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CORRELATION BETWEEN LEAF TRAITS AND MOISTURE AVAILIBILITY IN INDIAN MUSTARD (*Brassica juncea* L.)

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ABSTRACT

Drought stress affects plant growth in several ways including changes in leaf morphology and physiology. Field experiments were conducted in 2009-2011 at the Department of Plant Breeding and Genetics, PAU, Ludhiana (India) in split-plot design with three replications to analyze the effect of water stress and varying moisture regimes on leaf traits in identified Indian mustard (*Brassica juncea* L.) genotypes. Moisture stress adversely affected leaf traits while irrigation modules significantly improved leaf characteristics. Specific leaf weight (SLW) was in-significantly affected by irrigation regimes within the genotypes. Specific leaf area (SLA) and Leaf area ratio (LAR) were greatly influenced by irrigation and their interactions were significant. Water stress was intolerable for leaf area and associated traits like length, perimeter, ratio, SLW, SLA, LAR, leaf weight ratio and leaf shoot ratio recording reduction greater than 10%, except for leaf width. Genotype PLM-2 under moisture stress gave higher seed yield of 2210 kg ha^{-1} and had low drought susceptible index (DSI 1= 0.048) and high drought tolerant index (DTI 1 = 1.164) while genotype MLM-19 had higher DSI 1 of 2.72; low DTI 1 of 0.854 with least seed yield of 1712 kg ha^{-1}.

Key words: Drought susceptible index, drought tolerance index, leaf area, mustard, specific leaf weight, seed yield

INTRODUCTION

The oleiferous *Brassica* species, commonly called rapeseed-mustard, are one of the economically important agricultural commodities grown in more than 50 countries in Asia, Europe, America and Australia (Singh *et al.*, 2014). India is one of the largest rapeseed-mustard growing countries in the world occupying 1st position in area (20.2%) and 2nd in production (10.7%) after China. A large number of high yielding area-specific varieties have been developed but in spite these varieties having yield potential of 2.0 to 2.5 t ha^{-1}, the national average is around 1.0 t ha^{-1}. Moreover, the yield levels are not sustainable owing to the factors like growing the crop in marginal lands either rainfed or with limited irrigation facility, non-availability of tolerant varieties for biotic and abiotic stresses, different sowing conditions, etc. Indian mustard (*B. juncea*) is suitable for both irrigated and rainfed areas (Shekhawat *et al.*, 2012).

Water stress is one of the major causes for crop loss so reducing the average yields by 50% or more. Drought is characterized by decrease in precipitation along with high evapo-transpirational demand by crop (Mishra and Chirkauer, 2010). Inadequate irrigation limits plant growth and productivity in majority of agricultural fields throughout the world (Abedi and Pakniyat, 2010).

Water scarcity in arid and semi-arid regions adversely affects plant growth and crop productivity (Azadeh *et al.*, 2014) due to the closure of stomata and reduction in leaf area (Kumudini, 2010). Severe water stress may arrest photosynthesis causing disturbance in plant metabolism and finally leading to plant death. Water deficit being multifaceted stress causes multiple biochemical and physiological changes in plants thereby affects plant growth and development (Boutraa, 2010). The plant responses to drought stress differ significantly at various organizational levels and greatly depend on intensity and duration of stress, plant species and plant growth stage (Jaleel *et al.*, 2008). It is imperative to understand plant response to drought stress and induce plant stress tolerance through various manipulations (Zhao *et al.*, 2008). Decrease in photosynthetically active leaf area leads to reduction in growth of canola cultivars under stimulated water stress conditions as reported by Lawlor (2002). Drought/ water stress is a major factor which limits area under cultivation and yield of crops (Athar and Ashraf, 2005). Drought stress restricts transpirational rates and impairs active transport and membrane permeability and hence reduces the nutrient uptake by roots and transportation from root to shoot (Yuncai and Schmidhalter, 2005). Models based on climatic changes predict the further reduction in crop productivity in response to increasing water scarcity in many regions of the world (Kheradmand *et al.*, 2014).

Oilseed Brassicas are most sensitive to drought and have very low water use efficiency. Brassicas are mostly grown on light textured soils using the water conserved from monsoon rains, so inevitably suffers from moisture stress during reproductive growth when stored water becomes depleted. Due to low rainfall and increase in demand for other activities irrigation water has become scarce. In the present scenario existing water resources are fully exploited in Punjab and with the introduction of new high yielding varieties the present investigation was required. The present study was aimed to assess the variability in leaf characteristics in response to moisture stress and irrigation modules which contributed immensely to yield variations.

