Cereal Research Communications (2023) 51:207–216
https://doi.org/10.1007/s42976-022-00286-x

ORIGINAL PAPER

Study of relationship between morpho-physiological traits and grain yield under terminal drought stress conditions in barley genotypes

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Received: 26 November 2021 / Accepted: 13 June 2022 / Published online: 29 June 2022

Abstract
Climate change is a major threat to the growth of most crops in arid and semi-arid regions. Drought stress is one of the results of climate change that has a negative impact on the growth and yield of crops. In order to investigate the morpho-physiological traits and their relationship with grain yield in barley and to determine the best criteria for selection under terminal drought stress conditions, 20 barley genotypes (*Hordeum vulgare L.*) were evaluated during two cropping seasons 2016–2017 and 2017–2018 under terminal drought stress conditions (irrigation cut at 50% heading) using a randomized complete block design with three replications. During the experiment, days to heading, days to maturity, number of fertile tillers, plant height, peduncle length, peduncle weight, spike length, number of grain per spike, 1000-kernel weight, remobilization, remobilization efficiency, biological yield, harvest index and grain yield were measured. Variance analysis of the studied traits showed significant difference for most traits for genotype effects. Mean comparison showed that the highest grain yield was related to genotypes 16 and 11. Correlation, regression and path analysis showed that remobilization, harvest index, biological yield and peduncle weight had the most effects on grain yield under drought stress conditions. This indicates that these traits can be used in barley breeding for grain yield improvement under terminal drought stress conditions. Three genotypes, 4, 11 16 with the highest remobilization, harvest index, biological yield and peduncle weight achieved higher grain yields under the stress conditions.

Keywords Barley · Drought · Remobilization efficiency · Morpho-physiological traits

Introduction

Due to the rate of population growth, the world's population is expected to reach 9 billion by 2050 (FAO 2016). Therefore, the increase in crop production should be between 110 and 170% of current production in order to be able to feed the world's population at that time (Tester and Langridge 2010; Tilman et al. 2011). Climate change is a major threat to the growth of most crops in arid and semi-arid regions. Drought stress is one of the results of climate change that has a negative impact on the growth and yield of crops.

Barley (*Hordeum vulgare* L.) is one of the major cereal crops in the world. In terms of area under cultivation and production, it ranks fourth after wheat, corn and rice (FAO 2016). Although barley has more efficient mechanisms against water scarcity than other cereals, its yield is limited by terminal drought and high temperatures during grain filling (Gonzalez et al. 1999). Plants respond to water stress through multiple physiological mechanisms at the cell, tissue, and plant level. These responses, in addition to duration and its severity, are also related to the developmental stage, morphological and descriptive characteristics of the plant (Guo et al. 2009). Scientists believe that with rising global temperatures and the problems caused by climate change, barley cultivation will expand further due to its excellent adaptation to harsh climatic conditions (Greenway and Muns 1980; Muns and Tester 2008; Nevo and Chen

Communicated by T. Martinelli.

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2010). Although barley is more tolerant to drought stress than other cereals, nevertheless, sensitivity to water shortage and drought stress during the developmental stages, stem elongation and grain filling, leads to yield reduction. Therefore, understanding the mechanisms of drought tolerance is essential to apply proper management of resources (water, soil, plants, etc.) to achieve proper performance especially in arid areas, and reduce plant production costs and thus increase yield. Since basic genetic mechanisms for grain yield and biomass are influenced by the environment, breeding to enhance physiological and morphological traits with high inheritance that are effective in yield has particular importance in breeding programs (Ashraf et al. 2006; Richards et al. 2001). Despite being affected by the environment, grain yield is an index for cereals response to environmental stresses. In very harsh environments (with high stress), total biomass yield may be a better index for expressing stress tolerance than grain yield (Ceccarelli and Grando 1996). There is very strong evidence that show selection for specific drought-tolerant traits can significantly increase yield when soil moisture is an environmental limiting factor (Ceccarelli 1989; Araus et al. 2002; Olivares-Villegas et al. 2007). In applied breeding, these traits are valuable when their improvement is accompanied by higher yield potential and greater adaptability to stress levels. Harvest index is a function of plant using of water after pollination stage in drought stress conditions. If water consumption after pollination is high as a proportion of total water consumption, the harvest index will be high. If soil water is limited, preserving soil water before flowering can be used in grain filling, resulting in increase in harvest index. Therefore, achieving high grain yield depends on the balance between growth before and after pollination (Passioura 1977). Grain filling in barely depends on two sources of carbon. Nourished materials derived from current photosynthesis that are transferred directly to the grain and the ones that are stored in vegetative tissues before or after pollination and remobilized to the grains. Under environmental stresses such as drought, heat and salinity, the dependence of grain filling on stem storage increases.

