6.33 | 5.67 | 0.56 | 14.73 | 13.53 | 0.55 |
| Vardan | 208.20 | 193.00 | 0.94 | 7.07 | 5.27 | 1.36 | 17.33 | 11.07 | 1.32 |
| RGN-73 | 181.13 | 163.99 | 1.21 | 5.94 | 3.78 | 1.94 | 16.00 | 10.27 | 1.31 |
| Kranti | 190.67 | 169.18 | 1.44 | 5.60 | 4.40 | 1.15 | 11.93 | 6.63 | 1.63 |
| RH-749 | 200.00 | 180.31 | 1.26 | 5.87 | 5.20 | 0.61 | 14.53 | 9.24 | 1.33 |
| Giriraj | 203.25 | 181.69 | 1.36 | 5.27 | 4.60 | 0.68 | 12.80 | 8.40 | 1.26 |

*Irregular, *Rainfed, *Drought Susceptibility Index.
reduction in number of siliqua per plant under rainfed conditions up to 50.29% in RH-406×Kranti except 1.71% increase in Vardan×RH-749. The reduction in seed yield per plant ranged between 7.76% in RB-50 to 32.28% in Vardan×Kranti. The reduction in grain yield can be ascribed to the relative more reduction in the growth parameters including stem, root and leaf growth, further decreasing number of siliqua per plant, siliqua length and 1000 seed weight. Quantitative as well as the quality of the produce (as there were observed reductions in the oil content of the seeds as well) were adversely affected by moisture stress (Singh et al., 2019).

The decrease in siliqua per plant and seed yield recorded in our study is in confirmation with the study of Mirzaei et al. (2013) who stated that moisture stress had significant effect on seed yield, number of seeds/pod, number of pod per plant, number of branches per plant, 1000-seed weight, plant height and oil content of cultivars (Hyola-401, Hyola-308, Zarfam and PF) in Iran. In the present study, reductions in yield of Kranti (29.84%), RGN-298 (27.6%), Vardan×Kranti (32.28%) and Vardan×Giriraj (29.56%) along with simultaneous reduction in test weight in Vardan×Kranti was 9.78%, 10.64%, 14.29% and 14.08% respectively, was observed. This could be due to water stress during flowering stage which, causes decreased seed yield due to reduction in seed weight (Pandey et al., 2001).

**Drought Susceptibility Index**

Mean and DSI for various characteristics is presented in Tables 1-4. Larger DSI values indicate greater drought conditions.
susceptibility (Winter et al., 1988). It can be observed in Table 1 that, among the nine selected genotypes, genotypes RB-50, RGN-298, RH-119, RH-406 and Vardan for plant height while, RGN-298, RB-50, RH-749, Giriraj and RH-406 for number of primary branches were showing moderate drought tolerance. Likewise, the genotype RH-119 for number of secondary branches, RH-406 for number of siliqua per plant and genotypes RH-406, RB-50 and RH-119 for 1000 seed weight were found drought tolerant with the DSI values being 0.08, 0.29, 0.26, 0.3, 0.33 and 0.54 respectively. Seed yield per plant is most important trait to be focussed in any hybridisation programme. Genotype RB-50 was found as drought tolerant. Genotypes RH-406, RH-749 and RH-119 were found as moderately drought tolerant for seed yield per plant. Oil content (%) is an important trait for mustard growers since it is the third leading source of vegetable oil in the world after soybean and palm oils. Considering DSI for oil content, RB-50 and RGN-298 were found tolerant to drought with DSI of 0.04 and 0.36 respectively.

Perusal of Tables 3 and 4 for DSI of F

et al., 2014) found that overall mean performance of Brassica progenies was comparatively higher in irrigated environment for days to 50% flowering, siliqua per plant, 1000 seed weight, seed yield per plant and protein content and genotypes 07-515 and 07-510 which showed lower

*Irrigated, *Rainfed, *Drought Susceptibility Index

Table 4: DSI based on mean performance of hybrids under irrigated and rainfed conditions.

