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RESEARCH ARTICLE
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Identification of bread wheat genotypes (*Triticum aestivum* L.) with tolerance to drought conditions at the central coast of Peru

Identificación de genotipos de trigo harinero *Triticum aestivum* L.) con tolerancia a condiciones de sequía en la costa central del Perú

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Abstract

Wheat is sown mostly in Peru, in areas above 3000 m altitude, under rainfed conditions and frequent drought problems during the crop cycle. It is a cereal used as a staple food by the families of small-scale farmers who are dedicated to their cultivation, which is why it is necessary to develop varieties with drought tolerance. This investigation had as objectives (1) to determine the yield potential of wheat genotypes under drought stress conditions, (2) to determine the susceptibility indices and drought tolerance, and (3) to identify drought tolerant genotypes. Nine genotypes introduced from CIMMYT and the commercial variety "Centenario" wheat flour (*Triticum aestivum* L.) were studied in an environment with complete irrigation during the life cycle and another environment with terminal drought stress or deficit irrigation applied in the boot phase (Z4.0). A Random Complete Blocks design was used with three repetitions. Agronomic characteristics, quality evaluations were carried out following the established protocols for each characteristic evaluated and the stress tolerance indices (STI), mean productivity (MP), geometric mean productivity (GMP), tolerance index (TOL), and stress susceptibility index (SSI), were determined. The reduction in the grain yield varied from 17.95 % to 33.27 % mainly due to drought. The SSI ranged from 0.65 (G-3) to 1.21 (G-6 y G-9), meanwhile the TOL ranged from 1 316.8 (G-3) to 3 142.68 (G-7). The MP, STI and GMP indexes allowed the identification of genotypes with the greatest tolerance to irrigation and stress conditions of the 5 genotypes: G- 1, G-2, G-7, G-8 and G- 10. These results are important for developing new varieties that adapt to drought conditions and to face climate change in the Andean region.

Keywords: Bread wheat, drought, tolerance index, genotypes.

Resumen

El trigo se siembra mayormente en el Perú, en zonas sobre los 3000 m de altitud, bajo condiciones de secano y problemas de sequias frecuentes durante el ciclo de cultivo. Es un cereal empleado como alimento básico por las familias de los agricultores de pequeña escala que se dedican a su cultivo, razón por la que se requiere desarrollar variedades con tolerancia a la sequía. Esta investigación tuvo como objetivos (1) Determinar el

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potencial de rendimiento de genotipos de trigo en condiciones de estrés de sequía, (2) Determinar los índices de susceptibilidad y tolerancia a la sequía y (3) Identifi ar genotipos tolerantes a la sequía. Se estudiaron nueve genotipos introducidos del CIMMYT y la variedad comercial "Centenario" de trigo harinero (*Triticum aestivum* L.) en un ambiente con irrigación completa durante el ciclo de vida y otro ambiente con estrés de sequía terminal o riego deficitar o aplicado en la fase de bota (Z4.0). Se empleó un diseño de bloques completos al azar con tres repeticiones. Se realizaron evaluaciones de características agronómicas y de calidad siguiendo los protocolos establecidos para cada característica evaluada y se determinó los índices de tolerancia al estrés (ITE), productividad media (PM), = Producción media geométrica (PMG), índice de tolerancia (TOL) y el índice de susceptibilidad al estrés (SSI). La reducción en el rendimiento de granos varió de 17.95 % al 33.27 %, principalmente por efecto de la sequía. El SSI varió de 0.65 (G-3) a 1.21 (G-6 y G-9), mientras que el TOL varió de 1 316.8 (G-3) a 3 142.68 (G-7). Los índices MP, STI y GMP permitieron identificar a 5 genotipos con mayor tolerancia a condiciones de riego y de estrés: G-1, G-2, G-7, G-8 y G-10. Estos resultados son importantes para el desarrollo de nuevas variedades que se adapten a condiciones de sequía y enfrentar el cambio climático en la región Andina.

Palabras claves: trigo harinero, sequia, índice de tolerancia, genotipos.

Introduction

Wheat is one of the staple foods of Peru and around 80 % of its demand is satisfied mainly through imports. Almost all of the cultivated area of wheat is found in the Andean region above 3,000 m altitude, wheat cultivation is carried out by small-scale farmers, using low to medium technology and mainly allocating production to family consumption. Agriculture in the high Andean region is generally carried out under rainfed conditions or a rain regime characterized by its erratic distribution, affecting the crop at different stages of development with periods of different drought durations and which are exacerbated by the effect of climate change. Farmers in marginal areas with adverse climate problems must have wheat varieties with greater tolerance to drought to ensure their harvest in the high mountains of Peru.

Drought affects wheat yield and quality because it has negative effects on photosynthesis, chLorophyll content, plant height, yield, and yield components (Rivero et al. 2007; Sallam et al. 2015; Sallam et al., 2018). According to Bidinger et al. (1987) yield under water stress generally depends on three factors: potential yield, flowering date and stress tolerance, and the magnitude of the effect of each of these factors on yield under stress is associated with the species and its varieties. Bauder (2001) reported for wheat that drought stress at maturity decreases yield by 10 %, but moderate stress during early vegetative growth has no effect on yield.

Genetic improvement of drought tolerance is difficul due to its quantitative nature and the number of interacting traits. The level or severity of drought stress and the phenological state of the crop must be considered in the selection process. Drought can occur at any stage of crop development with different degrees of intensity. In most of the studies carried out, the effect of drought in the final phase of cultivation is measured, in which many yield components are defined. The effect of drought should also be considered in the growth phase of the crop considering the photosynthetic reserves accumulated in the stem before flowering and which contribute to the final yield of the crop (Gallagher et al., 1976; Abid et al., 2016).

Many investigations related to the response and determination of tolerance levels of wheat genotypes to drought (Manes et al., 2012; Khan et al., 2013; Aktas, 2016; Mwadzingeni et al., 2016; Patel et al., 2017; Sallam et al., 2018; Eid & Sabry, 2019). Kiliç & Yağbasanlar (2010) point out that a selection strategy should consider factors such as early flowering, grain filling period, late maturation, number of grains per spike, spike weight and length spike, to increase the yields under drought conditions.