MATERIALS AND METHODS

Field experiments were carried out in Oilseeds Farms at PAU, Ludhiana (India) situated at 30^{o}54'N latitude, 75^{o}48'E longitude and 247 m (amsl) during two consecutive years (2009-10 and 2010-11). The soil at the site was loamy sand with pH ~7.1, low in organic carbon (0.3%) and available P (24 kg ha^{-1}) and medium in available K (210 kg ha^{-1}). Flowering and pod filling are the critical stages affected by moisture stress. Package of practices (2009-2010) recommends two irrigation at one month's interval and 3rd need-based irrigation for Indian mustard. Therefore, three-irrigation schedule was designed to assess the impact of irrigation during crop growth. Water equivalence under moisture stress was 58.9 mm, with one-irrigation 118.9 mm and two irrigations 178.9 mm during 1st year; and 73.7, 133.7 and 193.7 mm, respectively, during 2nd year of study. Experiments were laid down in split-plot design with irrigations in main plots and genotypes (K-9-1-8, K-109-113, MLM-19, NLM-3, NLM-80, NPJ-79, PLM-2, PLM-4, QM-7-196, QM-7-335, RLC-1 and Varuna) in sub-plots. Irrigation regimes comprised of only pre-sowing irrigation designated as moisture stress (I_0), one irrigation at 35DAS (I_1, restricted moisture) and two irrigations at 35 and 65 DAS (I_2, normal moisture). Each treatment was replicated 3 times. Leaf characteristics like leaf area, length, width, perimeter leaf ratio were measured by Laser Leaf Area meter [CI-203] at 90 DAS. The 3rd, 4th and 5th physiologically fully opened leaves on main shoot were designated as representative leaves and used for computing leaf area and other associated leaf traits. Data values computed from representative leaves were multiplied with total number of leaves. This gave leaf area, length, width, perimeter and ratio on per plant basis. Based on leaf area and dry matter accumulation, following parameters were computed as per the formula given by Singh *et al*. (2007):

Specific leaf weight (SLW) (mg cm^{-2}) = Dry weight of leaves (mg)/leaf area (cm^2)

Specific leaf area (SLA) ($cm^2 g^{-1}$) = Leaf area (cm^2)/ dry weight of leaves (g)
Leaf area ratio (LAR) ($cm^2 g^{-1}$) = Leaf area (cm^2)/ dry weight of shoot (stem + leaves) (g)
Leaf weight ratio (LWR) = Leaf dry weight (g)/ total plant dry weight (g)
Leaf shoot ratio (LSR) = Leaf dry weight (g)/ shoot dry weight (g)

Drought susceptibility and tolerance indices were calculated as per the formula of Fischer and Maurer (1978) and Fernandez (1992), respectively. The DSI 1 and DTI 1 was computed between seed yield (SY) at moisture stress (I_0) and restricted moisture (I_1), DSI 2 and DTI 2 between SY at moisture stress (I_0) and normal moisture (I_2) while DSI 3 and DTI 3 between restricted moisture (I_1) and normal moisture (I_2). CPCS1 software (developed at PAU) was used to analyze the critical difference for variation in all the traits within genotypes, with irrigation schedules as well as the genotypes x irrigation interactions at 5% level of significance. The multiple correlations were worked out between leaf traits and yield indices computed with the CS11 software.

RESULTS AND DISCUSSION

Leaf characteristics in representative leaves (R_L)

The 3rd, 4th and 5th physiologically fully opened leaves on main shoot were selected for physiological traits and designated as representative leaves. Genotypes differed significantly for all the leaf characteristics studied, except leaf width. Irrigation had a profound effect on leaf area and length only. The interactions between G x I were significant only for LA and length (Table 1).

All the genotypes registered lower LA under moisture stress (I_0). Genotype MLM-19 registered lowest (62.5 cm^2) and Varuna possessed highest LA (76.7 cm^2). Irrigation modules improved LA to variable extent but registered a positive response in all the genotypes. LA varied from 68.2 (NLM-80) to 93.7 cm^2 (NPJ-79) under restricted moisture (I_1) and from 76.2 (NLM-80)

Table 1: Leaf area and related traits in representative leaves (90 DAS) as influenced by moisture regimes