Iran has always been one of the countries with the most severe droughts in the world, and forecasts show that in the coming years, Iran will continue to experience severe drought periods (Mesgaran et al. 2016). Due to the arid and semi-arid climate of Iran, water as one of the most important sources of production plays an important role in determining the type of agricultural activities. Therefore, the water required by agricultural systems is always very important (Osamu et al. 2005).

The objectives of this study were, to determine the effect of morpho-physiological traits on grain yield in a promising barley lines, and to identify the most important trait(s) affecting grain yield under terminal drought stress conditions.

Materials and methods

This research was conducted to study the effect of morpho-physiological traits on grain yield in promising barley lines under terminal drought stress (irrigation was cut at 50% of heading stage) at during the two cropping seasons 2016–2017 and 2017–2018 in the Yazd Agricultural Research station,. This station is located 31 degrees and 54 min north latitude, 54 degrees and 25 min east longitude and 1236 m above sea level. The average annual rainfall of Yazd city is 32 mm. Other meteorological information is provided in Table 1. To determine the physical and chemical characteristics of the soil at the experiment site, a mixed soil sample consisting of six random points was prepared from a depth of zero to 30 and 30 to 60 cm. Physical and chemical characteristics of soil are presented in Table 2.

In this study, 19 promising barley lines selected from the Advanced Barley line Yield Trial (ABYT, that were tested under terminal drought stress), with Yousef cultivar

Table 1 Meteorological date of Agricultural Research Station of Yazd during 2016–17 and 2017–18 cropping seasons

Year	Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun
	Min. RH (%)	10	13	21	26	25	18	16	14	5
	Max. RH (%)	25	33	51	63	70	59	47	45	13
2016–2017	Rainfall (mm)	0.0	0.0	1.9	1.5	9	1.3	1.7	11.6	0
	Min. temp. (°C)	16.7	10.7	3.6	2.2	2.8	6.6	13.5	18.8	24.0
	Max. temp. (°C)	31.0	25.3	16.1	15.9	15.1	19.8	27.1	32.2	39.1
	Evaporation(mm)	257.7	167.2	90.0	55.4	0.0	110.3	259.7	335.0	480.9
	Min. RH (%)	9.0	11.0	17.0	14.0	22.0	17.0	16.0	19.0	9.0
	Max. RH (%)	26.0	28.0	40.0	41.0	57.0	51.0	46.0	58.0	26.0
2017–2018	Rainfall (mm)	0.0	0.0	0.4	1.2	7.4	1.3	11.1	14.5	0.2
	Min. temp. (°C)	15.6	10.6	3.3	3.7	4.9	9.6	13.4	16.1	24.2
	Max. temp. (°C)	30.7	25.4	16.9	17.9	17.1	22.5	27.1	28.4	37.4
	Evaporation(mm)	262.0	160.8	65.9	0.0	0.0	130.7	246.5	283.0	416.0