Many approaches have been established to identify and select genotypes with the highest drought tolerance. One of the most widely used is the determination of the yield of genotypes in environments with drought problems and environments with optimal humidity to identify and select genotypes that have a high yield in both environments, since a genotype with high yield potential will work well in most environments; however, this method has limitations since it does not consider the concept of yield stability and adaptation to a stressful environments (Ceccarelli & Grando, 1991; Blum, 2005; Thiry et al., 2016; Patel et al., 2017). The other approach is the use of indices that measure drought susceptibility and tolerance (Fischer & Maurer, 1978; Rosielle & Hamblin, 1981; Fernández, 1992; Thiry et al., 2016; Patel et al., 2017; Khayatnezhad & Gholamin, 2018; Patel et al. 2019, Mohammadi, 2019). Many of them are efficien in identifying high-yield genotypes under conditions of moisture stress (Talebi et al., 2009). Patel et al. (2019) in a study carried out with 20 wheat genotypes and 13 different indices used, found highly significant differences for potential yield and yield under stress conditions (Yp and Ys) and all drought tolerance indices, except TOL, indicated that the genotypes under study have different genes for the characteristics used in the determination of the yield and drought tolerance indices.

This study was conducted to (1) determine the yield potential of wheat genotypes under drought stress conditions, (2) determine the drought susceptibility and tolerance indices, and (3) identify tolerant genotypes to drought.

Material and methods

Wheat genotypes

Nine genotypes and the "Centenario" commercial variety of bread wheat (*Triticum aestivum ssp. aestivum*) were studied (Table 1). The genotypes were selected under marginal conditions in the central highLands for their good yield performance and their resistance to yellow rust disease or *Puccinia striformis* f. sp. Tritici. These were introduced from the international breeding center of wheat and maize (CIMMYT).

Field experiment

The experiments were conducted from July to December 2019 in the research program in cereals and native grains of the National Agrarian University La Molina, located in Lima, Peru.

Table 1. Wheat genotypes (*Triticum aestivum* L.) studied in the experiment established in La Molina, Lima, Peru.

ID	Genetic material
G-1	BABAX/LR42//BABAX*2/4/SIN/TRAP#1/3/KAUZ
G-2	KAMB1/MNNK1//WBLL1
G-3	HD2281/YACO/3/KAUZ*2/TRAP//KAUZ
G-4	SITTA/PRINIA//FRTL
G-5	TEMPORALERA M 87*2/KONK
G-6	CENTENARIO
G-7	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
G-8	BABAX/LR42//BABAX*2/3/PAVON 7S3,+LR47
G-9	PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1
G-10	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ

The irrigation water used was from the river and distributed by gravity using the furrow of the field. Two experiments were raised, one of them was the control, which was watered throughout the life cycle considering the requirements of the crop and the soil moisture that was permanently monitored. In the second experiment, a terminal drought stress was applied in the booting phenological phase (Z4.0).

The surface of each experiment was 108 m^2, made up of 30 experimental plots of 9.6 m^2 each one. The experiment followed the protocols of a commercial wheat field. The sowing was carried out by hand and with a continuous stream, using a dose of 200 kg of seed per hectare. The N-P-K fertilization dose used in both environments was 100-60-00 kg/ha.

Data collection

Agronomic traits

Days to flowering, days to maturity and plant height were determined.

Yield and yield components

Grain yield (kg/ha), number of spikes per square meter, the number of grains per spike and thousand grains weight (g).

Quality data

Protein content and hectoliter weight; following the established protocols for evaluating these characteristics.

Tolerance stress indices

Drought resistance indices were calculated using the formulas in Table 2

Statistical analysis

A randomized complete block design with three replications was used. For each experiment the analysis of variance (ANOVA) of the evaluated characteristics was made and then for the combined ANOVA the homogeneity of variance was determined using the Barlett test (p = 0.05). The mean of the treatments was compared using the Duncan test (p = 0.05).

range varied from 100 cm to 108.3 cm, the lowest value corresponded to Genotypes 6 and 8, and the highest value for Genotype 5 and the mean value was equal to 103.3 cm.

The yield data and yield components are presented in Table 4 and it can be seen that the genotype values differed significantly between them (Duncan's test α = 0.05). The grain yield had an average of 8683.1 kg/ha and the range varied from 7335.3 kg/ha to 9614.6 kg/ha; Genotype 3 had the lowest value and Genotype 10 had the highest value. For the number of spikes per square meter, an average equal to 335.2 spikes per square meter and a range of 300 spikes per square meter to 374.8 spikes per square meter were observed; Genotype 7 was the one with the lowest number of spikes per square meter and Genotype 5 was the one with the highest

Table 2. Tolerance stress indices and their formulas

Indices	Formulas	Reference
Mean productivity (MP)	$MP = (Y_s + Y_p)/2$	Rosielle & Hamblin (1981)
Stress tolerance index (STI)	$STI = (Y_p \times Y_s)/Y_p^2$	Fernández (1992)
Geometric mean productivity (GMP)	$GMP = \sqrt{(Y_s \times Y_p)}$	Fernández (1992) and Schneider et al. (1997)
stress susceptibility index (SSI)	$SSI = (1-Y_s/Y_p)/SI$	Fischer & Maurer (1978)
Stress intensity (SI)	$SI = [1-Y_s/Y_p]$	Fischer & Maurer (1978)
Tolerance index (TOL)	$TOL = Y_p - Y_s$	Rosielle & Hamblin (1981)

Ys= Yield under drought conditions
Yp= Yield potential

Results

Agronomic efficienc experiment of bread wheat - control treatment (AEEW-CT)

Table 3 shows the results of the mean squares of the analysis of variance of the AEEW-CT experiment carried out for grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, plant height, grain protein and hectolitric weight. At the block level, there was a highly significant variation for yield, number of spikes per square meter, and significant differences in the number of spikes per square meter, days to maturity and protein content of the grain. Similarly, highly significant differences were observed at the genotype level for yield, number of grains per spike and days to maturity. The coefficien of variation for yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, plant height, protein content of the grain and hectolitic weight were equal to 7.99 %, 11.20 %, 9.92 %, 3.37 %, 3.59 %, 6.20 %, 3.96 %, and 2.74 %; respectively.

The results of the evaluations carried out for agronomic characteristics are presented in Table 4. It could be seen that all the characters differe significantly except for plant height (Duncan's Test, α = 0.05). For days at the heading stage, an average equal to 71.6 days and a range varying from 66 days to 76 days were observed, with the lowest value corresponding to Genotype 3 and the highest to Genotype 9. For days to maturity, the mean was equal to 119.7 days and the range varied from 111.67 days to 130.0 days, the Genotype 6 had the lowest value and the highest value was for Genotype 4. For plant height, the number of spikes per square meter. The number of grains per spike in the experiment presented a range that varied from 47.07 number of grains per spike to 72.07 number of grains per spike, the lowest value corresponded to Genotype 5 and the highest to Genotype 8 and the mean value was equal to 55.38 number of grains per spike. For the thousand grains weight, a range of 50.89 g to 61.98 g was observed, the lowest value corresponded to Genotype 8 and the highest to Genotype 2 and the average value was equal to 57.43 g.

