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Assessment of Multiple Tolerance Indices for Moisture Stress in Fenugreek (*Trigonella foenum-graecum* L.)

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ABSTRACT

Background: Drought and moisture stress is the most limiting factor affecting growth and productivity of crop plants. The genotypes may differ in their ability to withstand drought or moisture stress. Therefore, the research was carried out to identify suitable genotypes in moisture stress environments.

Methods: The forty eight genotypes of fenugreek were planted in randomized block design with three replications under two environmental conditions namely, (i) normal irrigation (E_1) and (ii) staggered irrigation (E_2) during *rabi* 2016-2017. Eight stress tolerance indices *viz.,* stress tolerance (TOL), stress susceptibility index (SSI), stress tolerance index (STI), mean production (MP), geometric mean production (GMP), yield index (YI), stress susceptibility percentage index (SSPI) and modified stress tolerance index (MSTI) were calculated based on seed yield under moisture stress (Ys) and non-stress condition (Yp). The correlation coefficient and mean rank of stress indices were calculated to identify the moisture stress tolerant genotypes.

Result: The seed yield under non-stress condition (Yp) had significant positive association with TOL, SSI, STI, MP, GMP, SSPI and K_1STI. The seed yield under stress condition (Ys) had significant positive association with STI, MP, GMP, YI and K_2STI, while significant negative association with TOL, SSI and SSPI. The results showed that MP, GMP and STI indices were more effective in identifying high yielding genotypes in both stress and non-stress conditions while TOL, SSI, YI and SSPI under moisture stress condition. Based upon the mean seed yield and stress tolerance indices, the genotypes UM-124, UM-60, UM-55, UM-28 and UM-4 were found tolerant to staggered irrigation conditions. Hence, these genotypes may be used further in breeding programmes for moisture stress tolerance.

Key words: Correlation, Fenugreek, Moisture stress, Seed yield, Tolerance indices.

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is an annual self-pollinated diploid species (2n=16, Frayer, 1930) belonging to the sub-family "Papilionaceae" of the family "Fabaceae". The place of origin of fenugreek is supposed to between Iran and North India (Smith, 1982). Fenugreek seed contains carbohydrates (48%), proteins (25.5%), mucilaginous matter (20%), fats (7.9%) and saponins (4.8%) (Rao and Sharma, 1987) that are generally found in most blends of curry powder, spice mixes, meat products and also serves as a soil renovating crop. Seeds are bitter in taste due to presence of an alkaloid known as "Trigonellin". A potential use of fenugreek is for extraction of diosgenin, which has importance to the pharmaceutical industry. It is used in certain Ayurvedic medicines. Fenugreek can be grown under wide range of climatic conditions. The insufficient soil water supply frequently occurs because of scarcity or uneven distribution of rainfall and high temperature during the end of growing season and seed filling period. Drought and moisture stress tolerance is a complex quantitative trait with low heritability hence breeding for resistance is complicated due to lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions where large populations can be evaluated efficiently (Ramirez and Kelly, 1998). The most effective selection criterion, among various morphological, physiological, yield and yield related traits, for identifying drought resistant genotypes is based on mean seed yield (the arithmetic and geometric) under drought stress and non-stress environments (Araus *et al.*, 2002; Ramirez and Kelly, 1998; White *et al.*, 1994).

Moisture stress is a result of an imbalance between the supply furnished by the soil water and the amount needed by the plant as determined by the atmosphere assuming a complete crop cover. Loss of yield is the main concern of plant breeders hence they emphasize on yield performance under stress conditions. The relative yield performance of genotypes in drought-stressed and favorable environments seems to be a common starting point in the identification of desirable genotypes for drought conditions (Nouri *et al.*, 2011). Thus, drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been

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used for screening drought-tolerant genotypes (Mitra, 2001). These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992). Drought resistance is defined by Hall (1993) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum, 1988). Various quantitative criteria have been proposed for selection of genotypes based on their yield performance in stress and non-stress environments such as TOL, SSI, STI, MP, GMP, YI, SSPI and MSTI.

Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress and non-stress environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Among the stress tolerance indicators, a larger value of TOL and SSI represent relatively more sensitivity to stress, thus a smaller value of TOL and SSI are favored. Selection based on these two criteria favors genotypes with low yield potential under non-stress conditions and high yield under stress conditions. Guttieri *et al.* (2001) using SSI criterion suggested that SSI > 1 indicating above-average susceptibility and SSI < 1 indicated below-average susceptibility to moisture stress. Fernandez (1992) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions and geometric mean productivity (GMP) is often used by breeders interested in relative performance, since moisture stress can vary in severity in field environments over years (Fernandez, 1992). On the other hand, selection based on STI and GMP will be resulted in genotypes with higher stress tolerance and yield potential will be selected (Fernandez, 1992). Gavuzzi *et al.* (1997) suggested yield index (YI) in order to evaluate the stability of genotypes in the both stress and non-stress conditions. Moosavi *et al.* (2008) introduced stress susceptibility percentage index (SSPI) for screening drought tolerant genotypes in stress and non-stress conditions. To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which corrects the STI as a weight. The objective of the present investigation was to identify moisture stress tolerant fenugreek genotypes.

MATERIALS AND METHODS

The experiment was carried out with 48 genotypes of fenugreek at Agronomy Farm, S.K.N. College of Agriculture, Jobner (20° 6′ N, 75° 25′ E and 420 m above sea level) in a randomized block design during *rabi* 2016-17 with three replications in two environments namely, (i) normal irrigation (E_1) and (ii) moisture stress or staggered irrigation (E_2) conditions. The crop was sown on 06.11.2016 in both the environmental conditions. In E_1 total seven irrigations were given at an interval of 15 days except 6th and 7th schedule where irrigation was given at an interval of 10 days due to full bloom stage of crop. Thus, in E_1 condition, crop received moisture regularly at vegetative, flowering, pod formation, pod filling and pod maturation stages. In E_2 total four irrigations were given at an interval of 15 days in 1st and 2nd irrigation while 3rd irrigation was given at 60 days after sowing which created moisture stress at flowering and pod formation stage because the irrigation was stopped after 30 days. The 4th last irrigation was given at 85 days which also created some moisture stress during grain filling and grain maturation stage. Thus, moisture stress environment was created by providing half of the irrigations as given in normal environment in staggered manner. There was no specific check for the said stress however; a short duration variety RMt-305 was included in the experiment with some released varieties. In each environment/replication, each genotype was sown in a single row plot of 3 m length. The row to row and plant to plant distance was maintained 30 cm and 10 cm, respectively. Seed yield per plant (g) was determined under both moisture stress and non-stress conditions and denoted as Ys and Yp, respectively.

Calculation of indices

Eight stress tolerance indices were calculated using the following relationships:

Stress tolerance (TOL) = Yp - Ys (Rosielle and Hamblin, 1981):

The genotypes with low values of this index are more stable in two different conditions.

$$\text{Stress susceptibility index (SSI)} = \frac{1-(Ys/Yp)}{1-(\bar{Y}s/\bar{Y}p)}$$

(Fischer and Maurer, 1978).

The genotypes with SSI< 1 are more resistant to moisture stress conditions.

$$\text{Stress tolerance index (STI)} = \frac{Yp \times Ys}{\bar{Y}^2p}$$

(Fernandez, 1992).

The genotypes with high STI values will be tolerant to moisture stress.

$$\text{Mean productivity (MP)} = \frac{Ys + Yp}{2}$$

(Rosielle and Hamblin, 1981).

The genotypes with high value of this index will be more desirable.

$$\text{Geometric mean productivity (GMP)} = \sqrt{Ys \times Yp}$$

(Fernandez, 1992).

The genotypes with high value of this index will be more desirable.

$$\text{Yield index (YI)} = (Ys) / (\bar{Y}s)$$

(Gavuzzi *et al.*, 1997).

The genotypes with high value of this index will be suitable for moisture stress condition.

$$\text{Stress susceptibility percentage index (SSPI)} = \frac{Yp - Ys}{2(\bar{Y}p)} \times 100$$

(Moosavi *et al.*, 2008).

The genotypes with low values of this index are more stable in two different conditions.

