

EVALUATION OF DROUGHT TOLERANCE INDICES AND RELATION WITH YIELD IN BREAD WHEAT GENOTYPES UNDER DROUGHT STRESS CONDITIONS

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Abstract

Drought stress is a main abiotic stress factor constraining wheat production in some years. Rainfall fluctuation during vegetative and generative growing periods causes grain yield reduction in Trakya Region, Turkey. This research was carried out in 2008-2009 and 2009-2010 growing years. Experiments were set up in a randomized completely blocks design in split-plot with three replications with 15 genotypes. The main plots were assigned for five moisture regimes, which included 3 drought stress environments (GS31-94, GS31-51 and GS51-94) one non-stress and non-treatment (control) environment. Droughts were created under mobile rain shelter at various plant growth stages from shooting up to maturing stage. Based on grain yield stress susceptible index (SSI), stress tolerance index (STI), tolerance index (TOL), mean productivity (MP), and geometric mean productivity (GMP) were calculated with their relation. The results of variance analyses for Yp, Ys and other drought tolerance indices indicated that genotypic differences were highly significant. Effect of drought stress on grain yield of all tested genotypes was different. Drought stress caused an average reduction of 59.9% on yield. Bereket was the highest yielding cultivar under fully drought stress condition. STI, MP and GMP showing the highest correlation coefficient with grain yield were the most desirable selection criteria for high yielding and drought tolerant genotypes. A positive and significant correlation was observed between Yp with TOL, MP, STI, GMP and HM, and negative correlation with YSI. These indices are the most suitable indices to screen genotypes in drought stress conditions.

Keywords: bread wheat, drought stress, drought tolerance index, yield

1. INTRODUCTION

Bread Wheat is a plant that is widely produced throughout the Thrace region of Turkey. Often winter and sometimes alternative varieties are preferred. Average wheat yield is over 4.5 tons/hectar because of favorable environment condition of the region. Although the amount of the rainfall (589.1 mm) during growing season is enough for wheat production, the distribution of this rainfall is not regular. This fluctuation of rainfall causes reducing grain yield and quality (Öztürk and Korkut, 2015). In most wheat growing regions and especially in the Mediterranean climate, plants subject to several physical and biotic stresses in grain filling period. Grain filling often occurs early, when air temperatures are increasing and moisture amount is decreasing in soil. Water deficit is the main environmental constraint limiting cereal yield worldwide and particularly within the Mediterranean basin, a problem likely to become even worse in the future. Cereal plants respond to drought through morphological, physiological and metabolic modifications occurring in all organs and therefore traits associated with improved performance under water limited conditions or improved survival to extremely low water availability are diverse (Slafer et al., 2005). Drought stress tolerance is a complex trait that is obstructed by low heritability and deficiency of successful selection approaches (Blum 1988). About 60% of the wheat area in the developing world (75 million ha) is affected by abiotic stresses, with approximately 45 million ha subjected to moisture stress (Pfeiffer et al., 2000). Various studies of wheat in Mediterranean and temperate regions (Austin et al., 1980; Simane et al., 1993; Blum, 1998) have indicated that the reproductive stage is more sensitive to drought than the seedling and tillering stages and causing yield reduction. Drought resistance is usually quantified by grain yield under drought. Wheat grain yield under drought, however, depends on yield potential as well as the phenology of the genotype (Acevedo, 1991). The problem of drought is acute in many developing countries, where about 37% of the wheat growing areas are semiarid and have low soil moisture