Table 4 shows the quality data: grain protein and hectolitric weight. The results differed significantly (Duncan's test, α = 0.05). For grain protein, the range varied from 12.21 % to 13.42 %; Genotype 1 appeared with the lowest value and Genotype 4 had the highest value and the average was equal to 12.8 %. For the hectolitric weight or specific weight (kg/hL), an average value equal to 79.3 kg/hL and a range from 76.42 kg/hL to 82.89 kg/hL was observed.

Table 3. Mean squares of the analysis of variance of grain yield, number of spikes per square meter, number of grains per spikes, thousand grains weight (g), days to maturity, plant height (cm), protein of grains (%) and hectolitric weight (kg/hL) of the control experiment of the assessment of tolerant wheat genotypes (Triticum aestivum L.) to drought under conditions of La Molina LM 2019B.

Variation source	df	Yield (kg/ha)	Number of spikes per square meter	Number of grains per spike	Thousand grains weight (g)	Days to maturity	Plant height (cm)	Protein content (%)	Hectolitric weight (kg/hL)
Block	2	4106985**	13163.7**	167.517*	2.053	100.833*	5.833	0.25105	23.1868*
Genotypes	9	1808957**	1692.1	159.512**	47.711	112.593***	24.074	0.42645	9.8199
Error	18	482042	1410	30.173	3.756	18.426	41.019	0.2551	4.7067
Total	29								
CV (%)		7.9959	11.201	9.9187	3.3746	3.5871	6.198	3.9591	2.7365
Mean		8683.143	335.2381	55.38	57.431	119.6667	103.3333	12.7573	79.2787

Significance Level: 0 '*** 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1.

Agronomic efficienc experiment of bread wheat - drought terminal treatment (AEEW-DT)

Table 5 showed the results of the mean squares of the analysis of variance of the AEEW-DT experiment carried out for grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, plant height, grain protein and hectolitric weight. At the block level, there was a highly significant variation for yield and significant differences for number of grains per spikes. Likewise, highly significant differences were observed at the genotype level in yield and number of grains per spike and significant differences for days to maturity. The coefficien of variation for yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, plant height, protein content of grains and hectolitic weight were equal to 5.46 %, 13.53 %, 7.11 %, 7.19 %, 2.98 %, 6.24 %, 3.29 %, and 3.25 %, respectively.

Table 6 presents the results of the evaluations of the agronomic characters and the Duncan test (α = 0.05) showed that there were differences for the evaluated characteristics except for plant height. For days to maturity, the range varied from 111.7 days to 130 days, the lowest value corresponded to Genotype 1 and the highest to Genotype 7 and the mean value was equal to 119.67 days. The plant height had a range that varied from 96.67 cm to 108.33 cm, the lowest value corresponded to Genotypes 8 and 5 and the highest to Genotype 9 and the mean value was equal to 102.8 cm.

The grain yield and the yield components presented values that differed significantly (Duncan test, α = 0.05) and are presented in Table 6. In grain yield, it was observed an average value equal to 6 290.1 kg/ha and a range that varied from 577 677.08 kg/ha to 7 097.84 kg/ha; with the lowest value for Genotype 4 and the highest to Genotype 2. The number of spikes per square meter varied from 251.91 to 355.71 spikes per square meter; the Genotype 9 had the

Table 4. Mean values of grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight (g), days to maturity, plant height (cm), grain protein (%) and hectolitric weight of the control experiments of the assessment of tolerant wheat genotypes (*Triticum aestivum L*) to Drought under Conditions of La Molina LM 2019B.

Genotypes	Genetic material	Yield (kg/ha)	Number of spikes per square meter	Number of grains per spike	Thousand grains weight (g)	Days to maturity	Plant height (cm)	Protein content (%)	Hectolitric weight (kg/hL)
1	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9052.33ab	323.33ab	59.53b	58.83ab	115cd	101.67a	12.21b	79.19abc
2	KAMB1/MNNK1//WBLL1	8688.64ab	344.76ab	49.63bc	61.98a	121.67bc	101.67a	12.42b	76.42c
3	HD2281/YACO/3/KAUZ*2/TRAP//KAUZ	7335.28c	307.14ab	52.4bc	50.90d	115cd	101.67a	12.88ab	78.01bc
4	SITTA/PRINIA//FRTL	7796.42bc	335.71ab	47.57c	59.04ab	130a	106.67a	13.42a	80abc
5	TEMPORALERA M 87*2/KONK	7900.50bc	374.76a	47.07c	60.07ab	123.33ab	108.33a	13.17ab	77.35bc
6	CENTENARIO	8688.64ab	368.57ab	54.73bc	54.42c	111.67d	100a	13.04ab	79.56abc
7	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9541.90a	300b	58.33b	59.46ab	123.33ab	105a	12.62ab	79.30abc
8	BABAX/LR42//BABAX*2/3/PAVON 7S3,+LR47	9351.90a	330ab	72.07a	50.89d	115cd	100a	12.38b	80.81ab
9	PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1	8832.28ab	326.67ab	56.53bc	60.91ab	126.67ab	105a	12.76ab	79.27abc
10	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9614.59a	341.43ab	55.93bc	57.80b	115cd	103.33a	12.66ab	82.89a

lowest number of spikes per square meter and Genotype 5 had the highest number of spikes per square meter and the average value was equal to 305.91 spikes per square meter. For the number of grains per spike, was observed an average value equal to 53.4 number of grains per spike and a range that varied from 45.77 number of grains per spike to 73.27 number of grains per spike, the lowest value corresponded to Genotype 2 and the highest to Genotype 8. For the thousand grains weight (g) the range varied from 44.31g to 63.21 g, the lowest value corresponded to Genotype 8 and the highest to Genotype 2 and the average value was equal to 51.9 g. Amado (2016) evaluated the effect of the hydric deficit from the heading stage to maturity, in 15 bread wheat genotypes, under controlled conditions, a reduction in the grain yield in a range of 35 % to 68 % and among yield components a maximum reduction in the number of grains per spike of 47 %, in the weight of grains of 68 % and in the harvest index of 42 % were observed. Ayed et al. (2017) studied the response to water stress of three varieties of durum wheat (Mâali, Nasr and Salim) and two varieties of bread wheat (Tahent and Utique), observing that the components plants per square meter, spikes per square meter, grains per spike and thousand grains weight were significantly affected by water stress

Table 6 also shows the results of the grains protein content and the hectolitric weight or specific weight (kg/hL). Duncan's test (α = 0.05) showed that there were significant differences in the results. For grain protein, it was obtained a range that varied from 11.4 % to 12.36 %; Genotype 7 appeared with the lowest value and Genotype 9 had the highest value and the average value was equal to 11.91 %. For the hectolitric weight the range varied from 76.84 kg/hL to 82.80 kg/hL; Genotype 2 had the lowest value and Genotype 4 had the highest hectolitric weight and the mean value was equal to 79.82 kg/hL.