Modified stress tolerance index (MSTI) =

$$KiSTI, K_1 = Y^2p / \bar{Y}^2p \text{ and } K_2 = Y^2s / \bar{Y}^2s$$

(Farshadfar and Sutka, 2002).

The genotypes with high value of this index will be more desirable.

Where,

Ys and Yp represent yield for each genotype in stress and non-stress conditions, respectively. Also, $\bar{Y}s$ and $\bar{Y}p$ are mean yield in stress and non-stress conditions, respectively (for all genotypes). In statistical basis, the efficiency of the stress tolerance indices will be evaluated based on their ability of discrimination between genotypes, correlation with grain yields of both the environments and their efficiency to target the best high yielding and stable genotypes.

Statistical analysis

Pooled analysis of variance (ANOVA) was used to interpret genotypes × environments interactions and the magnitude of variation attributable to each factor was estimated as percentage of variance explained of total sum of squares. Ranks were assigned to genotypes for each index. A genotype with least rank total was considered to be the best genotype. Based on indices, the genotype with the highest value for Ys, Yp, MP, GMP, STI, K_1STI, K_2STI and YI and the lowest value for SSI, TOL and SSPI received a rank 1. Besides, the most desirable moisture stress tolerance measures, the correlation coefficient between Yp, Ys and other quantitative indices of moisture stress tolerance were estimated using statistical software.

RESULTS AND DISCUSSION

Pooled ANOVA

Pooled analysis of variance revealed significant differences among the environments, genotypes and genotypes × environments interactions for seed yield per plant (g). This indicated differential/non-linear response of genotypes to the environments. The environments (E) effect were the most important source of yield variation, accounted for 44.13% of total sum of squares (TSS) followed by genotypes, error and G × E interactions effects which accounted for 23.22%, 16.11% and 15.88% of TSS, respectively (Table 1).

Mean comparison

Mean seed yield under E_1 (Yp) was 6.71 g and ranged from 4.84 g (UM-302) to 9.69 g (UM-40). While, mean seed yield under E_2 (Ys) was 4.80 g and ranged from 3.53 g (UM-163) to 6.18 g (UM-60 and UM-124). Thus the data indicated that mean seed yield per plant decreased under stress and the range was wider in E_1 as compared to E_2. The genotypes UM-40, UM-51, UM-112, UM-38 and RMt-143 showed higher seed yield and genotypes UM-302, RMt-1, UM-163, UM-44 and RMt-305 showed lower seed yield in E_1. Whereas, genotypes UM-124, UM-60, UM-55, UM-28 and UM-4 recorded higher seed yield and genotypes UM-163, RMt-305, UM-47, UM-302 and UM-45 showed lower seed yield in E_2 (Table 2). The most of genotypes showed increase seed yield in which genotypes UM-40, UM-51, UM-112, UM-38 and RMt-143 showed highest seed yield in comparison to short duration variety RMt-305, respectively (Table 2).

A wide range of variation was observed among the different stress indices for all 48 genotypes of fenugreek and Kumar *et al.* (2020) in mungbean also found the same findings. To evaluate drought tolerant genotypes using TOL index, higher value of TOL demonstrates more changes of genotype yield in stress and non-stress conditions and shows the susceptibility to non-stress condition. Fernandez (1992) and Rosielli and Hamblin (1981) stated that selection based on TOL index leads to selection of genotypes with their yields in non-stress condition are low and have lower MP. The results of this experiment showed that UM-53, RMt-1, UM-301, UM-50 and UM-4 were the most tolerant and UM-40, UM-112, UM-47, UM-100 and UM-26 were the most sensitive genotypes to the moisture stress based on TOL index. For SSI, the higher value refers to more susceptible to stress, therefore, the genotypes UM-112, UM-40, UM-47, UM-100 and UM-26 were the least tolerant genotypes and UM-53, RMt-1, UM-301, UM-50 and UM-4 were more tolerant genotypes. The SSPI resulted the same genotype ranking as TOL. Mean productivity (MP), geometric mean productivity (GMP) and stress tolerance index (STI) showed similar ranking of genotypes relative to stress tolerance (Sofi *et al.*, 2018).