Genotypes	Leaf traits in representative leaves (excised from 3rd and 4th leaf from main shoot)																			
	Leaf area				Leaf length				Leaf width				Leaf perimeter				Leaf ratio			
	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean
K-9-108	70.6	90.1	92.6	84.4	7.9	11.0	11.4	10.1	8.9	9.3	9.3	9.2	25.0	30.1	30.7	28.6	1.00	1.10	1.30	1.13
K-109-113	72.9	88.2	93.6	84.9	9.5	12.1	13.2	11.6	9.2	9.6	9.6	9.5	26.2	30.0	32.1	29.4	1.00	1.10	1.20	1.10
MLM-19	62.5	72.1	99.0	77.9	8.4	9.0	12.3	9.9	9.1	9.3	10.0	9.6	20.0	23.5	32.9	25.5	1.10	1.20	1.20	1.17
NLM-3	65.8	93.3	94.8	84.6	9.2	11.4	12.0	10.9	9.0	9.0	9.4	9.1	24.5	28.3	31.3	28.0	1.00	1.10	1.30	1.13
NLM-80	67.2	68.2	76.2	70.5	8.5	9.9	10.0	9.5	8.8	8.8	8.9	8.8	23.0	25.3	25.6	24.6	0.90	1.00	1.10	1.00
NPJ-79	66.3	93.7	97.0	85.7	8.4	8.7	10.6	9.2	8.6	8.8	8.9	8.8	21.3	22.9	28.8	24.3	0.90	0.90	1.20	1.00
PLM-2	69.8	92.4	102.9	88.4	8.5	10.9	11.2	10.2	9.0	10.0	10.4	9.9	25.0	28.3	30.6	28.0	1.00	1.10	1.10	1.07
PLM-4	72.8	76.3	101.9	83.7	7.9	10.0	12.4	10.1	9.0	9.0	9.1	9.5	21.1	26.2	27.2	24.8	1.10	1.10	1.10	1.10
QM-7-196	73.9	79.9	123.5	92.4	9.5	10.1	12.4	10.7	8.8	9.0	11.0	9.7	24.8	29.8	33.9	29.5	1.10	1.10	1.30	1.17
QM-7-335	72.9	74.0	87.0	78.0	10.1	10.2	10.9	10.4	8.7	9.0	9.8	9.3	24.3	25.4	28.0	25.9	1.10	1.10	1.10	1.10
RLC-1	64.6	83.4	90.3	79.4	8.1	11.3	11.4	10.3	8.4	10.0	10.5	9.8	22.2	31.7	32.9	28.9	1.00	1.10	1.20	1.10
Varuna	76.7	79.7	85.7	80.7	9.9	10.0	11.3	10.4	8.8	8.9	9.9	9.2	26.9	27.1	29.7	27.9	1.10	1.10	1.30	1.17
Mean	69.7	82.6	95.4		8.8	10.6	11.4		8.9	9.4	9.8		23.7	27.4	30.3		1.03	1.08	1.20	
$CD_{0.05}$ Genotypes (G)	7.03				3.28				ns				4.70				0.13			
$CD_{0.05}$ Irrigation (I)	3.87				1.39				ns				ns				ns			
$CD_{0.05}$ G x I	13.42				4.84				ns				ns				ns			

I_0: moisture stress I_1: restricted moisture I_2 : normal moisture to 123.5 cm^2 (QM-7-196) under normal moisture regime. Moisture stress reduced LA by 26.9% over normal and 15.5% over restricted moisture. The results are supported by Sheteawi and Tawfik (2007) and Thalooth *et al* (2006) who worked on mungbean genotypes. Variation in leaf length was recorded in genotypes with irrigation schedules. Cultivar QM-7-335 had comparable length in all the three irrigation modules. PLM-4 and K-9-108 possessed leaf length of 7.9 cm under I_0 while under I_1, 8.7 (NPJ-79) and 12.1 (K-109-113) was the range of leaf length. Under normal (I_2) irrigations 11.4 cm leaf length was registered in K-9-108 and RLC-1. However, moisture deficit reduced length by 22.8% over normal moisture (I_2) and 16.9% over restricted moisture (I_1). Insignificant differences were observed within genotypes, with irrigation schedules and also for their interactions. However, irrigation improved leaf width in all the cultivars marginally. Overall, PLM-2 possessed 9.9 cm leaf width while NLM-80 and NPJ-79 had 8.8 cm width. Decline in leaf width was 9.1 and 5.3% over normal and restricted moisture regimes. Genotypes differed significantly only for leaf perimeter and leaf ratio. Overall, the highest (29.5 cm) and lowest (24.3 cm) perimeter were seen in QM-7-196 and NPJ-79, respectively. Perimeter was reduced by 21.7% under moisture stress over normal moisture (I_2) and 13.5% over restricted moisture regime (I_1). Genotypes MLM-19, QM-7-335 and Varuna had highest but comparable ratio of 1.17 whereas cultivars NLM-80 and NPJ-79 had lowest ratio of 1.0. Moisture stress reduced leaf ratio by 14.1% over normal moisture and 4.6% over restricted moisture. Among the various plant parts, leaf growth is generally more sensitive to environmental stresses. One of the adaptive mechanisms possessed by plants in response to water stress is reduced leaf growth or senescence and abscission of older leaves (Athar and Ashraf, 2005). A decline in leaf area is one of the adaptive mechanisms of minimizing water loss from leaf surface (Vurayai *et al.,* 2011). Therefore, leaf area reduction in response to drought is an adaptive mechanism possessed by plants related with lowering or minimizing water loss from leaf surface.