content, thus presenting a limiting factor for higher yield (Rajaram, 2001). The quantification of drought resistance has also been approached by a yield stability index across environments (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966), as well as by drought susceptibility indexes (Fischer and Maurer, 1978). These indexes are highly dependent on yield potential and crop phenology, which are characters with a high genotype x environment interaction (Acevedo, 1991). To avoid these effects, Bidinger et al. (1987) proposed a drought resistance index (DRI) equivalent to the residual effect of yield under stress once the effects of yield potential, phenology and experimental error had been removed. The DRI is a criterion to be used to select drought resistant genotypes or genotypic traits related to drought resistance that could be manipulated as independent genetic characters (Acevedo and Ceccarelli, 1989). The geometric mean is often used by breeders interested in relative performance since drought stress can vary in severity in field environment over years (Ramirez and Kelly, 1998; Fernandez, 1992). Guttieri et al. (2001) suggested that using SSI criterion more than 1 indicated above-average susceptible to drought stress. Values of SSI lower than 1 indicate low drought susceptibility or higher yield stability and values higher than 1 show high drought susceptibility or poor yield stability. This study was carried out to assess the selection criteria for identifying drought tolerance in bread wheat genotypes, so that suitable genotypes can be recommended for cultivation in the drought prone area of Thrace region. Also, this study is an attempt to compare the usefulness of several drought stress indices for identification of cultivars with better performance at different levels of water and drought stress conditions.

2. MATERIALS AND METHODS

This research was carried out in the experimental field of Trakya Agriculture Research Institute Edirne (Turkey) (41 m above sea level, 41°64'N, 26°59'E), during two consecutive growing years in 2008-2009 and 2009-2010. Experiments were set up with randomized completely blocks design in a split-plot with three replications. Fifteen genotypes (Kate A-1, Gelibolu, Pehlivan, Tekirdağ, Selimiye, Aldane, Bereket, Flamura-85, Golia cultivars and 6 advanced lines) were used. Plots consist of 6 rows, 6 m long and 17 cm between the rows. The Zadoks Decimal Code (GS) was used to describe plant growth stages. Drought stress treatments are placed on main plot and genotypes on the sub-plot. The main plots were assigned to five moisture regimes, which included 3 drought stress environments, one non-stress and one non-treatment environment. The described plant growth stages created drought are; drought stress applied from GS31 (stem starts to elongate) to GS51 (10% of spikes visible), second drought stress applied from GS51 (10% of spikes visible) to GS94 (over-ripe, straw brittle), and fully drought stress applied from GS31 (stem starts to elongate) to GS94 (over-ripe, straw brittle). Droughts were created under mobile rain shelter at various plant growth stages from shooting up to maturing stage. A mobile rain shelter system was used to exclude rainfall and induce drought stress. In this experiment, all plots were covered only when raining. A drip irrigation set was used and each plot was irrigated separately by controlling dripping irrigation system. Sowing density was used as 500 seeds per square meter and sowing was done by an experimental sowing drill. Wheat seeds were sown to plots in the first week of November. Fertilizer was applied at 40 kg ha⁻¹ P₂O₅ and at 150 kg ha⁻¹ nitrogen three times at sowing, tillering and stem elongation stage. Also, chemical was used for weed control.

In order to identify drought tolerant genotypes some selection indices (GMP, MP, HM, TOL, STI, SSI, Yp and Ys) were used under various drought stress conditions. Drought resistance indices were calculated using the following relationships. Grain yield with stress susceptible index (SSI), stress tolerance index (STI), tolerance index (TOL), mean productivity (MP), and geometric mean productivity (GMP) were calculated with their correlation coefficient. Following indices for evaluation of some bread wheat cultivars were used. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield under non-stress (Yp) and stress (Ys) conditions and mean productivity (MP) as the average of Yp and Ys. Fischer and Maurer (1978) suggested a stress susceptibility index (SSI) of the cultivars. Fernandez (1992) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes producing high yield under both stress and non-stress

conditions. Geometric mean (GMP) (Ramirez and Kelly, 1998); (Fernandez, 1992) and harmonic mean (HM) (Kristin et al., 1997) other indices as given below.