Table 2 Physical and chemical properties of soil at the experiment site

Soil depth (cm)	Electrical conductivity EC(ds.m[1])	Acidity PH	Organic carbon O.C%	Total nitrogen %total N	Absorbable phosphorus P(av) mg.kg[1]	Absorbable potassium K(av) mg.kg[1]	Soil texture
0–30	2.4	7.43	1.194	0.05	14.6	472	Sandy Loam
30–60	2.33	7.3	1.067	0.05	16.4	212	Sandy Loam

as a terminal drought tolerant check (20 genotypes in total) (Table 3), were evaluated under terminal drought stress conditions in a randomized complete block design with three replications over two years. These promising barley lines were developed by the Iranian Barley Improvement Programs. The origin of their parents are from ICARDA and Iranian germplasms which are well adapted to Iran conditions and combines drought tolerant and high yielding. The experimental plots were fallow during the previous cropping seasons. Seedbeds were prepared in April by light plowing followed by disking and leveling. The seeding rate was about 350 seeds m^2. Fertilizers were applied based on soil tests, fertilizer application was 32 kg N ha^{-1} and 100 kg P2O5 at planting (ZGS 00) and 40 kg N ha^{-1} at stem elongation (ZGS 31) and before heading (ZGS 40) stages (Zadoks et al. 1974). No disease was observed during the growth period and weeds were controlled using herbicides (Granstar and Puma Extra). Each plot, including 6 rows with length of 6 m and distance of 20 cm were planted on two ridges. Recording and sampling was done during the growing season for different traits and after harvest, grain yield and 1000-kernel weight related to each genotype were measured. After crop ripening, plots were harvested using Wintersteiger plot combine. Grain yield per plot were weighed, then the data were converted to tonnes per hectare ($t.ha^{-1}$).

Morpho-physiological traits of genotypes were measured, depending on kind of traits, starting from the 50% heading stage and the last stage, i.e., physiological maturation. Plant samples consisting of 20 whole stems (including all leaves and spikes) were randomly cut at each plot from three replicates from the ground. Samples are dried after 72 h at 70 °C and then traits such as: biomass weight, peduncle weight (Pe.W) and peduncle length (Pe.L) at flowering time, biomass weight, peduncle weight (Pe.W) and length (Pe.L) at maturity, number of grains per spike (N.Gr/Sp), remobilization (Re.Asmlt), remobilization efficiency of photosynthetic materials (Rem.Eff) were measured. In addition to the above traits, traits such as number of days to heading (DHE), days to maturity (DMA), duration of grain filling (Dur.Fil.), number of fertile tillers (N.Til), grain yield (YLD), 1000-kernel

Table 3 Origin of genotypes examined in field conditions

Genotype	Origin	Name/Pedigree
1	Iran	Yousef(Check)(terminal drought tolerant)
2	Iran	Cr115/Por//Bc/3/Api/CM67/4/Giza120/5/H272/Bgs/3/Mzq/Gva/Alanda-01/6/Nik
3	Iran	Nosrat/5/Ciru/3/Agave/Sumbard400//Marco/4/Petunia1
4	Iran	Bgs/Dajia//L.1242/3/(L.B.IRAN/Una8271//Gloria'S'/3/Alm/Una80)/4/Nik
5	Iran	Dasht//EBC(a)/Badia/3/Sahra
6	Iran	Comino/Yousef
7	Iran	Puebla/Cardo//Tocte/5/Nosrat/4/Rhodes'S'//Tb/Chzo/3/Gloria'S'
8	Iran	Karoon/Kavir 2* /Sadik-10
9	Iran	Fajr30/Sahra//Nik/3/Goharan
10	Iran	LB.Iran/Una 8271//Gloria"S"/Come"s"-11 M/3/Kavir/4/Sadik-10
11	Iran	Nosrat/Goharan
12	Iran	Zarza'S'/Agave'S'//Cardo/3/79W40762/Puebleda/4/Nik
13	Iran	CM67/IPA265//Gustoe/IPA7/3/Goharan
14	Iran	L.131/Cerbel//Alger-Ceres/3/(Gloria"S"/Copal"S")/4/Rhn-03 /5/ Deir Alla 106//Hem/Bc/3/Rihane"S"/4/Nik
15	Iran	Karoon/Kavir 2* //Sadik-10
16	Iran	Nosrat/Sadik-10/3/Rihane//Aths/Bc/4/ Fajr30
17	Iran	Fajr30/Sahra//Nik/3/Goharan
18	Iran	Karoon/Kavir 2* /3/(Gloria'S'/Copal'S'//As46/Aths)
19	ICARDA	26,216/4/Arar/3/Mari/Aths*2/M-Att-73–337-1/5/Barjouj
20	ICARDA	SLB44-56/Lignee131

weight (TKW), biological yield (BY) and harvest index (HI) were also recorded.