Based on STI, the greater the difference between the yields found in normal and stress conditions, the smaller the amount of stress tolerance index and *vice versa*. Thus, genotypes UM-55, UM-28, UM-56, UM-124 and UM-40 were found moisture stress tolerant with high STI and high seed yield under normal irrigation and moisture stress conditions, while genotypes UM-163, UM-302, RMt-305, UM-44 and RMt-1 displayed the lowest amount of STI and seed yield under moisture stress environment. GMP resulted the same genotype ranking as STI. For MP, the higher value refers to more tolerant to moisture stress, therefore, the genotypes UM-40, UM-55, UM-28, UM-56 and UM-51 were more tolerant whereas, the genotypes UM-302, UM-163, RMt-305, RMt-1 and UM-44 were least tolerant to moisture stress. YI can be used as a selection criterion, although it only ranks cultivars on the basis of Ys (mean seed yield in E_2). Based

Table 1: Pooled ANOVA for seed yield per plant (g) in fenugreek genotypes evaluated under normal irrigation (E_1) and staggered irrigation (E_2) conditions.

Source of variation	df	Mean square	%TSS
Genotypes (G)	47	2.963**	23.22
Environments (E)	1	264.680**	44.13
Rep. within Env.	4	0.998	0.67
G × E	47	2.026**	15.88
Error	188	0.514	16.11

** represents significant at 1% level of significance.

Table 2: Seed yield and drought tolerance indices of genotypes of fenugreek in response to normal irrigation (E_1) and staggered irrigation (E_2) conditions.