Table 5. Mean squares of the analysis of variance of grain yield, number of spikes per square meter, number of grains per spikes, thousand grains weight (g), days to maturity, plant height (cm), protein of grains (%) and hectolitric weight (kg/hL) of the drought experiment of the assessment of tolerant wheat genotypes (*Triticum aestivum* L.) to drought under conditions of La Molina LM 2019B.

Variation source	df	Yield (kg/ha)	Number of spikes per square meter	Number of grains per spike	Thousand grains weight (g)	Days to maturity	Plant height (cm)	Protein content (%)	Hectolitric weight (kg/hL)
Block	2	784287**	470.3	68.48*	0.43	10.83	39.7	0.03	1.27
Genotypes	9	567592**	3294.5	190.63***	83.95***	121.83***	51.13	0.28	8.05
Error	18	118124	1712.3	14.4	13.91	12.69	41.18	0.15	6.74
Total	29								
CV (%)		5.46	13.53	7.11	7.19	2.98	6.24	3.29	3.25
Mean		6290.09	305.95	53.37	51.90	119.67	102.8	11.91	79.82

Significance Level: 0 '*** 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1.

Table 6. Mean values of grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight (g), days to maturity, plant height (cm), grain protein (%) and hectolitric weight of the drought experiments of the assessment of tolerant wheat genotypes (*Triticum aestivum* L) to drought under conditions of La Molina LM 2019B.

Genotypes	Genetic material	Yield (kg/ha)	number of spike per square meter	Number of grains per spike	Thousand grains weight (g)	Days to maturity	Plant height (cm)	Protein content (%)	Hectolitric weight (kg/hL)
1	**BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ**	6346.70bc	316.67abc	51.63bcd	50.48bcd	111.67f	101.67a	11.91abc	79.18ab
2	**KAMB1/MNNK1//WBLL1**	7097.84a	299.52abc	45.77d	63.21a	123.33bcd	103.33a	11.97abc	76.84b
3	**HD2281/YACO/3/KAUZ*2/TRAP//KAUZ**	6018.48c	342.86ab	56.8b	45.62d	113.33f	98.33a	11.9abc	81.19ab
4	**SITTA/PRINIA//FRTL**	5776.77c	291.43abc	47.67cd	55.58b	126.67ab	106.67a	12.29ab	82.80a
5	**TEMPORALERA M 87*2/KONK**	6344.45bc	355.71a	45.8d	50.76bcd	120cde	106.67a	11.79abc	79.83ab
6	**CENTENARIO**	5814.08c	288.10abc	50.47bcd	49.74bcd	115ef	101.67a	12.14abc	79.03ab
7	**BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ**	6399.23bc	314.29abc	52.63bcd	52.49bc	130a	106.33a	11.40c	79.59ab
8	**BABAX/LR42//BAB-AX*2/3/PAVON 7S3,+LR47**	6368.0bc	265.71bc	73.27a	44.31d	118.33def	96.67a	11.53bc	81.43ab
9	**PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1**	5893.20c	251.91c	54.5bc	53.93b	125abc	108.33a	12.36a	79.30ab
10	**BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ**	6842.17ab	333.33ab	55.2b	52.88b	113.33f	98.33a	11.79abc	79.05ab

A combined analysis of the control experiment (complete irrigation) and drought treatment (deficit irrigation)

The results of the mean squares of the combined analysis of variance of the control experiment (complete irrigation) and drought treatment (deficit irrigation) carried out for grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, plant height, grain protein, and hectolitric weight are shown in Table 7. It was appreciated at the treatment level (control and drought) that there was a high y significant variation in yield, thousand grains weight and grain protein and significant variation for number of spikes per square meter. At the block level, highly significant differences were observed for yield and significant differences for number of spikes per square. At the genotype level, highly significant differences were obtained for yield, days to maturity and thousand grains weight and significant differences in protein content. For the genotype X treatment interaction, significant differences were observed for grain yield. The coefficien of variation for grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight, days to maturity, grain protein, and hectolitric weight were 7.54 %, 13.07 %, 10.56 %, 3.63 %, 6.19 %, 5.31 %, 3.65 % and 3.08 %, respectively.

The results of the evaluations carried out for the agronomic traits of the genotypes are shown in Table 8. Duncan's test (α = 0.05) showed no significan differences for days to maturity. However, there were significant differences for plant height. For days to maturity, it was observed that both treatments reach the maturity stage at 119.67 days. For plant height the value in the control-complete irrigation treatment was equal to 103.3 cm and that in the terminal drought-deficit irrigation treatment was 102.8 cm

For yield and yield components, the average results of all genotypes showed significant differences for yield, number of spikes per square meter and thousand weight grains (Duncan test α = 0.05) (Table 8). It could be seen that the grain yield in the control-complete irrigation treatment was equal to 8683.14 kg/ha and that in the terminal drought-irrigation deficit treatment was equal to 6 290.09 kg/ha. For the number of spikes per square meter, a value of 335.24 spikes per square meter for the control-complete irrigation treatment and a result of 305.95 spikes per square meter for the terminal drought-deficit irrigation treatment was found. The number of grains per spike, in the control-complete irrigation treatment was equal to 55.38 number of grains per spike and in the terminal drought-deficit irrigation treatment was equal to 53.37 number of grains per spike. For the thousand grains weight (g), the value in the control-complete irrigation treatment was equal to 57.43 g and that in the terminal drought-deficit irrigation treatment was 51.9 g. Abayomi & Wright (1999) point out that drought stress can reduce all yield components, especially the number of fertile spikes per unit area and the number of grains per spike. Kiliç & Yağbasanlar (2010) in a study of 14 wheat genotypes (*Triticum turgidum* ssp. Durum) under conditions with and without drought stress and found that drought stress reduced the number of days of heading, grain filling period, the number of days to maturity, plant height, spike number per square meter, peduncle length, ear length, number of grains per spike, thousand grains weight, whereas the chlorophyl content increased, the content of grain protein and SDS sedimentation. Spikelets per spike were not affected by drought stress, and they point out that the differenti l response of the genotypes shows the different levels of drought tolerance capacity of the wheat genotypes studied. Askary et al. (2018) studied the effect of drought stress on the yield and some physiological characteristics of six wheat cultivars, and point out that drought stress decreased grain yield. Cultivars 'Alvand' and 'Chamran' showed the highest level of photosystem II (PSII) photochemical efficien , membrane stability and grain yield under drought stress and were considered the most drought stress tolerant cultivars in their investigation. Mohammadi (2019), indicated a wide variation in the yield of the wheat genotypes studied under rainfed conditions (642 to 5603) kg/ha and supplementary irrigation conditions (931–6389 kg/ha) with an average of 2686 kg/ha and 3516 kg/ha, respectively, over four years and showing a 24 % increase in yield productivity under irrigation compared to rainfed conditions.