Leaf characteristics on per plant basis

Leaf area and related traits varied significantly within cultivars, and irrigation had a profound effect on these traits, except leaf ratio. However, the interactive effects of G x I were significant for all the studied traits (Table 2). Leaf area varied from 658.2 (K-9-108) to 1429.7 cm^2 (PLM-2), 1087.7 (QM-7-335) to 2132.8 cm^2 (QM-7-196) and 1216 (QM-7-335) to 3256.4 cm^2 (QM-7-196) under stress (I_0), restricted moisture (I_1) and normal irrigation module (I_2), respectively. Overall, genotype QM-7-196 showed maximum LA (2130.4 cm^2) followed by NPJ-79(2045.8 cm^2 $plant^{-1}$). Moisture stress reduced LA by 55.6% over normal and 33.6% over restricted moisture. Decline in leaf area has been reported under saline and drought conditions in *B. juncea* (Siddique *et al.,* 2008) and in *B. napus* under water stress (Naderkheraji *et al.,* 2008). Stomatal closure led to decline in LA expansion ultimately leading to the senescence and/or abscission. Moisture stress reduced leaf area in soybean (Amira and Qados, 2014) and groundnut (Madhusudan and Sudhakar, 2014). Our results are corroborated with the observations of Tesfamariam *et al.* (2010) and Mansouri and Moosavi (2013) who found decrease in leaf length and leaf area in *B. napus* genotypes under drought stress condition. Moisture stress reduced leaf length (LL) by 51.4 and 24.0% over normal and restricted moisture regimes. Irrigation improved leaf length considerably from 144.6 cm (I_0) to 190.3 cm (I_1) and 298.1 cm (I_2). Variation in mean LL was from 179.9 (QM-7-335) to 266.9 cm (RLC-1). Leaf width improved by 35.9% with one irrigation (I_1) and by 88.1% with two irrigations (I_2) over moisture stress. Significant increase in leaf width (LW) from 129.5 to 176.1 cm and 243.6 cm was observed with increase in moisture regimes while genotypic LW varied from 131.8 (K-9-108) to 230.4 cm (NPJ-79). Leaf perimeter (LP) and LW was highest in QM-7-196 and lowest in PLM-4 under restricted moisture (I_1) (Table 2). Moisture stress reduced LP by 55.2% over normal and 31.7% under restricted moisture. Moisture stress reduced mean leaf ratio (LR) by 55.7% over normal moisture (I_2) and 26.8% over restricted moisture level. Genotypic mean of LR indicated maximum LR in QM-7-335 and NPJ-79 and comparable LR in PLM-4 and NLM-3. Reduction in plant size, leaf area and leaf area index in response to water stress are the main characteristics for moderating plant water use under water limited environment; therefore leaf growth parameters play vital role in study of drought tolerance mechanisms in crop plants. Leaf area is determined by phenology, stem morphology, rate of leaf emergence and potential leaf size. Any effect of moisture deficit on any of these traits affects leaf area and thereby disturbs photosynthetic mechanism. All leaf traits like leaf length, width and perimeter are related with leaf size, specifically, leaf area. Hence, one or the other leaf traits contribute significantly towards seed yield. Reduced leaf area in response to water stress has been reported in crop cultivars and used as selection criteria for drought stress tolerance under water limited environment by many researchers. Under different moisture conditions, K-109-113 possessed lowest specific leaf weight (SLW) and highest specific leaf area (SLA). Genotype QM-7-335 recorded highest SLW under I_0 (2.5 mg cm^{-2}) and I_1 (3.3 mg cm^{-2}) and lowest SLA (407.5 cm^2 g^{-1}) with two irrigations (I_2). SLW was highest under I_2 in NLM-3 (4.0 mg cm^{-2}) under normal moisture. Specific leaf weight was reduced by 33.3 and 21.7% while SLA by 34.9 and 18.7% over two irrigations (I_2) and restricted irrigation, respectively. NLM-3 possessed highest SLW (4.0 mg cm^{-2}) and lowest SLA (248.4 cm^2 g^{-1}) under normal and stressed condition. SLW was reduced in *Phaseolus vulgaris* (Ghanbari *et al.*, 2013) at all stages of crop growth. Cultivar QM-7-196 had highest LAR under restricted moisture (179.9) and normal moisture (226.9). Least LAR was noticed in NLM-80 (103.5) under restricted moisture and QM-7-335 (110.6) under normal moisture. Moisture stress reduced LAR by 29.8 and 17.8% under normal and restricted moisture regimes, respectively. Genotype NPJ-79 possessed highest LWR (0.26) and LAR (157.0) under moisture stress. Interestingly, genotype K-109-113 had least LWR under 3 moisture regimes. Under 2-irrigations/normal, LWR was highest in QM-7-196 (0.44). Moisture stress reduced LWR of cultivars by 26.7 and 18.5% when compared with normal and restricted moisture regimes, respectively. Water deficit reduced LWR by 26.7 and 18.5% while LSR by 40.3 and 17.3% under two irrigations (normal) and one irrigation (restricted) moisture regimes, respectively. Genotypes differed significantly for all the traits, except SLW. Specific leaf area and LAR were greatly influenced by irrigation and their interactions were significant too (Table 3).