Geno-types	Seed yield per plant (g)				% increase /decrease compare to RMt-305	TOL	Rank	SSI	Rank	STI	Rank	MP	Rank	GMP	Rank	YI	Rank	SSPI	Rank	MSTI (K_1)	Rank	MSTI (K_2)	Rank
	E_1	Rank	E_2	Rank																			
UM-4	6.25	30	5.64	5	19.96	0.61	5	0.34	5	0.78	15	5.95	20	5.94	15	1.18	5	4.54	5	0.87	30	1.38	5
UM-8	6.73	21	5.27	12	29.17	1.46	19	0.76	16	0.79	14	6.00	17	5.96	14	1.10	12	10.87	19	1.00	21	1.21	12
UM-10	5.77	38	4.34	39	10.75	1.43	17	0.87	22	0.56	42	5.06	41	5.00	42	0.90	39	10.65	17	0.74	38	0.82	39
UM-13	6.08	35	4.50	34	16.70	1.58	24	0.91	24	0.61	38	5.29	38	5.23	38	0.94	34	11.77	24	0.82	35	0.88	34
UM-24	6.35	28	5.10	14	21.88	1.25	15	0.69	14	0.72	21	5.73	23	5.69	21	1.06	14	9.31	15	0.89	28	1.13	14
UM-26	8.18	6	4.49	35	57.01	3.69	44	1.58	44	0.81	12	6.34	12	6.06	12	0.94	35	27.48	44	1.48	6	0.88	35
UM-27	7.61	14	4.62	30	46.07	2.99	40	1.38	40	0.78	17	6.12	14	5.93	17	0.96	30	22.27	40	1.28	14	0.93	30
UM-28	7.90	8	5.73	4	51.63	2.17	31	0.96	28	1.00	2	6.82	3	6.73	2	1.19	4	16.16	31	1.38	8	1.43	4
UM-29	7.46	16	4.58	31	43.19	2.88	38	1.35	38	0.76	18	6.02	16	5.85	18	0.95	31	21.45	38	1.23	16	0.91	31
UM-36	6.16	34	4.72	28	18.23	1.44	18	0.82	20	0.65	32	5.44	33	5.39	32	0.98	28	10.72	18	0.84	34	0.97	28
UM-37	5.91	37	5.02	15	13.44	0.89	9	0.53	10	0.66	28	5.47	32	5.45	28	1.05	15	6.63	9	0.77	37	1.10	15
UM-38	8.31	4	4.80	24	59.50	3.51	42	1.48	42	0.89	10	6.56	10	6.32	10	1.00	24	26.14	42	1.53	4	1.00	24
UM-40	9.69	1	4.52	33	85.99	5.17	48	1.87	47	0.97	5	7.11	1	6.62	5	0.94	33	38.51	48	2.08	1	0.89	33
UM-41	5.52	40	4.86	21	5.95	0.66	6	0.42	6	0.60	39	5.19	39	5.18	39	1.01	21	4.92	6	0.68	40	1.03	21
UM-44	5.19	45	4.29	40	-0.38	0.90	10	0.61	12	0.49	45	4.74	44	4.72	45	0.89	40	6.70	10	0.60	45	0.80	40
UM-45	6.21	32	3.81	44	19.19	2.40	35	1.35	39	0.52	43	5.01	43	4.86	43	0.79	44	17.87	35	0.86	32	0.63	44
UM-46	6.67	22	4.37	37	28.02	2.30	34	1.21	36	0.65	31	5.52	28	5.40	31	0.91	37	17.13	34	0.99	22	0.83	37
UM-47	7.65	11	3.74	46	46.83	3.91	46	1.79	46	0.63	33	5.70	25	5.35	33	0.78	46	29.12	46	1.30	11	0.61	46
UM-48	6.87	20	5.33	9	31.86	1.54	23	0.78	18	0.81	13	6.10	15	6.05	13	1.11	9	11.47	23	1.05	20	1.24	9
UM-49	6.23	31	4.81	23	19.58	1.42	16	0.80	19	0.66	26	5.52	28	5.47	26	1.00	23	10.58	16	0.86	31	1.01	23
UM-50	5.29	43	4.79	25	1.54	0.50	4	0.33	4	0.56	41	5.04	42	5.03	41	1.00	25	3.72	4	0.62	43	1.00	25
UM-51	8.56	2	5.01	16	64.30	3.55	43	1.45	41	0.95	8	6.79	5	6.55	8	1.04	16	26.44	43	1.63	2	1.09	16
UM-52	6.19	33	4.49	35	18.81	1.70	28	0.96	27	0.62	37	5.34	36	5.27	37	0.94	35	12.66	28	0.85	33	0.88	35
UM-53	5.30	42	5.33	9	1.73	-0.03	1	-0.02	1	0.63	36	5.32	37	5.31	36	1.11	9	-0.22	1	0.62	42	1.24	9
UM-54	6.06	36	4.92	19	16.31	1.14	14	0.66	13	0.66	27	5.49	31	5.46	27	1.03	19	8.49	14	0.81	36	1.05	19
UM-55	7.66	10	6.13	3	47.02	1.53	21	0.70	15	1.04	1	6.90	2	6.85	1	1.28	3	11.40	21	1.30	10	1.63	3
UM-56	8.03	7	5.55	6	54.13	2.48	37	1.08	31	0.99	3	6.79	4	6.68	3	1.16	6	18.47	37	1.43	7	1.34	6
UM-57	6.39	27	4.73	27	22.65	1.66	26	0.91	23	0.67	25	5.56	27	5.50	25	0.99	27	12.36	26	0.91	27	0.97	27
UM-58	7.08	18	4.82	22	35.89	2.26	33	1.12	33	0.76	19	5.95	18	5.84	19	1.01	22	16.83	33	1.11	18	1.01	22
UM-60	7.06	19	6.18	1	35.51	0.88	8	0.44	7	0.97	6	6.62	9	6.61	6	1.29	1	6.55	8	1.11	19	1.66	1
UM-61	5.76	39	4.96	17	10.56	0.80	7	0.49	9	0.63	34	5.36	35	5.35	34	1.03	17	5.96	7	0.74	39	1.07	17
UM-62	6.48	24	4.95	18	24.38	1.53	21	0.83	21	0.71	22	5.72	24	5.66	22	1.03	18	11.40	21	0.93	24	1.07	18
UM-63	6.53	23	4.74	26	25.34	1.79	29	0.96	26	0.69	24	5.64	26	5.56	24	0.99	26	13.33	29	0.95	23	0.98	26

Table 2: Continue...

Table 2: Continue...