Table 7. Mean squares of the combined analysis of variance of grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight (g), days to maturity, plant height (cm), protein of grains (%) and hectolitric weight (kg/hL) of the control experiment (complete irrigation) and drought treatment (deficit irrigation) of tolerant wheat genotypes (*Triticum aestivum* L.) to drought under conditions of La Molina LM 2019B.

Variation source	df	Yield (kg/ha)	Number of spikes per square meter	Number of grains per spike	Days to maturity	Plant height (cm)	Thousand grains weight (g)	Proteíns content (%)	Hectolitric weight (kg/hL)
Treatment	1	85900314***	12864.8*	60.4	0	4.27	459.01***	10.83***	4.47
Block	2	4235628***	8376*	10.98	32.92	11.52	1.13	0.11	13.29
Genotypes	9	1651012***	2722.9	331***	215.93***	64.27	118.57***	0.51*	11.75
Trat x Gen	9	725537*	2263.7	19.15	18.512	10.93	13.09	0.19	6.12
Error	38	318797	1755.7	32.96	18.88	40.73	8.44	0.20	6.01
Total	59								
CV (%)		7.54	13.07	10.56	3.63	6.19	5.31	3.65	3.08
Mean		7486.62	320.6	54.38	119.67	103.07	54.67	12.33	79.55

Significance Level: 0 '*** 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1.

Table 8. Mean values of grain yield, number of spikes per square meter, number of grains per spike, thousand grains weight (g), days to maturity, plant height (cm), protein of grains (%) and hectolitric weight (kg/hL) of the control experiment (complete irrigation) and drought treatment (deficit irrigation) of tolerant wheat genotypes (*Triticum aestivum* L.) to drought under conditions of La Molina LM 2019B.

Treatment	Yield (kg/ha)	Number of spikes per square meter	Number of grains per spike	Thousand grains weight (g)	Days to maturity	Plant height (cm)	Proteíns content (%)	Hectolitric weight (kg/hL)
Control	8683.14a	335.24a	55.38a	57.43a	119.67a	103.33a	12.7a	79.82a
Drought	6290.09b	305.95b	53.37a	51.90b	119.67a	102.8b	11.91b	79.28a

Duncan's test (α = 0.05) also showed that there were significant difference for grain protein (%) (Table 8). The protein content of the grains in the control-complete irrigation treatment presented a value of 12.7 % and that in the terminal drought-deficit irrigation treatment was 11.91 %. For the hectolitric weight, the value for the control-complete irrigation treatment was equal to 79.28 kg/hL and for terminal drought-deficit irrigation, it was equal to 79.82 kg/hL.

Comparing the values obtained in the different characters evaluated in the control-complete irrigation treatments and the terminal drought-deficit irrigation treatment, a greater reduction in grain yield, number of spikes per square meter, number of grains per spike and thousand grains weight equal to 27.6 %, 8.7 %, 3.6 %, and 9.6 %, respectively.

Determination of stress indices to drought

The stress intensity (SI) equal to 0.3 for all genotypes studied are shown in Table 9. This value can be classified as moderate stress compared to that reported by Mohammadi (2019), who studied three levels of drought: SI<0.4: low 0.4<SI<0.7: moderate and SI>0.7: severe stress. Patel et al. (2019) recommended the use of moderate drought stress environments to detect drought tolerant genotypes rather than severe drought stress environments.

Considering the stress indices yield losses percentage (YL), tolerance index (TOL), and stress susceptibility index (SSI), the genotypes (G-2), (G-3) and (G-5), reached the lowest values for these indices so they would be the ones with the highest tolerance to water stress under the conditions of the experiment.

The highest values for the mean productivity (MP) corresponded to the genotypes (G-2), (G-7), (G-8) and (G-10).

For geometric mean productivity (GMP), the highest values were observed in the genotypes (G-2), (G-7) and (G-10).

Similarly, the highest values of the stress tolerance index (STI) corresponded to the genotypes (G-2), (G-7) and (G-10).

Among the genotypes that showed better behavior under stress conditions, genotype G-2 stands out, which had the highest value of MP, GMP and STI and low values of YL, TOL and SSI. The grains yield of genotype G-2 under control conditions-complete irrigation was equal to 8 688.64 kg/ha and that under stress-deficit irrigation conditions was equal to 7 097.84 kg/ha.

Talebi et al. (2009) suggested that the selection of drought tolerance in wheat could be carried out by selecting for high MP, BPM and STI under stress and without stress, and concluded that among the genotypes studied, GW 173, GW 487, GW 488 and GW 477 could be considered as superior wheat genotypes with higher stress resistance and better yield potential under irrigation and stress conditions.

Mohammadi (2019) pointed out that a good yield of genotypes under irrigation and in drought conditions leads to high values of STI, MP, GMP, YSI and YI; and low values of TOL and SSI.

The correlation coefficien showed that the STI, GMP and MP indices were the ones that best correlated with grain yield in both environments, presenting positive highly significant values (Table 10); as reported by Zebarjadi et al. (2012) in a study conducted with 20 wheat genotypes.

Alternatively, the TOL and SSI indices presented significant positive correlation values 0.831 and 0.703; respectively, for the control experiment; while for the drought treatment the correlation coefficient were negative and not significant (-0.116 and -0.310), for this reason the use of these indices in the identification of genotypes tolerant to stress conditions would be limited, since when obtaining significant coefficient of correlation only with one environment (without stress) would imply that the selected genotypes would have an optimal behavior only under irrigation conditions. Golabaldi et al. (2006) in their study with durum wheat genotypes found similar results when correlating the mentioned indices with the average yields of the environment with stress and without stress.

According to the correlation coefficient obtained in Table 10, the STI, GMP and MP indices were the ones that helped distinguish genotypes with a high productive capacity and tolerant to drought conditions of this experiment. Khodarahmpour et al. (2011); Mohammadi et al. (2011); Sareen et al. (2012) and Thiry et al. (2016) postulated that these indices are adequate for selecting genotypes with high performance in environments with and without stress. Similarly, Pourdad (2008) and Golabadi et al. (2006) pointed out that STI and GMP indices are good for selecting genotypes with stress tolerance. However, Khayatnezhad et al. (2010), indicated that these indices may not be accurate to identify high performing genotypes in environments with stress and without stress.