The rate of transferred material from stem to grain, which is the difference between the dry weight of the stem after flowering and after maturity based on gram (gr), and the efficiency of the stem in transferring material reserves to the grain, which is based on the percentage of plant dry matter at the time of flowering, was calculated using the following formulas: 1 and 2 (Kobata et al. 1992; Palta et al. 1994):

(1) Rate of remobilization from stem to grain (Re.Asmlt) = Stem dry weight after flowering /Stem dry weight at maturity
(2) Stem efficiency in remobilizing stocks to grain (Rem.Eff) = remobilizing of material from stem to grain / Stem dry weight after flowering × 100.

Data were analyzed using the SAS statistical software for combined analysis of variance and path analysis. Mean comparisons were performed using Least Significant Differences (LSD) test. Years were considered as random variables while the genotypes were treated as fixed variables. Also, Excel and SPSS softwares were used to correlation and Stepwise regression analysis.

Results

In case of assuming the years were considered as random variables, and the genotypes were treated as fixed variables, in order to generalize the results to the environmental conditions of the evaluated area (in terms of number of years), the results of analysis of variance of the measured traits in stress conditions showed that the effect of year on the traits of days to maturity (DMA), duration of grain filling (Dur.Fil), number of fertile tillers (N.Til), plant height (PLH), peduncle length (Pe.L), peduncle weight (Pe.W), remobilization (Re.Asmlt), harvest index (HI) and grain yield (YLD) was significantly different (Table 4). The effect of genotype on days to heading (DHE), days to maturity (DMA), duration of grain filling (Dur.Fil), plant height (PLH), peduncle length (Pe.L), peduncle weight (Pe.W), spike length (Sp.L), number of fertile tillers (N.Til), number of grains per spike (N.Gr/Sp), 1000-kernel weight (TKW), remobilization (Re.Asmlt), remobilization efficiency (Rem.Eff), biological yield (BY) and harvest index (HI) was significant (Table 4). Significance of the effect of genotypes on different traits indicates genetic differences between the studied lines. The existence of effective genetic diversity in the studied traits can be useful for selecting lines with different traits in barley. The effect of genotype × year on days to maturity (DMA), number of fertile tillers (N.Til), plant height (PLH), peduncle length (Pe.L), peduncle weight (Pe.W), remobilization

Table 4 Results of analysis of variance of different traits of barley lines under terminal drought stress conditions

		Average squares of traits														
S.O.V	Df	DHE	DMA	Dur.Fil	PLH	Pe.L	Pe.W	Sp.L	N.Til	N.Gr/Sp	TKW	Re.Asmlt	Rem.Eff	BY	HI	YLD
Year (Y)	1	63.08 ns	1062.07**	1642.8**	12,322.1**	223.8**	403.3**	1.26 ns	472.03**	6992.1*	4320.0**	175.2*	30.2 ns	1.407 ns	6498.8**	32.62**
E1	4	13.59	0.75	17.892	93.48	2.243	3.283	2.938	8.133	1799.4	8.483	13.33	225.9	2.012	66.66	0.012
Genotype (G)	19	191.04**	56.63**	92.08**	321.3**	81.96*	8.394**	1.393**	3.919 *	6996.5**	48.53*	147.7**	1221.3**	2.79 *	162 *	1.193 ns
G × Y	19	42.74**	11.56**	15.01**	77.23**	33.56**	2.614**	0.4967 ns	3.489**	865.1 ns	16.34**	36.1**	356.4**	1.882 ns	146.6**	0.826**
E2	76	4.89	2.557	6.058	32.65	4.463	0.993	0.474	1.264	1039.3	0.863	12.31	96.47	1.171	55.71	0.017
CV		1.794	0.994	6.552	7.579	7.547	17.85	13.283	14.54	13.54	3.081	29.02	24.8	15.71	20.84	5.495

ns, *, **Non-significant, significant at the level of 5% and 1%, respectively

(Re.Asmlt) and remobilization efficiency (Rem.Eff), harvest index (HI) and grain yield (YLD) was observed significant (Table 4). Significance of genotype × year effect indicated that the response of genotypes to environmental conditions and consequently their traits are different during two years in the same spatial conditions.