Correlation

LA of representative leaves showed a positive correlation with perimeter but negative association with DSI 1, leaf perimeter (LP) and length (LL) under moisture stress. LP had a negative correlation with LWR, LSR and DSI 1 (Table 4). LA/plant was negatively correlated with DSI 2 and DTI 2. A negative correlation was observed between LAR and DSI 1 and DSI 2; and also between DSI 1 and DTI 1. With one irrigation given at 35 DAS (I_1), LL in representative leaves was positively correlated with leaf width (LW), leaf perimeter (LP), DTI 3 and yield. Highly negative correlation existed between SLW and SLA and SLW and LAR. LWR and LSR were positively correlated. DSI 3 showed negative correlation with seed yield while DTI 3 exhibited highly positive significant correlation with yield. Under two irrigations given at 35 and 65DAS highly positive significant association existed between LL and LP, LL and SLA, LW and LP, LP and LR and also for leaf area /plant. SLW showed positive correlation with LWR and LSR. SLA and LAR were negatively correlated while a significant positive correlation was observed between LWR and LSR. DTI 3 had a positive significant correlation with the seed yield (Table 5).

Conclusion: Moisture deficiency has a marked impact on leaf growth parameters like LA, LWR, LSR and seed yield of Indian mustard genotypes. A positive correlation existed between SY and LA, LL, LWR, LAR, SLA and SLW under irrigation schedules; however, differential variations existed in the magnitude of association. Drought resistance parameters revealed PLM-2 and NPJ-79 under moisture stress and restricted moisture, NPJ-79, PLM-2, PLM-4 and QM-7-335 under moisture stress (I_0) and normal irrigation schedule (I_2) while Varuna, K-9-108, NLM-3 under normal and restricted moisture as highly tolerant. Overall, PLM-2 showed better performance in terms of seed yield under the irrigation schedules and mean SY was 2238 kg ha^{-1}.

Table 2: Leaf area per plant and associated traits in mustard (90 DAS) as affected by moisture regimes

Genotypes	Leaf traits per plant																			
	Leaf area				Leaf length				Leaf width				Leaf perimeter				Leaf ratio			
	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean
K-9-108	658	1393	1561	1204	191.0	207.5	308.7	235.7	106.3	136.1	153.0	131.8	263.3	472.4	514	416.6	10.3	16.9	21.1	16.1
K-109-113	1014	1577	2171	1587	134.4	143.5	272.4	183.4	130.8	178.7	232.2	180.6	370.9	438.5	746.9	518.8	14.6	17.9	28.1	20.2
MLM-19	1213	1306	2145	1555	159.7	163.8	265.2	196.2	146.4	174.5	211.6	177.5	412.6	422.7	717.6	517.6	17.4	18.3	27.1	20.9
NLM-3	770	1245	2452	1489	97.8	157.6	310.8	188.7	116.5	138.4	242.8	165.9	255.8	446.9	814.5	505.7	10.2	16.0	32.8	19.7
NLM-80	756	1450	1967	1391	152.9	209.1	261.3	207.8	146.5	203.7	232.4	194.2	290.6	548.1	662.4	500.4	15.0	24.5	29.4	23.0
NPJ-79	1404	2002	2731	2046	157.0	239.3	371.9	256.1	173.9	211.5	305.8	230.4	450.6	613.1	994.3	686.0	15.9	23.9	41.9	27.2
PLM-2	1421	1516	2356	1764	117.0	165.8	287.0	189.9	149.4	161.9	251.2	187.5	421.2	432.9	782.9	545.7	12.3	16.6	29.2	19.4
PLM-4	977	1193	2199	1456	129.4	144.7	286.8	187.0	110.4	119.9	259.4	163.2	337.3	374.8	777.7	496.6	14.0	14.3	31.1	19.8
QM-7-196	1002	2133	3256	2130	135.1	270.1	343.5	249.6	125.8	253.2	305.5	228.2	345.3	802.2	935.3	694.3	16.1	30.2	35.6	27.3
QM-7-335	1019	1088	1216	1107	173.0	174.2	192.5	179.9	129.1	131.0	175.3	145.1	352.6	394.4	433.3	393.4	15.9	17.3	33.6	22.3
RLC-1	754	1488	3054	1765	182.5	218.0	400.1	266.9	93.1	171.1	377.5	213.9	251.9	514.3	1136.4	634.2	12.0	16.9	44.5	24.5
Varuna	1086	1802	2094	1661	105.8	190.4	276.5	190.9	125.3	189.0	220.6	178.3	388.9	604	729.1	574.0	15.4	21.0	31.2	22.5
Mean	1006	1516	2267		144.6	190.3	298.1		129.5	176.1	243.6		345.1	505.4	770.4		14.2	19.4	32.1	
$CD_{0.05}$ Genotypes (G)			4.92			11.64				19.61				10.22				5.10		
Irrigation (I)			3.05			4.50				8.19				5.05				ns		
G x I			10.56			15.60				28.36				17.47				9.98		