1- TOL = Stress tolerance; $TOL = Y_p - Y_s$ (Rosielle and Hamblin, 1981)

2- SSI = Stress susceptibility index; $SSI = 1 - (Y_s/Y_p)/SI$

$SI = 1 - (Y_{sm}/Y_{pm})$ (Fisher and Maurer, 1978). Y_{pm} = Mean yield potential of non-stress environments. Y_{sm} = Mean yield potential of stress environments.

3- YI =Yield index (Gavuzzi et al., 1997; Lin et al., 1986); $YI = Y_s/Y_{sm}$

4- YSI = Yield stability index (Bousslama and Schapaugh, 1984); $YSI = Y_s/Y_p$

Y_s = Yield potential of each cultivar in stress environments. Y_p = Yield potential of each cultivar in non-stress environments.

5- STI = Stress tolerance index (Fernandez, 1992); $STI = (Y_p)(Y_s)/(Y_{pm})^2$

6- HM = Harmonic mean (Kristin et al., 1997); $HM = 2(Y_p * Y_s) / (Y_p + Y_s)$

7- MP = Mean productivity; (Ramirez and Kelly, 1998); $MP = (Y_s + Y_p)/2$

8- GMP =Geometric mean; $GMP = \sqrt{Y_s * Y_p}$ (Ramirez and Kelly, 1998; Fernandez, 1992).

Regression graphs are used to make relation among characters of the genotypes. Data were analysed statistically for analysis of variance following the method described by Gomez and Gomez (1984). The significance of differences among means was compared by using Least Significant Difference (L.S.D. at a %5) test.

3. RESULTS AND DISCUSSION

The results of variance analyses for grain yield (Y_p and Y_s) and other related traits in both stress and non-stress environments are given in Table 1. Results of the study showed that there was significant difference among wheat genotypes in view of grain yield under drought stress ($p < 0.01$) and non-stress ($p < 0.01$) conditions. Drought stress conditions and water stress consistently lowered the yield under non-irrigated rather than irrigated conditions. The mean yield of the genotypes was 763.8 kg da^{-1} under non-stress conditions, and 457.8 kg da^{-1} under fully drought stress conditions, this indicate that drought stress decreased grain yield by 59.9%. The highest grain yield (894.8 kg da^{-1}) was determined in BBVD7 line and Bereket and Kate A-1 were the other highest yielding cultivars under non-stress conditions. Bereket was the highest yielding cultivar with 522.6 kg da^{-1} yield under fully drought stress condition. These findings showed that Bereket cultivar was the most drought tolerant with high yielding under favourable and drought stress conditions. The lowest yield was determined in BBVD21-07 line both under non-stress and fully drought stress conditions.

Tolerance index (TOL) as the difference in grain yield both under non-stressed and stressed conditions, was used to select drought tolerant genotypes. Genotypes with lower TOL values are assumed to be more stable in variable conditions (favourable and unfavourable environments). The greater value of TOL means that larger yield reduction under stress conditions and higher the drought sensitivity. 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 favoured. Selection based on these two indices favours genotypes with low yield under non-stress conditions and high yield under stress conditions (Golabadi et al., 2006; Fernandez, 1992). Regarding TOL, the highest value and highest differences between stress and non-stress conditions were determined for EBVD24-07 (402.9 kg da^{-1}), BBVD7 (397.0 kg da^{-1}), Kate A-1 (351.0 kg da^{-1}) and Bereket (334.1 kg da^{-1}) genotypes which were determined yield reduction under stress conditions and higher drought sensitivity. The lowest differences were also calculated in ÖVD2/21-07, BBVD21-07, Golia and ÖVD2/27-07 genotypes which they are the least relative tolerances to drought.

Stability in grain yield was estimated for each genotype using the stress susceptibility index (SSI) derived from the yield differences between stressed and non-stressed environments (Fischer and Maurer, 1978). There was a significant difference between genotypes for SSI and lowest value was observed in Golia (0.764), followed by ÖVD2/27-07 (0.852) and ÖVD2/21-07 (0.899) which was considered as genotypes with low drought susceptibility and high yield stability in both conditions. According the parameters SSI the highest value was determined in EBVD24-07 (1.233) and BBVD21-07 (1.201) genotypes. So, these results can be interpreted that these genotypes were high drought susceptibility and poor yield stability. The SSI estimates for each genotype the rate of change in yield between the stressed and non-stressed conditions relative to the mean change for all genotypes.