Mean comparison for all studied traits under terminal drought stress conditions that was calculated by the least significant difference (LSD) test at a probability level of 5% is presented in Table 5. The results showed that the maximum of value for days to heading (DHE) was observed in genotypes 9 and 10 with averages of 135.6 and 131 days, respectively, and the minimum of value was observed in genotypes 17 and 20 with averages of 116.1 and 111.6 days, respectively, and the highest days to maturity (DMA) was related to genotypes 9 and 6 with means of 165.1 and 165 days, respectively, and the lowest value was related to genotypes 16 and 20 with averages of 157.8 and 153 days, respectively (Table 5). Therefore, genotypes 16 and 20 showed the earliest maturity, that is very important to escape the terminal drought stress. Comparison of the mean for the number of fertile tillers showed that the highest number of fertile tillers (N.Til) belonged to genotypes 20 and 16, with an average of 9.167, and the lowest number was observed in genotypes 15 and 6, with an average of 6.833. Under drought stress conditions, lines 8 and 13 with averages of 94 and 84.16 cm, had the highest plant height (PLH) and the lowest value observed in lines 17 and 12 with the average of 65.33 cm, respectively. Lines 8 and 3 had maximum peduncle length (Pe.L) with averages of 34.76 and 33.16 cm, respectively, and lines 11 and 3 had maximum peduncle weight (Pe.W) with means of 8 and 7.50 g, respectively. Mean comparison showed that the highest spike length (Sp.L) was related to genotypes 2 and 3 with 5.950 and 5.916 cm, respectively (Table 5). Mean comparison of number of grains per spike showed that the maximum of value related to 6 and 14 lines with 300/6 and 275.3, respectively, and the minimum values belonged to line 20 with the number of 128.5. Lines 20 and 4 had the highest value for thousand-kernel weight (TKW) with mean of 37.96 and 34.76 gr., respectively, and the lowest value was related to 13 and 14 genotypes with an average of 27.16 and 24.66 gr., respectively. The mean comparison of remobilization of stored carbohydrates in stem to grains (Re.Asmlt) showed that the highest value belonged to genotypes 4 and 16 with means of 19.83 and 19.50 gr, respectively, while lines 10 and 9 had the lower remobilization (Re.Asmlt) with means of 5.72 and 3 gr., respectively (Table 5). Maximum remobilization efficiency (Rem.Eff) percentage was related to genotypes 4 and 20 with averages of 59.28 and 56.27%, respectively, and the lowest was observed in genotypes 10 and 9 with averages of 18.88 and 10.37%, respectively. Under drought stress conditions, lines 4 and 16 had maximum value for biological yield (BY), while lines 6 and 2 had minimum value biological yield (BY), respectively. In terms of harvest index (HI), the mean comparison showed that the highest related to genotypes 5 and 16 with averages of 45.01 and 42.20%, respectively, and the lowest belonged to genotypes 15 and 9 with averages of 28.68 and 23.90 percent, respectively. Mean comparison of grain yield under drought stress conditions showed that the highest were observed in genotypes 16 and 11 with averages of 3.466 and 3.165 tons per hectare (t/ha), respectively, and the lowest value were observed in genotypes 6 and 9 with averages of 1.734 and 1.634 (t/ha) (Table 5). Due to the significant interaction genotype × year, mean comparison of combinations for each trait presented in supplementary table1. Almost all the traits had slightly higher mean values of traits during second cropping season than the first year (Suppl. Table 1). The mean comparison of genotype × year combinations showed that the maximum value for important traits such as grain yield (YLD), harvest index (HI), biological yield (BY), remobilization (Re.Asmlt) and thousand-kernel weight (TKW) were observed in lines 16, 5, 16, 20, 20, respectively, in second year (Suppl. Table1).