I_0: moisture stress; I_1: restricted moisture; I_2 : normal moisture

Table 3: Specific leaf weight (SLW, mg cm^{-2}), specific leaf area (SLA, cm^2 g^{-1}), leaf area ratio (LAR), and leaf weight ratio (LWR) and leaf shoot ratio (LSR) of mustard under different moisture regimes

Genotypes	Leaf traits per plant																			
	SLW				SLA				LAR				LWR				LSR			
	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean	I_0	I_1	I_2	Mean
K-9-108	1.7	2.1	2.6	2.1	387.2	480.2	578.1	481.8	121.9	140.6	160.1	140.9	0.21	0.26	0.27	0.25	0.32	0.46	0.50	0.43
K-109-113	1.5	1.6	1.8	1.6	542.9	630.8	675.7	616.5	125.5	155.9	185.5	155.6	0.18	0.19	0.24	0.20	0.30	0.30	0.42	0.34
MLM-19	1.7	2.0	2.3	2.0	429.0	502.5	577.6	503.0	99.8	167.5	173.3	146.9	0.20	0.25	0.27	0.24	0.30	0.43	0.50	0.41
NLM-3	1.6	2.8	4.0	2.8	248.4	355.7	613.0	405.7	108.5	146.5	168.0	141.0	0.23	0.34	0.35	0.31	0.38	0.70	0.78	0.62
NLM-80	1.8	2.3	2.6	2.2	377.9	437.0	557.5	457.5	98.3	103.5	164.7	122.2	0.19	0.24	0.25	0.23	0.29	0.38	0.42	0.36
NPJ-79	1.9	2.0	2.2	2.1	444.8	501.4	525.3	490.5	157.0	172.6	173.3	167.7	0.26	0.29	0.32	0.29	0.43	0.53	0.63	0.53
PLM-2	1.8	2.2	2.3	2.1	433.3	458.3	560.9	484.2	137.8	151.1	153.2	147.4	0.21	0.27	0.29	0.26	0.33	0.49	0.55	0.46
PLM-4	1.6	2.8	3.5	2.6	287.4	351.0	628.3	422.2	102.9	118.1	156.0	125.7	0.22	0.28	0.30	0.27	0.33	0.51	0.56	0.47
QM-7-196	1.5	1.8	2.7	2.0	371.1	546.9	651.3	523.1	145.2	179.9	226.9	131.5	0.23	0.33	0.44	0.33	0.38	0.64	0.71	0.58
QM-7-335	2.5	3.3	3.4	3.1	294.0	304.1	407.5	335.2	103.6	109.5	110.6	136.4	0.23	0.29	0.31	0.28	0.37	0.54	0.57	0.49
RLC-1	1.8	2.2	3.3	2.1	301.5	465.1	565.6	444.1	87.7	144.5	162.4	184.0	0.24	0.26	0.26	0.25	0.40	0.41	0.45	0.42
Varuna	1.9	2.2	2.9	2.3	350.5	462.0	523.6	445.4	118.1	121.1	170.0	107.9	0.19	0.28	0.30	0.26	0.30	0.51	0.58	0.46
Mean	1.8	2.3	2.7		372.3	457.9	572.0		117.2	142.6	167.0		0.22	0.27	0.30		0.34	0.49	0.56	
$CD_{0.05}$	Genotypes (G) = ns					27.50				5.56				0.75				0.15		
	Irrigation (I) = ns					13.43				1.62				ns				ns		
	G x I = ns					46.52				5.60				ns				ns		

I_0: moisture stress; I_1: restricted moisture; I_2: normal moisture

Table 4: Correlation coefficients of various leaf traits with yield under moisture stress (below diagonal) and restricted moisture (above diagonal)