Ayed et al. (2017) reported a positive and significant correlation coefficien between Ys (grain yield in stress) and Yp (yield potential) with the STI and MP indices, and with this result he could detect that the 'Salim' variety was the genotype most susceptible to drought, while the 'Nasr' variety was the most drought tolerant genotype and therefore the most suitable for cultivation in semi-arid regions.

Using the STI, GMP and MP indices, Mohammadi (2019) identified the G-2 genotype (new cultivar) and the improved G-8 line as the most drought stress tolerant genotypes, implying that the indices used were useful to identify genotypes that perform well without stress and relatively well under severe stress and he could select the G-4 and G-7 genotypes with good yield under stress using the TOL and SSI indices.

Table 9. Grain yield values under total irrigation conditions (Yp), deficit irrigation (Ys), percentage of yield loss due to drought stress (YL), Stress Susceptibility Index (SSI), Stress Intensity (SI), Tolerance Index, (TOL) Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI) of the assessment of tolerant wheat genotypes (*Triticum aestivum* L.) to drought in conditions of La Molina LM 2019B.

Genotipes	Genetic material	Ys (kg/ha)	Yp (kg/ha)	YL (%)	SI	MP	STI	GMP	TOL	SSI
1	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9052.33	6346.70	29.9	0.3	7,699.52	1.45	7,579.74	2,705.63	1.08
2	KAMB1/MNNK1//WBLL1	8688.64	7097.84	18.3	0.3	7,893.24	1.56	7,853.06	1,590.79	0.66
3	HD2281/YACO/3/KAUZ*2/TRAP//KAUZ	7335.28	6018.48	18.0	0.3	6,676.88	1.12	6,644.34	1,316.80	0.65
4	SITTA/PRINIA//FRTL	7796.42	5776.77	25.9	0.3	6,786.59	1.14	6,711.04	2,019.65	0.94
5	TEMPORALERA M 87*2/KONK	7900.50	6344.45	19.7	0.3	7,122.48	1.27	7,079.85	1,556.05	0.71
6	CENTENARIO	8688.64	5814.08	33.1	0.3	7,266.13	1.28	7,119.56	2,904.10	1.21
7	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9541.90	6399.23	32.9	0.3	7,970.57	1.54	7,814.14	3,142.68	1.20
8	BABAX/LR42//BABAX*2/3/PAVON 7S3,+LR47	9351.90	6368.0	31.9	0.3	7,859.66	1.51	7,716.81	2,983.31	1.16
9	PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1	8832.28	5893.20	33.3	0.3	7,362.74	1.32	7,214.60	2,939.08	1.21
10	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9614.59	6842.17	28.8	0.3	8,228.38	1.66	8,110.78	2,772.42	1.05

Table 10. Correlations among different drought stress indices and grain yield under irrigated conditions and drought stress conditions or deficit irrigation of the assessment of tolerant wheat genotypes (*Triticum aestivum* L.) to drought in conditions of La Molina LM 2019B.

	Ys	Yp	STI	MP	GMP	TOL	SSI
Ys	1						
Yp	0.46	1					
STI	0.889***	0.813**	1				
MP	0.930***	0.753*	0.995***	1			
GMP	0.894***	0.807**	0.999***	0.996***	1		
TOL	0.831**	-0.116	0.484	0.567	0.494	1	
SSI	0.703*	-0.310	0.300	0.392	0.311	0.978***	1

Significance Level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1; Yp = Grains yield under Irrigated conditions, Ys = Grain yield under deficient irrigation; STI = Stress Tolerance Index; MP = Mean Productivity; GMP = Geometric Mean Production; TOL = Tolerance Index; SSI = Stress Susceptibility index.

Indentification of tolerants genotypes to drought conditions

The classification of the genotypes studied according to Fernández (1999) is presented in Figure 1 and Table 11. It could be seen that the genotypes G-1, G-2, G-7, G-8, and G-10 were classified in group A, which groups those with high yield under stress and without stress conditions. The G-6 and G-9 genotypes were classified in Group B, which considers genotypes with high yield in ambient without stress. The G-5 genotype was considered in Group C for a good grain yield under stress conditions. The G-3 and G-4 genotypes were grouped in Group D that groups the genotypes with low grain yield in enviroments under stress and without stress. Mohammadi (2019) pointed out that under mild stress there is no response with a clear tendency to drought stress between the improved lines and the local varieties: noting that the modern cultivar Saji in group A was very sensitive in both rainfed and irrigated conditions. Under mild stress, no significant correlation was found between the rainfed and irrigated plots. Under moderate stress, the local varieties were separated from the breeding lines. Most of the improvement lines were grouped in Group B and the local varieties in Group C.

Conclusions

Drought stress affects agronomic traits significantly in different degrees in the genotypes studied, the grain yield varied from 5 776.77 kg/ha (G-4) to 7 097.84 kg/ha (G-2).The susceptibility indices variation (SSI) ranged from 0.65 (G-

Table 11. Classification of genotypes based on their grain yield in a complete control-irrigation enviroment and in a deficit-stress-irrigation ambient of the assessment of tolerant wheat genotypes (*Triticum aestivum* L.) to drought in conditions of La Molina LM 2019B.

Group*	N° of genotype	Genetic material	Ys (kg/ha)	Yp (kg/ha)
Group A	1	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9052.33	6346.7
	2	KAMB1/MNNK1//WBLL1	8688.64	7097.84
	7	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9541.9	6399.23
	8	BABAX/LR42//BABAX*2/3/PAVON 7S3,+LR47	9351.9	6368
	10	BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	9614.59	6842.17
Group B	6	CENTENARIO	8688.64	5814.08
	9	PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1	8832.28	5893.2
Group C	5	TEMPORALERA M 87*2/KONK	7900.5	6344.45
Group D	3	HD2281/YACO/3/KAUZ*2/TRAP//KAUZ	7335.28	6018.48
	4	SITTA/PRINIA//FRTL	7796.42	5776.77

Group A: genotypes expressing uniform superiority in both stress and non-stress conditions.
Group B: genotypes expressing good performance only in yield potential conditions and not under stress conditions.
Group C: genotypes presenting a relatively higher yield only under stress.
Group D: genotypes with poor yield performance in both environments.