The correlation coefficients of different traits were calculated using the average of two-year data to evaluate the relationship between the studied traits in terminal drought stress conditions and to determine the extent of their common changes, (Table 6). The results of correlation coefficients showed that grain yield had positive and very significant correlation with the number of fertile tillers ($r = 0.669^{**}$), peduncle length ($r = 0.589^{**}$), peduncle weight ($r = 0.699^{**}$), remobilization ($r = 0.854^{**}$), remobilization efficiency ($r = 0.795^{**}$), biological yield ($r = 0.627^{**}$) and harvest index ($r = 0.768^{**}$) and had a negative and significant correlation with the number of days to maturity ($r = 0.659^{**}$) and the number of days to heading ($r = -0.439^{*}$) (Table 6). Harvest index had a positive and significant correlation with remobilization efficiency ($r = 0.785^{**}$), remobilization ($r = 0.766^{**}$), peduncle weight ($r = 0.511^{*}$), peduncle length ($r = 0.526^{*}$) number of fertile tillers ($r = 0.536^{*}$) and had a negative and very significant correlation with days to heading ($r = -0.670^{**}$) and days to maturity ($r = -0.703^{**}$). Biological yield showed a positive and significant correlation with peduncle weight ($r = 0.547^{*}$). Correlation coefficients between other traits and their level of significance are given in Table 6.

Analysis of stepwise regression, when grain yield (YLD) was considered as a dependent variable showed that three traits of remobilization (Re.Asmlt), biological yield (BY) and harvest index (HI) were entered into the model and showed the greatest effect on grain yield (YLD), respectively (Table 7).

In this regression model, all traits (Re.Asmlt, BY and HI) had a positive effect on grain yield under drought

Table 5 Comparison of the mean of traits studied by LSD method under terminal drought stress conditions

Genotype	DHE	DMA	Dur.Fil	PLH (cm)	Pe.L. (cm)	Pe.W (gr)	Sp.L (cm)	N.Til	N.Gr/Sp	TKW(gr)	Re.Asmlt(gr)	Rem.Eff	BY(t/ha)	HI	YLD(t/ha)
1	117.5	158.3	40.8	74.2	27.8	5.8	5.5	7.0	247.1	31.0	8.5	28.6	6.451	38.7	2.262
2	120.7	164.0	43.3	70.8	22.7	5.0	6.0	7.0	240.0	30.6	9.8	35.2	5.718	37.5	2.114
3	121.3	159.3	38.0	81.0	33.2	7.5	5.9	7.5	264.6	28.5	14.7	46.5	6.866	39.4	2.581
4	119.4	159.1	39.9	72.3	29.0	6.7	4.6	8.5	231.0	34.8	19.8	59.3	8.213	37.5	3.082
5	121.7	158.0	36.4	70.0	31.1	6.3	5.5	8.5	250.8	30.4	17.7	55.4	6.380	45.0	2.708
6	122.2	165.0	42.8	73.8	22.6	4.3	5.7	6.8	300.6	28.5	6.5	22.3	5.922	29.4	1.734
7	126.0	162.3	36.4	69.7	30.3	5.2	5.4	7.0	272.1	27.8	11.5	43.4	6.477	40.3	2.453
8	125.0	162.0	37.0	94.0	34.8	5.3	4.9	9.0	231.5	31.1	13.3	48.6	6.659	34.0	2.226
9	135.7	165.1	29.5	76.5	25.6	5.2	4.2	6.8	222.3	27.4	3.0	10.4	7.018	24.0	1.634
10	131.0	163.3	32.3	74.7	24.6	3.8	4.6	7.7	215.0	30.0	5.2	18.9	6.289	33.7	2.088
11	120.0	159.1	39.2	81.5	30.9	8.0	5.5	8.3	236.5	30.4	16.5	48.0	7.840	41.0	3.165
12	122.9	162.6	39.8	65.3	22.4	4.5	5.5	7.7	244.6	31.6	9.0	33.8	6.837	34.2	2.348
13	130.2	162.1	32.0	84.2	28.2	6.3	5.2	7.3	243.6	27.2	11.7	34.1	7.065	29.4	2.080
14	122.7	162.6	40.0	69.3	22.5	4.2	5.3	7.5	275.3	24.7	8.2	31.5	6.949	32.0	2.193
15	130.8	164.5	33.7	82.8	27.0	5.2	5.3	6.8	256.3	28.4	6.3	22.2	7.921	28.7	2.252
16	121.0	157.8	36.8	81.8	32.6	7.3	4.7	9.2	226.0	29.1	19.5	55.8	8.112	42.2	3.466
17	116.2	158.8	42.7	65.3	28.7	6.2	4.7	8.3	222.1	32.2	16.7	55.7	6.676	39.0	2.546
18	126.7	160.3	33.7	80.3	29.2	5.5	4.8	7.3	206.0	30.2	13.0	39.1	7.074	35.8	2.452
19	122.9	158.6	35.8	67.8	27.4	4.0	4.9	7.2	245.5	31.3	13.2	47.2	6.777	36.2	2.464
20	111.7	153.0	41.4	72.2	29.3	5.3	5.5	9.2	128.5	38.0	17.8	56.3	6.511	38.1	2.520
LSD5%	7.900	4.100	4.682	10.62	7.001	1.954	0.852	2.257	35.54	4.884	7.261	22.81	1.658	14.631	1.099