The parameters of stress tolerance index (STI) and geometric mean productivity (GMP) also were calculated to estimate drought tolerance. Selection based on STI and GMP will result in genotypes with higher stress tolerance and yield potential will be selected (Fernandez, 1992). STI can be used in order to identify genotypes that produce high yield under both stress and non-stress conditions. The highest values of STI were found in Bereket (0.778), BBVD7 (0.766) and Kate A-1 (0.736) cultivars. Yield stability index (YSI) is calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions. The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions (Bousslama and Schapaugh, 1984). Golia (0.684), ÖVD2/21-07 (0.662) and ÖVD2/27-07 (0.661) had higher YSI.

Mean productivity (MP) proposed by Rosielle and Hamblin (1981) the mean production under both stressed and non-stressed conditions was also used to more description of the response of the genotypes. The highest MP was determined in BBVD7 (696.3), followed by cultivars Bereket (689.7) and Kate A-1 (677.2).

Table 1. Drought tolerance indices and their relationship with grain yield for wheat genotypes under stress and non-stress conditions

No	Genotypes	Yp	Ys	TOL	MP	YSI	YI	STI	SSI	GMP	HM
1	Kate A-1	852.7 ab	501.7 a-d	351.0 ab	677.2 a	0.594 bc	1.092 a-d	0.736 ab	1.008 bc	651.3 ab	626.8 ab
2	Gelibolu	785.7 cd	475.0 b-e	310.7 bcd	630.3 bc	0.605 bc	1.031 b-f	0.650 cd	0.982 bc	608.7 cd	588.1 cd
3	Pehlivan	778.2 d	476.7 bcd	301.5 b-f	627.5 bc	0.613 bc	1.039 b-e	0.645 cd	0.976 bc	607.8 cd	588.9 cd
4	Tekirdağ	745.7 de	461.3 def	284.4 c-f	603.5 cde	0.624 abc	1.002 ef	0.598 def	0.927 bcd	584.1 def	565.7 de
5	Selimiye	785.4 cd	468.9 cde	316.6 bcd	627.1 bc	0.600 bc	1.022 c-f	0.637 cde	1.000 bc	605.0 cde	583.9 cd
6	Aldane	716.5 ef	433.9 ef	282.6 c-f	575.2 e	0.618 abc	0.947 f	0.530 f	0.940 bcd	554.9 f	535.6 e
7	Flamura-85	674.8 f	384.5 g	290.3 b-f	529.7 f	0.573 cd	0.844 g	0.446 g	1.092 ab	507.8 g	487.0 f
8	Golia	767.4 d	511.8 ab	255.6 def	639.6 b	0.684 a	1.120 ab	0.668 bcd	0.764 d	623.9 bc	608.8 bc
9	BBVD7	894.8 a	497.8 a-d	397.0 a	696.3 a	0.560 cd	1.089 a-e	0.766 a	1.109 ab	665.7 a	636.7 ab
10	Bereket	856.7 ab	522.6 a	334.1 bc	689.7 a	0.611 bc	1.139 a	0.778 a	0.977 bc	667.8 a	646.8 a
11	ÖVD26-07	769.9 d	462.7 def	307.2 b-e	616.3 bcd	0.612 bc	1.011 def	0.608 cde	0.963 bc	594.3 cde	573.5 cd
12	ÖVD2/21-07	708.5 ef	465.6 c-f	243.0 f	587.1 de	0.662 ab	1.027 c-f	0.565 ef	0.899 cd	573.5 ef	560.2 de
13	ÖVD2/27-07	770.8 d	505.8 abc	265.0 def	638.3 b	0.661 ab	1.104 abc	0.675 bc	0.852 cd	622.9 bc	608.0 bc
14	EBVD24-07	830.2 bc	427.3 f	402.9 a	628.7 bc	0.518 d	0.943 f	0.608 cde	1.233 a	595.1 cde	563.4 de
15	BBVD21-07	519.3 g	271.5 h	247.7 ef	395.4 g	0.524 d	0.590 h	0.246 h	1.201 a	374.1 h	354.2 g
Mean		763.8	457.8	306.0	610.8	0.604	1.000	0.610	0.995	589.1	568.5
LSD (0.05)		49.53	41.12	62.31	33.19	0.068	0.089	0.072	0.18	34.24	36.59
LSD (year: 0.05)		60.98	27.67	70.49	31.63	0.078	0.062	0.056	0.24	29.15	27.57
F		**	**	**	**	**	**	**	**	**	**