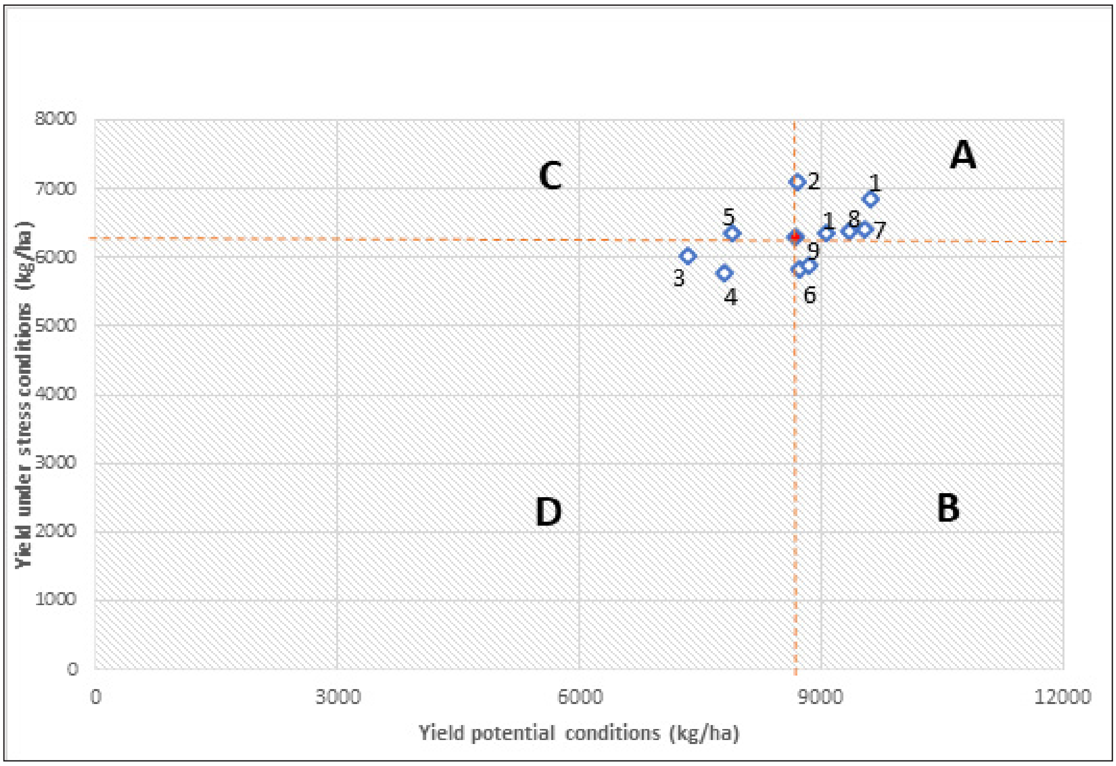

Figure 1. Wheat genotypes (*Triticum aestivum* L.) classified based on the average yield under irrigation conditions and under water stress conditions, in groups A, B, C and D (Fernández, 1992).

3) to 1.21 (G-6 y G-9), meanwhile the drought tolerance indices (TOL) ranged from 1 316.8 (G-3) to 3 142.68 (G-7).The MP, STI and GMP indices allowed to identify the genotypes with the highest tolerance to stress conditions among them BABAX / LR42 // BABAX * 2/4 / SNI / TRAP # 1/3 / KAUZ * 2 / TRAP // KAUZ (G- 1), KAMB1 / MNNK1 // WBLL1 (G-2), BABAX / LR42 // BABAX * 2/4 / SNI / TRAP # 1/3 / KAUZ * 2 / TRAP // KAUZ (G-7), BABAX / LR42 // BABAX * 2/3 / PAVON 7S3, + LR47 (G-8) and BABAX / LR42 // BABAX * 2/4 / SNI / TRAP # 1/3 / KAUZ * 2 / TRAP // KAUZ (G-10).These results are important for developing new varieties that adapt to drought conditions and to face climate change in the Andean region, which will improve the food security for the small farmers and promote a sustainable development of agriculture in the Peruvian highlands.

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Author contributions

Elaboration and execution, development of methodology, conception and design; editing of articles and supervision of the study have involved all authors.

Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

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References

Abayomi, Y. A., & Wright, D. (1999). Effects of water stress on growth and yield of spring wheat (*Triticum aestivum* L.) cultivars. *Tropical Agriculture (Trinidad and Tobago), 76*(2), 120–125.

Abid, M., Tian, Z., Ata-Ul-Karim, S. T., Cui, Y., Lui, Y., Zahoor, R., Jiang, D., & Dai, T. (2016). Nitrogen nutrition improves the potential of wheat (Triticum aestivum L.) to alleviate the effects of drought stress during vegetative growth periods. *Front Plant Sci 7*(981). https://doi.org/10.3389/fpls.2016.00981

Aktas, H. (2016). Drought tolerance indices of selected landraces and bread wheat (*Triticum aestivum* L.) genotypes derived from synthetic wheat. *Applied Ecology and Environmental Research, 14*(4), 177–189. http://www.aloki.hu/pdf/1404_177189.pdf

Amado, A. G. (2016). Efecto del déficit hídrico moderado en la fase fenológica del espigado y madurez de grano en 15 líneas avanzadas de *Triticum Aestivum* L. "Trigo Harinero", la Molina, Lima – Perú. [Bachelor's thesis, Universidad Nacional San Agustin] Institutional repository. http://repositorio.unsa.edu.pe/handle/UNSA/1822

Askary, M., Maghsoudi, A., Saffari, V., Askari, A. (2018). Effects of drought stree on some physiological variables and grain yield of different wheat varieties. *Journal of Plant Physiology and Breeding, 8*(1), 57–73.

Ayed, S., Rezgui, M., Othmani, A., Rezgui, M., Trad, H., Texeira-da Silva, J., Ben M., Ben, H., & Kharrat, M. (2017). Response of Tunisian durum (*Triticum turgidum* ssp. durum) and bread (*Triticum aestivum*

L.) wheats to water stress. *Agrociencia*, *51*(1), 13–26.

Bauder. J. (2001). *Irrigation with Limited Water Supplies.* Montana State University, Communications Services. Montana Hall. Bozeman, MT 59717. USA. http://region8water.colostate.edu/PDFs/Irrigating%20with%20Limited%20Water%20Supplies.pdf

Bidinger, F., Mahalakshimi, V., & Rao, G. (1987). Assessment of drought resistance in pearl millet (*Pennisetum americanum* L. Leeke) I factor affecting yields understress. *Australian Journal Agricultural Research, 38*, 37–48.