UM-64	7.74	9	5.51	7	48.56	2.23	32	1.01	30	0.95	9	6.63	8	6.53	9	1.15	7	16.61	32	1.33	9	1.32	7
UM-65	7.60	15	4.22	41	45.87	3.38	41	1.56	43	0.71	23	5.91	21	5.66	23	0.88	41	25.17	41	1.28	15	0.77	41
UM-66	6.44	26	5.46	8	23.61	0.98	11	0.53	11	0.78	16	5.95	18	5.93	16	1.14	8	7.30	11	0.92	26	1.30	8
UM-100	7.62	13	3.86	42	46.26	3.76	45	1.73	45	0.65	30	5.74	22	5.42	30	0.80	42	28.00	45	1.29	13	0.65	42
UM-112	8.42	3	3.85	43	61.61	4.57	47	1.90	48	0.72	20	6.14	13	5.69	20	0.80	43	34.04	47	1.57	3	0.64	43
UM-118	6.35	28	4.66	29	21.88	1.69	27	0.93	25	0.66	29	5.51	30	5.44	29	0.97	29	12.59	27	0.89	28	0.94	29
UM-124	7.17	17	6.18	1	37.62	0.99	12	0.48	8	0.98	4	6.68	7	6.66	4	1.29	1	7.37	12	1.14	17	1.66	1
UM-163	5.18	46	3.53	48	-0.58	1.65	25	1.12	32	0.41	48	4.36	47	4.28	48	0.74	48	12.29	25	0.60	46	0.54	48
UM-301	5.32	41	4.91	20	2.11	0.41	3	0.27	3	0.58	40	5.12	40	5.11	40	1.02	20	3.05	3	0.63	41	1.05	20
UM-302	4.84	48	3.79	45	-7.10	1.05	13	0.76	17	0.41	47	4.32	48	4.28	47	0.79	45	7.82	13	0.52	48	0.62	45
UM-304	6.47	25	4.37	37	24.18	2.10	30	1.14	35	0.63	35	5.42	34	5.32	35	0.91	37	15.64	30	0.93	25	0.83	37
RMt-1	4.91	47	4.55	32	-5.76	0.36	2	0.26	2	0.50	44	4.73	45	4.73	44	0.95	32	2.68	2	0.53	47	0.90	32
RMt-143	8.21	5	5.28	11	57.58	2.93	39	1.25	37	0.96	7	6.75	6	6.58	7	1.10	11	21.82	39	1.50	5	1.21	11
RMt-305	5.21	44	3.71	47	0.00	1.50	20	1.01	29	0.43	46	4.46	46	4.40	46	0.77	47	11.17	20	0.60	44	0.60	47
RMt-361	7.63	12	5.18	13	46.45	2.45	36	1.12	34	0.88	11	6.41	11	6.29	11	1.08	13	18.25	36	1.29	12	1.17	13

on YI, genotypes UM-60, UM-124, UM-55, UM-28 and UM-4 had the highest YI and Ys, hence more tolerant whereas, UM-163, RMt-305, UM-47, UM-302 and UM-45 had the lower YI and Ys. According to K_1STI, the genotypes UM-40, UM-51, UM-112, UM-38 and RMt-143 were the most tolerant whereas, the genotypes UM-302, RMt-1, UM-163, UM-44 and RMt-305 were the most sensitive. According to K_2STI, the genotypes UM-124, UM-60, UM-55, UM-28 and UM-4 were the most tolerant whereas, the genotypes UM-163, RMt-305, UM-47, UM-302 and UM-45 were the most sensitive (Table 2). It was concluded that MP, GMP and STI values are convenient parameters to select high yielding genotypes in both the stress and non-stress conditions (Susmitha and Ramesh, 2020) whereas relative decrease in yield under stress, TOL, SSI and SSPI values are better indices to determine tolerance levels.

Correlation coefficient

To determine the most desirable stress tolerance index, the correlation coefficient between Yp, Ys and stress indices were calculated (Table 3). The best indices are those which have high correlation with seed yield in both E_1 and E_2 conditions and would be able to identify potential upper yielding and drought tolerant genotypes (Talebi *et al.*, 2007).