Note: *: P <0.05; **: P<0.01. Yp: Grain yield under non-stress conditions, Ys: Grain yield under drought stress conditions, TOL: Stress tolerance, MP: Mean productivity, YSI: Yield stability index,

YI: Yield index, STI: Stress tolerance index, SSI: Stress susceptibility index, GMP: Geometric mean productivity, HM: Harmonic mean.

According to GMP and HM, Bereket, BBVD7 and Kate A-1 were higher grain yield and better than the other genotypes. In this research similar rank were observed by GMP, MP and STI, so these result suggested that these three parameters are in equal for selecting high yielding genotypes. The higher HM indicate the higher drought tolerance and have more yield potential of the genotypes. The indices which have high correlation with grain yield in both stressed and non-stressed conditions have been selected as the best ones, because these are able to separate and identify genotypes with high grain yield in both conditions. Selection based on GMP will result in genotypes with higher stress tolerance and its yield potential will be selected (Fernandez, 1992). Yield index means that the ratio of yield potential of each cultivar in stress conditions of mean yield potential of stress environments. So, high value of YI is preferable. This parameter is calculated for a given genotype using grain yield under stressed relative to its grain yield under non-stressed conditions. The highest YI was determined in Bereket (1.139) and Golia (1.120). The genotypes with high YSI is expected to have high yield under stressed and low yield under non-stressed conditions.

Table 2. Correlation coefficient between Yp, Ys and drought tolerance indices under drought stress and non-stress conditions

Traits	Yp	Ys	TOL	MP	YSI	YI	STI	SSI	GMP
Ys	0.442**								
TOL	0.691**	-0.343**							
MP	0.889**	0.804**	0.284**						
YSI	-0.304**	0.711**	-0.891**	0.161					
YI	0.634**	0.893**	-0.055	0.876**	0.465**				
STI	0.653**	0.927**	-0.063	0.906**	0.451**	0.817**			
SSI	0.163	-0.552**	0.615**	-0.173	-0.751**	-0.600**	-0.232*		
GMP	0.810**	0.883**	0.137	0.988**	0.303**	0.912**	0.948**	-0.265*	
HM	0.722**	0.938**	0.001	0.958**	0.427**	0.926**	0.966**	-0.345**	0.990**

Note: *: $P < 0.05$; **: $P < 0.01$. Yp: Grain yield under non-stress conditions, Ys: Grain yield under drought stress conditions, TOL: Stress tolerance, MP: mean productivity, YSI: yield stability index, YI: yield index, STI: stress tolerance index, SSI: stress susceptibility index, GMP: Geometric mean productivity, HM: Harmonic mean