Blum A. (2005). Drought resistance, water-use efficien , and yield potential—Are they compatible, dissonant, or mutually exclusive?. *Australian Journal of Agricultural Research, 56*(11), 1159–1168. https://doi.org/10.1071/AR05069

Ceccarelli, S., & Grando S. (1991). Selection environment and environmental sensitivity in barley. *Euphytica, 57*, 157–167. https://doi.org/10.1007/BF00023074

Eid, M. H., & Sabry, S. (2019). Assessment of Variability for Drought Tolerance Indices in Some Wheat (*Triticum aestivum* L.). *Genotypes. Egypt. J. Agron. 41*(2), 79–91. https://doi.org/10.21608/AGRO.2019.10401.1153

Fernández, G. C. J. (1992). Effective selection criteria for assessing plant stress tolerance. In: C. G. Kuo (Ed.), *Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, Publication, Tainan, Taiwan,* 257–270 https://doi.org/10.22001/wvc.72511

Fischer, R. A. & Maurer, R. (1978). Drought resistance in spring wheat cultivars: I. Grain yield response. *Australian Journal of Agricultural Research 29*(5) 897–912. https://doi.org/10.1071/AR9780897

Gallagher, J. N., Biscoe, P.V., & Hunter, B. (1976) Effects of drought on grain growth. *Nature, 264*, 541–542. https://doi.org/10.1038/264541a0

Golabadi, M., Arzani, A., & Maibody, M. (2006). Assessment of drought tolerance in segregation population in durum wheat. *African Journal of Agricultural Research, 1*(5), 162–171. https://www.researchgate.net/publication/228787570_Assessment_of_drought_tolerance_in_segregating_Populations_in_durum_wheat

Kiliç, H. & Yağbasanlar, T. (2010). The effect of drought stress on grain yield, yield components and some quality traits of durum wheat (*Triticum turgidum* ssp. durum) Cultivars. *Not. Bot. Hort. Agrobot. Cluj, 38* (1), 164–170. https://doi.org/10.15835/nbha3814274

Khan, M., Shabbir, G., Akram, Z., Shah, Ansar, M. M., Cheema, N. M., & Iqbal, M. (2013). Character association studies of seedling traits in different wheat genotypes under moisture stress conditions. *SABRAO journal of breeding and genetics, 45*(3), 458–467. https://www.researchgate.net/publication/263001737_Character_association_studies_of_seedling_traits_in_different_wheat_genotypes_under_moisture_stress_conditions

Khayatnezhad, M., Zaeifizadeh, M., & Gholamin, R. (2010). Investigation and selection index for drought stress. *Australian Journal of Basic and Applied Sciences, 4*(10), 4815–4822.

Khayatnezhad, M., & Gholamin, R. 2018. The new formula is proposed for drought resistance for seed selection on Breeding program (DSTI). Sci. Agri. 21 (2), 2018: 73-76.

Khodarahmpour, Z., Choukan, R., Bihamta, M. R., & Hervan, E. M. (2011). Determination of the best heat stress tolerance indices in maize (*Zea mays* L.) inbred lines and hybrids under Khuzestan Province conditions. *Journal of Agricultural Science* *and Technology 13*, 111–121. http://jast.modares.ac.ir/article-23-6969-en.html

Manes, Y., Gomez, H., PuhL, L., Reynolds, M., Braun, H., Trethowan, R. (2012). Genetic yield gains of the CIMMYT international semi-arid wheat yield trials from 1994 to 2010. *Crop Science, 52*, 1543–1552. https://doi.org/10.2135/cropsci2011.10.0574

Mohammadi, R. (2019). The use of a combination scoring index to improve durum productivity under drought stress. *Experimental Agriculture*, 56(2), 161-170 https://doi.org/10.1017/S0014479719000231

Mohammadi, M., Karimizadeh, R., & Abdipour, M. (2011). Evaluation of drought tolerance in bread wheat genotypes under dryland and supplemental irrigation conditions. *Australian Journal of Crop Science, 5*(4), 487-493

Mwadzingeni, L., Shimelis, H., Dube, E., Laing, M. D., & Tsilo T. J. (2016). Breeding wheat for drought tolerance: Progress and technologies. *Journal of Integrative Agriculture, 15*(5), 935–943. https://doi.org/10.1016/S2095-3119(15)61102-9

Patel, J. M., Patel, A. S., Patel, C. R., Pansuria, A. G., Patel, R. M. & Vanapariya, L. G. (2017). Evaluation of selection indices for drought tolerance in some bread wheat genotypes. *Electronic Journal of Plant Breeding, 8*(3), 834–841. https://doi.org/10.5958/0975-928X.2017.00133.8

Patel, J. M., Patel, A. S., Patel, C. R., Mamrutha, H. M., Pradeep, S., & Pachchigar, K. P. (2019). Evaluation of Selection Indices in Screening Durum Wheat Genotypes Combining Drought Tolerance and High Yield Potential. *International Journal of Current Microbiology and Applied Sciences, 8*(4), 1165–1178, ISSN: 2319–7706 https://doi.org/10.20546/ijcmas.2019.804.134

Pourdad, S. S. (2008). Study of drought resistance indices in spring safflow . *Acta Agronomica Hungarica, 56*(2), 203–212. https://doi.org/10.1556/AAgr.56.2008.2.9

Rivero, R. M., Kojima, M., Gepstein, A., Sakakibara, H., Mittler, R., Gepstein, S., & Blumwald, E. (2007). Delayed leaf senescence induces extreme drought tolerance in a flowering plant. *Proc Natl Acad Sci, 104(*49), 19631–19636. https://doi.org/10.1073/pnas.0709453104

Rosielle, A. A., & Hamblin, J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment. *Crop Sci., 21*, 943–946. https://doi.org/10.2135/cropsci1981.0011183X002100060033x

Sallam, A., Hashad, M., Hamed, E-S., & Omara, M. (2015). Genetic variation of stem characters in wheat and their relation to kernel weight under drought and heat stresses. *Journal of Crop Science and Biotechnology, 18*, 137–146 https://doi.org/10.1007/s12892-015-0014-z

Sallam, A., Mourad, A. M. I., Hussain, W., & Baenziger, P. S. (2018). Genetic variation in drought tolerance at seedling stage and grain yield in low rainfall environments in wheat (*Triticum aestivum* L.). *Euphytica 214*, 169. https://doi.org/10.1007/s10681-018-2245-9

Sareen, S., Tyagi, B. S., & Sharma, I. (2012). Response estimation of wheat synthetic lines to terminal heat stress using stress indices. *Journal of Agricultural Science, 4*(10), http://dx.doi.org/10.5539/jas.v4n10p97

Talebi, R., Fayaz, F. & Naji, A. M. (2009). Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Deft.). *General and Applied Plant Physiology, 35*, 64–74.

Thiry, A. A., Chavez, P., Reynolds, M. P., & Davies, W. J. (2016). How can we improve crop genotypes to increase stress resilience and productivity in a future climate? A new crop screening method based on productivity and resistance to abiotic stress. *Journal of Experimental Botany, 67*(19), 5593–5603. https://doi.org/10.1093/jxb/erw330

Zebarjadi, A., Mirany, T., Kahrizi, D., Ghobadi, M., & Nikoseresht, R. (2012). Assessment of drought tolerance in some bread wheat genotypes using drought resistance indices. *Biharean Biologist 6*(2), 94–98.