Traits	Leaf traits under moisture stress (I_0)																					
	Representative leaves					Per plant										Drought susceptibility/tolerance indices						Seed yield
	LA	LL	LW	LP	LR	LA	LL	LW	LP	LR	SLW	SLA	LAR	LWR	LSR	DSI1	DTI1	DSI 2	DTI 2	DSI 3	DTI 3	yield
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1	0.41	0.33	0.36	-0.26	0.26	0.02	-0.09	-0.02	-0.20	-0.25	0.24	0.50	0.17	0.24	-0.50	0.19	-0.13	-0.28	-0.36	0.07	0.25
2	0.55	1	0.58[a]	0.84[b]	0.31	-0.24	-0.34	-0.33	-0.27	-0.42	-0.05	0.13	-0.78	-0.23	-0.17	-0.08	-0.10	0.17	-0.05	-0.25	0.36	0.39
3	0.14	0.06	1	0.59[a]	0.40	-0.14	-0.22	-0.19	-0.31	-0.44	-0.28	0.30	0.25	-0.40	-0.41	0.21	-0.35	0.07	-0.52	-0.33	0.58[a]	0.59[a]
4	0.69[a]	0.63[a]	0.18	1	0.33	0.09	0.09	-0.04	0.13	-0.13	-0.25	0.28	0.12	-0.06	-0.06	.011	-0.25	0.28	0.04	-0.37	0.48	0.54
5	0.45	0.38	0.23	0.10	1	-0.44	-0.46	-0.35	-0.36	-0.42	0.07	-0.03	0.02	-0.07	-0.03	0.41	0.02	0.48	-0.06	-.323	0.32	0.40
6	0.02	0.11	0.13	-0.15	0.06	1	0.73[b]	0.88[b]	0.90[b]	0.80[b]	-0.69[a]	0.65[a]	0.58[a]	0.15	0.12	-0.39	0.03	-0.27	-0.02	-0.10	-0.31	-0.17
7	-0.31	-0.39	-0.46	-0.38	-0.16	-0.28	1	0.74[b]	0.88[b]	0.81[b]	-0.35	0.28	0.35	0.35	0.23	-0.06	-0.16	-0.02	0.26	-0.14	0.08	0.13
8	-0.19	0.08	0.12	-0.20	-0.39	0.75[b]	-0.14	1	0.89[b]	0.93[b]	-0.67[b]	0.63	0.49	0.06	0.01	-0.11	-0.03	-0.20	0.05	-0.04	-0.21	-0.13
9	0.13	0.19	0.20	-0.11	0.11	0.96[b]	-0.23	0.78[b]	1	0.92[b]	-0.49	0.43	0.41	0.36	0.30	-0.22	0.00	-0.06	0.22	0.15	-0.15	-0.03
10	0.13	0.35	-0.01	-0.27	0.29	0.51	0.04	0.56	0.66[a]	1	-0.45	0.42	0.33	0.23	0.18	0.19	0.12	-0.23	0.20	0.06	-0.23	-0.20
11	0.09	0.35	-0.48	0.00	0.08	0.17	0.34	0.18	0.17	0.24	1	-0.97[b]	-0.66[b]	0.43	0.42	-0.02	0.06	0.02	0.12	0.20	0.16	0.01
12	0.01	-0.02	0.38	0.13	-.302	0.47	.078	0.56	.58[a]	0.33	-0.27	1	0.65a	-0.50	.471	-0.04	-0.06	0.10	-0.07	-0.13	-0.22	-0.84
13	0.29	0.14	0.06	0.27	-0.21	0.58[a]	-0.22	0.55	0.57	0.14	-0.17	0.52	1	0.15	0.17	-0.04	0.07	-0.09	-0.09	-0.23	0.08	0.19
14	-0.30	-0.18	-0.64[a]	-0.41	-0.14	0.13	0.23	0.02	-0.03	-0.11	0.24	-0.41	0.25	1	0.98[b]	-0.22	0.26	.071	0.15	-0.18	0.20	0.24
15	-0.25	-0.02	-0.65[a]	-0.25	-0.19	0.12	0.16	0.02	-0.04	-0.12	0.20	-0.32	0.31	0.96[b]	1	0.31	0.39	0.03	0.12	-0.18	0.13	0.19
16	-0.66[a]	-0.48	-0.09	-0.63[a]	0.08	-0.41	0.42	-0.34	-0.42	0.01	-0.18	-0.22	-0.75[b]	-0.07	-0.15	1	0.59[a]	0.65[a]	0.31	-0.08	0.46	0.37
17	0.32	0.28	8.61[a]	0.38	0.08	0.27	-0.44	0.41	0.31	-0.00	-.047	0.19	0.50	-0.25	-0.29	-0.59[a]	1	-0.29	-0.33	-0.06	-0.23	-0.13
18	-0.35	-0.18	-0.07	-0.05	0.15	-0.63[a]	0.14	-0.58[a]	-0.62[a]	-0.37	-0.19	-0.41	-0.61[a]	-0.16	-0.19	0.65[a]	-0.29	1	0.40	-0.64[a]	0.28	0.54
19	-0.01	0.12	-0.26	-0.15	0.10	-0.63[a]	0.32	-0.40	-.50	0.09	-0.04	-0.35	-0.30	0.19	0.21	0.31	0.33	0.40	1	0.17	-0.20	-0.23
20	0.21	-.10	0.10	-0.38	-0.01	0.13	0.06	0.20	0.20	0.41	.021	0.07	0.01	0.07	0.01	-0.08	-0.06	-0.64[a]	0.17	1	-0.26	-0.72
21	0.44	-0.44	-0.17	-0.20	-0.04	-0.33	0.24	-0.43	-0.54	-0.55	0 .38	-0.37	-0.33	0.26	0.22	0.46	-0.23	0.28	-0.20	-0.26	1	0.86[b]
22	0.18	0.17	-0.04	0.59[a]	-0.08	0.08	-0.25	-0.07	-0.09	-0.57	0.05	-0.08	0.43	0.18	0.25	-0.52	0.42	-0.08	-0.50	-0.57	0.40	1