To determine the most desirable drought tolerance criteria, correlation coefficients between grain yield under stress and non-stress conditions and drought tolerance indices were calculated. The yield potential (Yp) under non-stress conditions had significantly positive correlation ($r=0.442^{**}$) with grain yield under stress conditions (Ys). A positive and significant correlation was observed between Yp with TOL, MP, STI, GMP and HM, and negative correlation with YSI. These indices are the most suitable indices to screen genotypes in drought stress conditions. Stress tolerance (TOL) was strongly correlated with yield under non-stress condition and negatively correlated with yield under stress conditions. There were positive significant correlations between Yp and Ys ($r=0.442^{**}$), TOL ($r=0.691^{**}$), MP ($r=0.889^{**}$), YI ($r=0.634^{**}$), STI ($r=0.653^{**}$), GMP ($r=0.810^{**}$) and HM ($r=0.722^{**}$) under non-stress condition. In this research, it was found that positive significant correlations between grain yield under stressed (Ys) with MP ($r=0.804^{**}$), YSI ($r=0.711^{**}$), YI ($r=0.893^{**}$), STI ($r=0.927^{**}$), GMP ($r=0.883^{**}$) and HM ($r=0.938^{**}$) and negative significant

correlation between TOL ($r=-0.343^{**}$) and SSI ($r=-0.552^{**}$) under stress condition (Table 2). As it expected that mean productivity (MP), geometric mean productivity (GMP) and harmonic mean (HM) were strongly correlated with both Y_p and Y_s . The significant and positive correlation of Y_p and MP, GMP and STI showed that these indices were more effective in identifying high yielding cultivars under different moisture conditions.