Seed yield under stress condition (Ys) had a weak positive association (r = 0.216) with seed yield under non-stress condition (Yp), indicating that high potential yield under optimal conditions does not necessarily result in improved yield in a moisture stress environment (and the opposite is true) because the genes controlling yield and drought tolerance are different (Rosielle and Hamblin, 1981). Similar findings were reported by Fernandez (1992), Mohammadi *et al.* (2010), Farshadfar *et al.* (2013) and Sahar *et al.* (2016). The seed yield under non-stress (Yp) had significant positive association with TOL (0.841), SSI (0.720), STI (0.810), MP (0.894), GMP (0.815), SSPI (0.841) and K_1STI (0.995), whereas non-significant and positive association with YI (0.214) and K_2STI (0.217). The seed yield under stress (Ys) had significant positive association with STI (0.741), MP (0.630), GMP (0.740), YI (1.000) and K_2STI (0.996), while K_1STI (0.185) exhibited non-significant and positive association. In addition, TOL (-0.347), SSI (-0.501) and SSPI (-0.346) showed significantly negative association with yield under stress (Ys). The indices STI, MP and GMP exhibited good correlation with seed yield under both the environmental conditions, therefore, selection based on MP, GMP and STI will result in the selection of genotypes with higher moisture stress tolerance and yield potential in both the environments, while TOL, SSI, YI and SSPI exhibited good correlation with seed yield under moisture stress condition. Similar findings were also reported by Siahsar *et al.* (2010) in lentil, Zare (2012) and Saeidi *et al.* (2013) in barley, Singh *et al.* (2015) and Mohammed and Kadhem (2017) in wheat. Thus, these indices may be used as selection criteria in breeding programme for moisture stress tolerance.

Ranking method

The estimated values of various stress tolerance indices indicated that the identification of moisture stress tolerant genotypes based on a single criterion was contradictory. Different indices introduced different or same genotypes as stress tolerant. To determine the most desirable moisture stress tolerant genotype according to the all indices, mean rank of all indices were calculated and based on this criterion the most desirable and moisture stress tolerant genotypes were identified (Table 4). The genotypes UM-124, UM-60, UM-55, UM-28 and UM-4 were identified as the most tolerant genotypes for moisture stress, while genotypes UM-163, RMt-305, UM-45, UM-302 and UM-47 as the most sensitive (Table 4). Such strategies of using different tolerance indices and ranking pattern for screening of tolerant genotypes were used by several other workers such as Farshadfar *et al.* (2012), Farshadfar *et al.* (2014) and Mohammed and Kadhem (2017) in wheat.

Table 3: Correlation coefficients between drought tolerance indices and yield.

Tolerance indices	Ys	Yp	TOL	SSI	STI	MP	GMP	YI	SSPI	K_1STI
Yp	0.216									
TOL	-0.347*	0.841**								
SSI	-0.501**	0.720**	0.970**							
STI	0.741**	0.810**	0.368*	0.200						
MP	0.630**	0.894**	0.510**	0.343*	0.984**					
GMP	0.740**	0.815**	0.373**	0.205	0.997**	0.987**				
YI	1.000**	0.214	-0.348*	-0.503**	0.739**	0.628**	0.738**			
SSPI	-0.346*	0.841**	1.000**	0.970**	0.368*	0.510**	0.373**	-0.348*		
K_1STI	0.185	0.995**	0.854**	0.726**	0.790**	0.877**	0.792**	0.183	0.854**	
K_2STI	0.996**	0.217	-0.344*	-0.494**	0.742**	0.629**	0.738**	0.996**	-0.344*	0.187

* and ** represent significant at 5% and 1% level of significance, respectively.

Table 4: The overall rank of genotypes based upon yield and drought tolerance indices.