| Entry                        | Siliqua/plant | 1000 seed weight (g) | Seed yield/plant (g) | Oil content (%) |
|------------------------------|---------------|----------------------|----------------------|----------------|
|                             | I*            | R*                   | DSI*                 | I             |
| RH-406×RGN-73                | 428.27        | 286.13               | 1.09                 | 4.53          |
| RH-406×Kranti                | 505.6         | 251.33               | 1.65                 | 3.73          |
| RH-406×RGN-74                | 319.2         | 324.67               | 0.06                 | 4.77          |
| RH- 406×Giriraj              | 538.33        | 363.47               | 1.07                 | 4.63          |
| RH-119×RGN-73                | 415.4         | 267.4                | 1.17                 | 4.77          |
| RH-406×Kranti                | 358.27        | 282.87               | 0.69                 | 5.37          |
| RB-50×RGN-73                 | 507.2         | 430.33               | 0.5                  | 4.77          |
| RH-119×RH-74                 | 324.87        | 327.73               | 0.03                 | 4.67          |
| RH-119×RH-74                 | 423.93        | 296                  | 0.99                 | 5              |
| RH-119×Kranti                | 573.2         | 300.27               | 1.56                 | 4.17          |
| RH-119×RH-406                | 470.73        | 384.67               | 0.6                  | 4.27          |
| RH-119×Giriraj               | 468.47        | 308.07               | 1.12                 | 4.9            |
| RH-119×Kranti                | 343.07        | 288.6                | 0.52                 | 4.97          |
| RGN-298×RGN-73               | 424.33        | 311.27               | 0.87                 | 4.63          |
| RGN-298×Kranti               | 641.67        | 437.27               | 1.04                 | 4.7            |
| RGN-298×Kranti               | 516.2         | 382                  | 0.85                 | 4.97          |
| RGN-298×Giriraj              | 475.47        | 291.47               | 1.27                 | 3.63          |
| Vardan×RGN-73                | 539           | 283                  | 1.56                 | 4.2           |
| Vardan×Kranti                | 586.93        | 420.67               | 0.93                 | 4.17          |
| Vardan×Giriraj               | 553.73        | 301.2                | 1.5                  | 5.07          |

* IRR='Irrigated', R='Rainfed', DSI='Drought Susceptibility Index'
Table 5: Classification of hybrids on the basis of drought susceptibility index (DSI) for seed yield per plant.

| Entry               | DSI* for Seed yield/plant | DSI range | Reaction          |
|---------------------|---------------------------|-----------|-------------------|
| RB-50×Kranti        | 0.4                       | <0.5      | Drought tolerant  |
| RB-50×RH-749        | 0.43                      |          |                   |
| RB-50×Giriraj       | 0.46                      |          |                   |
| RH-406×RH-749       | 0.59                      | >0.5-1    | Moderately tolerant|
| RH-119×Kranti       | 0.67                      |          | Drought tolerant  |
| RH-119×Giriraj      | 0.78                      |          |                   |
| RH-406×Giriraj      | 0.81                      |          |                   |
| RGN-298×RGN-73      | 0.83                      |          |                   |
| RH-406×RGN-73       | 0.9                       |          |                   |
| RH-298×RGN-73       | 0.98                      |          |                   |
| RH-119×RH-749       | 1.02                      |          |                   |
| RH-406×Kranti       | 1.08                      | 1-1.5     | Moderately tolerant|
| RGN-298×RH-749      | 1.1                       |          | Drought susceptible|
| RGN-298×Kranti      | 1.11                      |          |                   |
| Varadan×RH-749      | 1.17                      |          |                   |
| RB-50×RGN-73        | 1.39                      |          |                   |
| RH-119×RGN-73       | 1.4                       |          |                   |
| Vardan×RGN-73       | 1.41                      |          |                   |
| Vardan×Giriraj      | 1.48                      |          |                   |
| Vardan×Kranti       | 1.61                      | >1.5      | Drought susceptible|

#Drought Susceptibility Index.