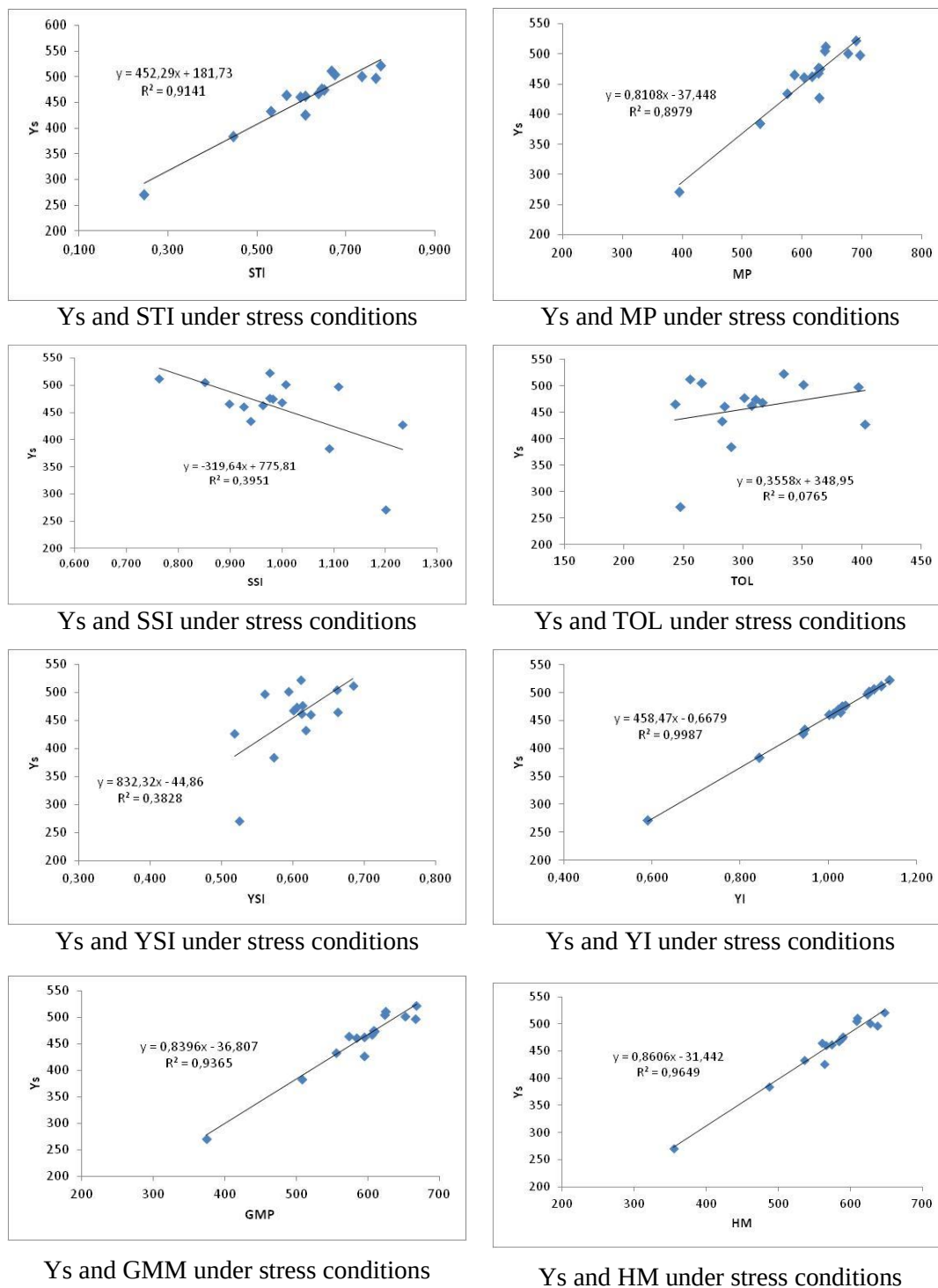


Figure 1. Relation between stress yield (Y_s) and other stress tolerance attributes under severe drought stress conditions

Linear regression was used to determining between grain yield and other drought stress indices. Grain yield under drought stress (Y_s) was positively correlated with STI ($R^2 = 0.914$). Also, it was found similar result under drought stress conditions between Y_s with YSI ($R^2 = 0.382$), YI ($R^2 = 0.998$), MP ($R^2 = 0.897$), GMP ($R^2 = 0.936$) and, HM ($R^2 = 0.964$). There was a negative relationship between Y_s and SSI ($R^2 = 0.395$) (Figure1). Regression analysis was made to determine between yield potential (Y_p) and drought tolerance indices under non-stress condition. It was determined a positive correlation between Y_p with STI ($R^2 = 0.915$), YI ($R^2 = 0.728$), MP ($R^2 = 0.873$), GMP ($R^2 = 0.914$), TOL ($R^2 = 0.546$), and MP ($R^2 = 0.949$) (Figure 2).