Genotypes	Yp	Ys	TOL	SSI	STI	MP	GMP	YI	SSPI	MSTI (K_1)	MSTI (K_2)	Sum	Overall rank
UM-4	30	5	5	5	15	20	15	5	5	30	5	140	5
UM-8	21	12	19	16	14	17	14	12	19	21	12	177	10
UM-10	38	39	17	22	42	41	42	39	17	38	39	374	42
UM-13	35	34	24	24	38	38	38	34	24	35	34	358	38
UM-24	28	14	15	14	21	23	21	14	15	28	14	207	14
UM-26	6	35	44	44	12	12	12	35	44	6	35	285	27
UM-27	14	30	40	40	17	14	17	30	40	14	30	286	28
UM-28	8	4	31	28	2	3	2	4	31	8	4	125	4
UM-29	16	31	38	38	18	16	18	31	38	16	31	291	30
UM-36	34	28	18	20	32	33	32	28	18	34	28	305	32
UM-37	37	15	9	10	28	32	28	15	9	37	15	235	17
UM-38	4	24	42	42	10	10	10	24	42	4	24	236	18
UM-40	1	33	48	47	5	1	5	33	48	1	33	255	19
UM-41	40	21	6	6	39	39	39	21	6	40	21	278	25
UM-44	45	40	10	12	45	44	45	40	10	45	40	376	43
UM-45	32	44	35	39	43	43	43	44	35	32	44	434	46
UM-46	22	37	34	36	31	28	31	37	34	22	37	349	37
UM-47	11	46	46	46	33	25	33	46	46	11	46	389	44
UM-48	20	9	23	18	13	15	13	9	23	20	9	172	9
UM-49	31	23	16	19	26	28	26	23	16	31	23	262	23
UM-50	43	25	4	4	41	42	41	25	4	43	25	297	31
UM-51	2	16	43	41	8	5	8	16	43	2	16	200	12
UM-52	33	35	28	27	37	36	37	35	28	33	35	364	40
UM-53	42	9	1	1	36	37	36	9	1	42	9	223	15
UM-54	36	19	14	13	27	31	27	19	14	36	19	255	19
UM-55	10	3	21	15	1	2	1	3	21	10	3	90	3

Table 4: Continue...

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UM-56	7	6	37	31	3	4	3	6	37	7	6	147	6
UM-57	27	27	26	23	25	27	25	27	26	27	27	287	29
UM-58	18	22	33	33	19	18	19	22	33	18	22	257	22
UM-60	19	1	8	7	6	9	6	1	8	19	1	85	2
UM-61	39	17	7	9	34	35	34	17	7	39	17	255	19
UM-62	24	18	21	21	22	24	22	18	21	24	18	233	16
UM-63	23	26	29	26	24	26	24	26	29	23	26	282	26
UM-64	9	7	32	30	9	8	9	7	32	9	7	159	7
UM-65	15	41	41	43	23	21	23	41	41	15	41	345	36
UM-66	26	8	11	11	16	18	16	8	11	26	8	159	7
UM-100	13	42	45	45	30	22	30	42	45	13	42	369	41
UM-112	3	43	47	48	20	13	20	43	47	3	43	330	35
UM-118	28	29	27	25	29	30	29	29	27	28	29	310	33
UM-124	17	1	12	8	4	7	4	1	12	17	1	84	1
UM-163	46	48	25	32	48	47	48	48	25	46	48	461	48
UM-301	41	20	3	3	40	40	40	20	3	41	20	271	24
UM-302	48	45	13	17	47	48	47	45	13	48	45	416	45
RMt-1	47	32	2	2	44	45	44	32	2	47	32	329	34
RMt-143	5	11	39	37	7	6	7	11	39	5	11	178	11
RMt-305	44	47	20	29	46	46	46	47	20	44	47	436	47
RMt-361	12	13	36	34	11	11	11	13	36	12	13	202	13

CONCLUSION

Based upon the mean seed yield and various stress tolerance indices, the genotypes UM-124, UM-60, UM-55, UM-28 and UM-4 were found tolerant to moisture stress. The indices STI, MP and GMP exhibited good correlation with seed yield under both the environmental conditions while TOL, SSI, YI and SSPI exhibited good correlation with seed yield under moisture stress condition. Hence, these genotypes may be used in breeding programme especially for staggered irrigation condition or limited moisture stress. It is advocated that the genotypes identified tolerant to moisture stress in the present study should be further tested at multi-locations and those found suitable can be used in improvement of breeding programmes for the development of superior genotypes in fenugreek.

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