I_0 = moisture stress; I_1 = restricted moisture; I_2 = normal moisture; DSI 1 and DTI 1 = Seed yield at I_0 and I_1; DSI 2 and DTI 2:=Seed yield at I_0 and I_2; DSI 3 and DTI 3 = Seed yield at I_1 and I_2; [a] and [b] refer to significant correlation coefficients at 5 at 1%, respectively. LA: leaf area, LL: leaf length, LW: leaf width, LP: leaf perimeter, LR: leaf ratio, SLW: specific leaf weight, SLA: specific leaf area, LWR: leaf weight ratio, and LSR: leaf shoot ratio

Table 5: Correlation coefficients of various leaf traits with yield under normal moisture regime

Traits	Leaf traits under normal moisture (I_2)																					
	Representative leaves					On per plant basis										Drought susceptibility/tolerance indices						Seed yield
	LA	LL	LW	LP	LR	LA	LL	LW	LP	LR	SLW	SLA	LAR	LWR	LSR	DSI1	DTI1	DSI2	DTI 2	DSI3	DTI3	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1	.																				
2	0.56	1																				
3	0.56	0.32	1																			
4	0.58[a]	0.62[a]	0.734[b]	1																		
5	0.26	0.31	0.225	0.60[a]	1																	
6	0.58[a]	0.23	0.466	0.53	0.30	1																
7	0.35	0.03	0.199	0.43	0.41	0.83[b]	1															
8	0.32	0.03	0.356	0.30	0.01	0.90[b]	0.80[b]	1														
9	0.37	0.13	0.321	0.42	0.19	0.94[b]	0.87[b]	0.96[b]	1													
10	0.11	-0.21	0.224	0.10	-0.04	0.65[b]	0.60[a]	0.85[b]	0.70[a]	1												
11	-0.03	-0.05	-0.210	-0.33	0.07	-0.24	-0.26	-0.22	-0.26	0.01	1											
12	0.49	0.72[b]	0.109	0.45	0.32	0.51	0.37	0.27	0.38	-0.19	-0.20	1										
13	0.61[a]	0.45	0.341	0.56	0.57	0.73[b]	0.52	0.41	0.53	0.08	-0.33	0.75[b]	1									
14	0.50	0.01	0.139	0.07	0.34	0.28	0.14	0.12	0.15	0.32	0.67[a]	-0.11	0.13	1								
15	0.52	0.11	0.144	0.18	0.45	0.32	0.18	0.11	0.18	0.25	0.64[a]	0.03	0.24	0.98[b]	1							
16	-0.17	0.09	0.076	0.20	-0.08	0.11	0.15	0.19	0.17	0.04	-0.08	0.14	0.01	-0.42	-0.39	1						
17	0.23	0.02	-0.153	-0.15	0.12	-0.36	-0.48	-0.65[a]	-0.56	-0.63[a]	0.25	0.02	0.05	0.39	0.43	-0.59[a]	1					
18	-0.27	0.07	0.082	0.32	0.54	-0.02	0.17	-0.08	0.01	-0.16	0.20	0.09	0.05	-0.13	-0.04	0.65[a]	-0.29	1				
19	-0.12	0.14	-0.244	0.01	0.41	-0.00	0.13	0.02	0.00	0.18	0.30	0.07	0.17	0.11	0.11	0.31	-0.33	0.40	1			
20	0.08	0.09	-0.403	-0.53	-0.63[a]	-0.08	-0.22	0.08	-0.06	0.10	0.07	0.10	-0.08	-0.07	-0.16	-0.08	-0.06	-0.64[a]	0.17	1		
21	0.22	-0.02	0.433	0.31	-0.13	0.26	0.29	0.30	0.22	0.10	0.08	0.13	-0.07	-0.02	-0.00	0.46	-0.23	0.28	-0.20	0.26	1	
22	0.26	0.05	0.094	-0.12	-0.56	0.16	0.09	0.31	0.14	0.14	0.16	0.19	-0.13	-0.05	-0.11	0.36	-0.24	-0.18	-0.06	0.48	0.72[b]	1

I_0 = moisture stress; I_1 = restricted moisture; I_2 = normal moisture; DSI 1 and DTI 1= seed yield at I_0 and I_1; DSI 2 and DTI 2 = seed yield at I_0 and I_2; DSI 3 and DTI 3 = Seed yield at I_1 and I_2; [a] and [b] refer to significant correlation coefficients at 5 at 1%, respectively. LA: leaf area, LL: leaf length, LW: leaf width, LP: leaf perimeter, LR: leaf ratio, SLW: specific leaf weight, SLA: specific leaf area, LWR: leaf weight ratio, LSR: leaf shoot ratio normal and restricted moisture as highly tolerant. Overall, PLM-2 showed better performance in terms of seed yield under the irrigation schedules and mean SY was 2238 kg ha^{-1}.

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