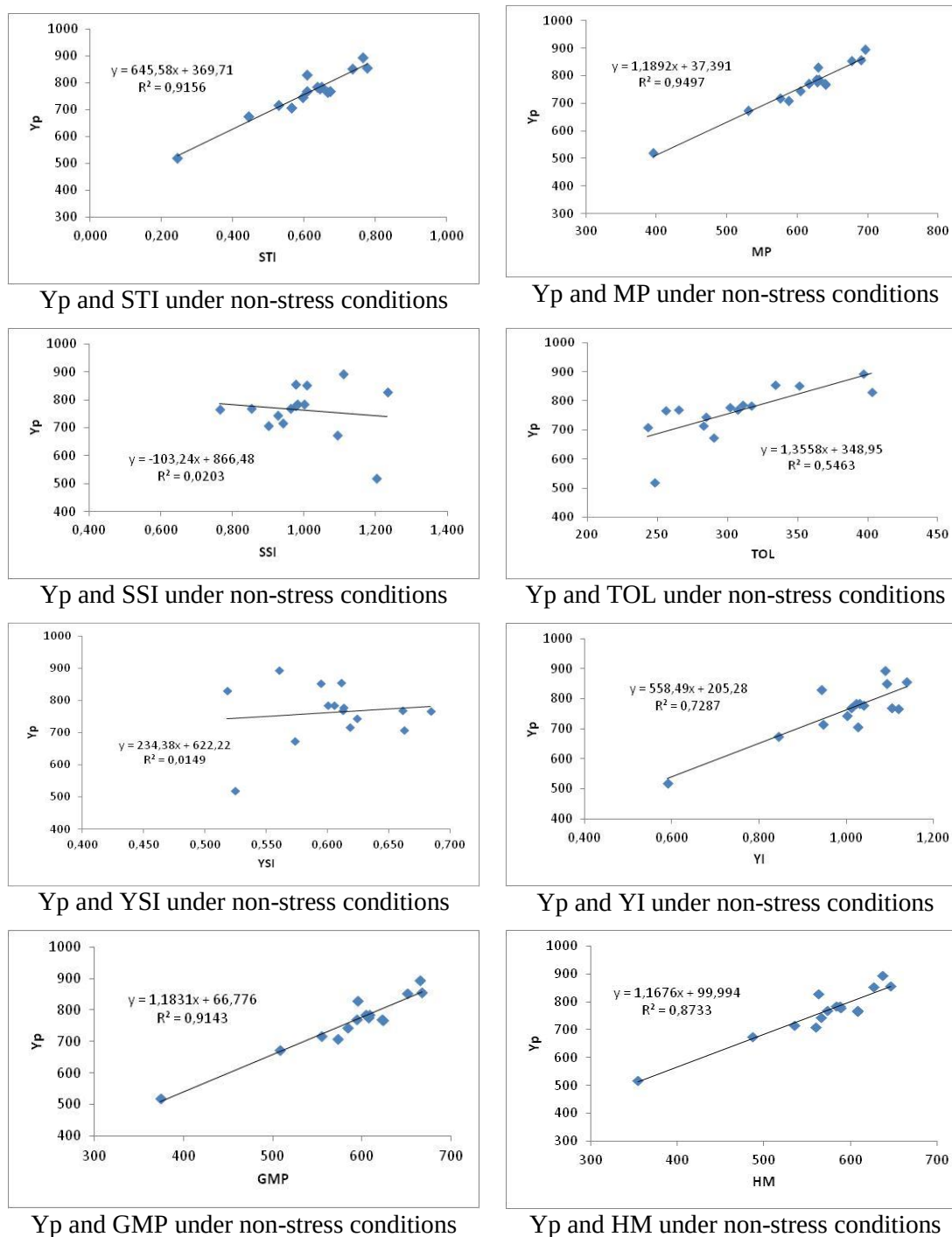


Figure 2. Relationship between potential yield (Y_p) and other stress tolerance attributes under non-stress conditions

4. CONCLUSION

Based on mean yield of the genotypes drought stress condition caused yield decreased by 59.9%. Bereket was the most tolerant cultivar under favourable and drought stress conditions. According to TOL the lowest differences were determined in ÖVD2/21-07, BBVD21-07 and Golia genotypes and for SSI the lowest value was observed in Golia and ÖVD2/27-07 which was considered as genotypes with low drought susceptibility and high yield stability in both conditions. The STI, MP, and GMP were the most desirable selection criteria for high yielding and drought tolerant genotypes. Grain yield under non-stress environment (Y_p) was positively and significantly correlated with TOL, MP, YI, STI, GMP, and HM similarly, positive and significant association has also been observed between grain yield under stress condition (Y_s) and MP, YSI, YI, STI, GMP and HM. These indices are the most suitable indices to screen genotypes in drought stress conditions. Y_p and Y_s was the better predictor for potential yield. According to Fernandez model; Bereket, BBVD7, Kate A-1, Gelibolu and Selimiye have superiority under both stress and irrigated conditions. BBVD7, Bereket, Kate A-1, and EBVD24-07 were recommended for irrigated conditions. Bereket, Golia, ÖVD2/27-07 and Kate A-1 were identified suitable for stress conditions. It was also showed that GMP, MP, HM and STI indices had very high correlation with yield under stress and irrigation conditions and were recognized as optimum indices for identifying cultivar with high production and low sensitivity to drought stress.

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