DSI values (< or ~0.00), were rated as drought tolerant. Similarly, Chauhan et al., (2007) reported top six drought tolerant genotypes for seed yield at either or both locations (Bharatpur and Jobner) as JMMWR-941, RC 1446, PSR 20, RH-819, Varuna and RC-53, as indicated by their relatively low DSI. Singh and Choudhary (2003) used DSI values and seed yield under drought conditions as a selection criterion for drought tolerance in Indian mustard. Similarly, Sodani et al. (2017) in a study also reported RH-0749 and RH-0406 was better under irrigated condition while RB-50 and RGN-48 maintain higher seed yield and oil quantity under drought situation due to lesser reduction in yield attributes and tolerance mechanism which was in agreement with our study.

Drought is considered as a major factor of yield penalty for all important agricultural crops. Water stress during and after the flowering stage has a more adverse effect on seed yield than during other stages of plant development (Champolivier and Merrien, 1996). Generally, abiotic stresses including drought are controlled by multiple genes with complex underpinning mechanisms and are of great importance in selecting desirable parents for executing effective breeding program to evolve efficient varieties for stress condition (Lamaoui et al., 2018). Genotypes of Brassica species with drought-tolerance traits are known to produce the highest seed yield under drought conditions (Singh et al. 1988 and Kumawat et al. 1997). Table 5 classifies hybrids on the basis of drought susceptibility index for seed yield per plant (DSI). Crosses RB-50×Kranti, RB-50×RH-749 and RB-50×Giriraj were found drought tolerant with DSI 0.4, 0.43 and 0.46 respectively.

CONCLUSION

On the basis of mean performance and DSI values, crosses RH-406×RH-749, RB-50×RH-749 and RB-50×Giriraj were found drought tolerant to moderately drought tolerant for all the characters studied. Likewise, parents RB-50 and RH-406 and crosses RH-406×RH-749, RB-50×RH-749, RB-50×Giriraj, RH-119×Kranti and RH-119×RH-749 were showing <15% yield reduction in rainfall conditions. Hybrids RB-50×RH-749 and RB-50×Giriraj were found tolerant for silique per plant, 1000 seed weight, seed yield per plant and oil content with DSI<0.5. In general, the reduction in most of the characteristics under rain-fed conditions could be attributed to decreased translocation of assimilates and growth substances, impairing nitrogen metabolism, loss of turgidity and consequently reduced sink size (Kumawat et al. 1997). Donors with multi-characteristics for drought tolerance identified in the present study should therefore be utilized in breeding programmes.

ACKNOWLEDGEMENT

Authors are grateful to Banaras Hindu University, Varanasi, India for providing necessary support and ICAR-DRMR for sharing germplasm.

REFERENCES

Alipour A. and Zahedi. H. (2016). Difference in drought resistance among three Brassica species at different growing stages and application of zeolite. Indian Journal of Agricultural Research. 50(2): 193-196. doi: 10.18805/iare.v50iOF.9359.

Champolivier, L. and Merrien, A. (1996). Effects of water stress applied at different growth stages to Brassica napus L. var. oilefera on yield, yield components and seed quality. European Journal of Agronomy. 5(3-4): 153-160. doi: 10.1016/S1161-0301(96)00204-7.

Chauhan, J.S., Tyagi, M.K., Kumar, A., Naishaat, N.I., Singh, M., Singh, N.B., Jakhar, M.L. and Welham, S.J. (2007). Drought effects on yield and its components in Indian mustard (Brassica juncea L.). Plant Breeding, 126: 399-402. doi:10.1111/j.1439-0523.2007.01394.x.

Fischer, R.A. and Maurer, R. (1978). Drought resistance in spring wheat cultivars: I. Grain yields responses. Australian Journal of Agricultural Research. 29(4): 897-907. doi: 10.1071/AR9780897.

Gunasekara, C.P., Martin, L.D., French, R.J., Siddique, K. and Walton, M.G. (2006). Genotype by environment interactions of Indian mustard (Brassica juncea L.) and canola (Brassica napus L.) in Mediterranean type environments: crop growth and seed yield. European Journal of Agronomy. 25: 1-12.

Karthika, M., Krishnaveni and Thirunavukkarasu, V. (2017). Forecasting of meteorological drought using ARIMA model. Indian Journal of Agricultural Research. 51(2): 103-111. doi: 0.18805/iare.v51iOF.7631
Kumar, S. and Upadhyay, S.K. (2019). Impact of climate change on agricultural productivity and food security in India: A State level analysis. Indian Journal of Agricultural Research. 53(2): 133-142. doi: 10.18805/IJARe.A-5134.

Kumawat, B.L., Sharma, D.D. and Jat, S.C. (1997). Effect of brassinosteroid on yield and yield attributing characteristics under water deficit stress condition in mustard (Brassica juncea L.). Annals of Biology. 13(1): 91-93.

Lamaoui, M., Jemo, M., Datla, R. and Bekkaoui F. (2018). Heat and Drought Stresses in Crops and Approaches for Their Mitigation. Frontiers in Chemistry. 6. doi: 10.3389/fchem.2018.00026.

Mirzaei, A., Naseri, R., Moghadam, A. and Jahromi, M.E. (2013). The effects of drought stress on seed yield and some agronomic traits of canola cultivars at different growth stages. Bulletin of Environment, Pharmacology and Life Sciences. 2(10): 115-121.

Nagaharu, U. (1935). Genome Analysis in Brassica with Special Reference to the Experimental Formation of B. Napus and Peculiar Mode of Fertilization. Japanese Journal of Botany. 7: 389-452.

Pandey, P.K., Maranville, J.W. and Admou A. (2001). Tropical wheat response to irrigation and nitrogen in a Sahelian environment - Grain yield, yield components and water use efficiency. European Journal of Agronomy. 15: 93-105.

Pocket Book of Agricultural statistics (2017). Government of India Ministry of Agriculture and Farmers Welfare Department of Agriculture, Cooperation and Farmers Welfare Directorate of Agriculture, Cooperation and Farmers Welfare Directorate of Economics and Statistics, New Delhi. Accessed from http://agricoop.nic.in/sites/default/files/pocketbook_0.pdf on 1 March 2019.

Singh, J., Varma, S.K., Bhatia, J.N. and Raj L. (2019). Effect of different soil moisture regimes and salinity level on growth and yield in mustard. Indian Journal of Agricultural Research. 53(4): 488-491. doi: 10.18805/IJARe.A-5124.

Singh, M., Rathore, S.S. and Raja, P. (2014). Physiological and Stress Studies of Different Rapeseed-Mustard Genotypes Under Terminal Heat Stress. International Journal of Genetic Engineering and Biotechnology. 5(2): 133-142.

Singh, R.P., Singh, D.P. and Singh, P. (1988). Variation for plant water relations and yield structure in Brassica juncea L. under drought conditions. Narendra Deva Journal of Agricultural Research. 3: 91-98.

Singh, S.P. and Choudhary, A.K. (2003). Selection criteria for drought tolerance in Indian mustard [Brassica juncea (L.) Czern and Coss]. Indian Journal of Genetics and Plant Breeding. 63(3): 263-264.

Singh, V.V., Garg, P., Meena, H.S. and Meena, M.L. (2018). Drought stress response of Indian mustard (Brassica juncea L.) genotypes. International Journal of Current Microbiology and Applied Sciences. 7(3): 2519-2526. doi: 10.20546/ijcmas.2018.703.291.

Singh, V.V., Ram, B., Singh, M., Meena, M.L. and Chauhan, J.S. (2014). Generation mean analysis of water stress tolerance parameters in Indian mustard [Brassica juncea(l.) Czern and coss] crosses. SABRAO Journal of Breeding and Genetics. 46(1): 76-80.

Sodani, R., Seema, Singhal, R.K., Gupta, S., Gupta, N., Chauhan, K.S. and Chauhan, J. (2017). Performance of Yield and Yield Attributes of Ten Indian Mustard (Brassica juncea L.) Genotypes under Drought Stress. International Journal of Pure and Applied Bioscience. 5(3): 467-476. doi: 10.1872/2320-7051.4018.

Winter, S.R., Musick, J.T. and Porter, K.B. (1988). Evaluation of screening techniques for breeding drought resistance winter wheat. Crop Science. 28(3): 512-516. doi: 10.2135/cropsci1988.0011183X002800030018x.

Yang, J., Sears, R.G., Gill, B.S. and Paulsen, G.M. (2002). Genotypic differences in utilization of assimilate sources during maturation of wheat under chronic heat and heat shock stresses. Euphytica. 125: 179-188. 2002.