Table 6 Correlation coefficients between plant traits in barley genotypes under drought stress conditions

	DHE	DMA	Dur.Fil	PLH	Pe.L	Pe.W	Sp.L	N.Til	N.Gr/Sp	TKW	Re.Asmlt	Rem.Eff	BY	HI
DMA	0.748**													
Dur.Fil	−0.853**	−0.293												
PLH	0.349	0.114	−0.412											
Pe.L	−0.182	−0.548*	−0.167	0.556*										
Pe.W	−0.291	−0.453*	0.065	0.368	0.691**									
Sp.L	−0.413	−0.059	0.548*	−0.113	−0.112	0.079								
N.Til	−0.520*	−0.676**	0.218	0.176	0.576**	0.428	−0.185							
N.Gr/Sp	0.271	0.592**	0.073	−0.049	−0.226	−0.085	0.321	−0.552*						
TKW	−0.640**	−0.669**	0.394	−0.195	0.206	0.106	−0.029	0.565**	−0.716**					
Re.Asmlt	−0.654**	−0.798**	0.315	0.028	0.677**	0.668**	0.013	0.775**	−0.346	0.535*				
Rem.Eff	−0.693**	−0.777**	0.387	−0.055	0.651**	0.544*	0.056	0.761**	−0.309	0.551*	0.974**			
BY	0.100	−0.170	−0.280	0.345	0.364	0.547*	−0.399	0.302	−0.091	−0.001	0.372	0.257		
HI	−0.670**	−0.703**	0.415	−0.203	0.526*	0.511*	0.286	0.536*	−0.140	0.385	0.766**	0.785**	0.019	
YLD	−0.498*	−0.659**	0.198	0.047	0.589**	0.699**	−0.042	0.669**	−0.209	0.345	0.854**	0.795**	0.627**	.768**

* and **: significant at 5% and 1% probability levels, respectively

Table 7 Results of stepwise regression for grain yield of barley genotypes in drought stress conditions

Variable entered to model	Partial R^2	Model R^2	F Value	Pr > F
Re.Asmlt	0.729	0. 729	48.375	< .0001
Biological Yield	0.111	0.840	44.586	< .0001
Harvest Index	0.097	0.973	191.582	< .0001

stress conditions. The grain yield model (1) according to the mentioned traits was obtained as follows:

(1) $YLD = -2.205 + 0.015\ Re.Asmlt + 0.363BY + 0.54HI$

In the model 1, the determination coefficient (R^2) was 0.973, which justified about 72.9% of the changes in grain yield for remobilization (Re.Asmlt). Biological yield (BY) and harvest index (HI) were two traits that were entered into the model after remobilization. These two traits together explained about 14.4% of the grain yield variation. In order to explain the causal relationships between the traits affecting yield under stress conditions, path analysis was used. Selection of effective traits for path analysis was performed based on regression analysis and correlation coefficients of traits (Table 8). Path analysis on grain yield showed that the direct effects of number of days to maturity, number of fertile tillers, remobilization, biological yield and harvest index on grain yield were positive, the highest of which was related to harvest index (0.677) and then related to biological yield (0.584) (Table 8). The direct effect of peduncle weight on grain yield was negative (− 0.078). The direct effects of number of days to maturity, number of fertile tillers, peduncle weight and remobilization on grain yield were low: 0.061, 0.084, − 0.078 and 0.153, respectively, while their maximum indirect effect on grain yield was via the harvest index. The results of this experiment showed that in order to increase grain yield in barley genotypes in terminal drought stress conditions, special attention should be paid to remobilization, biological yield and harvest index traits. Due to the high direct effect of harvest index (0.677) and indirect positive or negative effects of other traits via it (such as number of days to maturity, number of fertile tillers, peduncle weight and remobilization) on yield, in this experiment, harvest index with remobilization were recognized as the most important effective traits for the selection of barley genotypes that are exposed to drought stress at the end of the growing season. The results of simple correlation and regression analysis confirm this conclusion. It should be noted that residual effects of other traits that were not studied in this experiment may be effective in grain yield of barley genotypes in drought conditions and are in a set of unknown factors.

Table 8 Results of path analysis of plant traits of barley genotypes in drought stress conditions

Variable	Direct effect	DMA	Indirect effects					Correlation with grain yield
			N.Til	Pe.W	Re.Asmlt	BY	HI	
DMA	0.061	–	−0.057	0.035	−0.123	−0.104	−0.457	−0.661**
N.Til	0.084	−0.042	–	−0.035	0.119	0.181	0.359	0.669**
Pe.W	−0.078	−0.029	0.037	–	0.102	0.315	0.347	0.698**
Re.Asmlt	0.153	−0.049	0.065	−0.052	–	0.218	0.517	0.853**
BY	0.584	−0.011	0.026	−0.042	0.057	–	0.011	0.626**
HI	0.677	−0.043	0.044	−0.040	0.116	0.009	–	0.767**
Residual effects	0.143							

Discussion

Due to the arid and semi-arid climate of the major barley production regions of Iran, water as one of the most important sources of production plays an important role in determining the type of agricultural activities. Barley is an important crop to cultivate in the most areas of Iran, due to its excellent adaptation to harsh climatic conditions and marginal lands. Although barley is more tolerant to drought stress than other cereals, nevertheless, during its growth and development in the two stages of stem elongation and grain filling, it is sensitive to water shortage and drought stress in these stages leads to reduced yield. The use of drought-tolerant genotype can be one of the important methods of the optimal use of water. There is very evidences that show selection for specific drought-tolerant traits can significantly increase yield under drought stress conditions (Ceccarelli 1989; Araus et al. 2002 and Olivares-Villegas et al. 2007). In this study, simple correlation coefficients showed that the number of days to maturity (r = −0.669**), number of fertile tillers (r = 0.669**), peduncle weight (r = 0.698**), remobilization of assimilates to grain (r = 0.853**), biological yield (r = 0.626**) and harvest index (r = 0.667**) had a high significant correlation with grain yield. Stepwise regression and path analysis showed that these traits had the greatest effects on grain yield of barley genotypes in terminal drought conditions. Traits, which have a positive and significant correlation with grain yield, can be considered as useful traits for enhancement of performance under drought stress conditions. In this experiment the genotypes 4, 11 and 16, that showed the highest amount of peduncle weight, remobilization of assimilates from stem to grain, biological yield and harvest index, produced the highest grain yield under drought stress. Mohammadi et al (2006) reported that, the rate of production, especially in the last stages of the growing season, depends on the power of the remobilization of assimilates in the plant under stress conditions. One of the most important parts of the plant in this regard is the length of the peduncle. As the length of the peduncle increases, the thousand kernel weight increases. Research on six-row barley showed that the number of grains per spike is an important factor in determining yield and increases yield under optimal irrigation and decreases yield in terminal drought stress conditions. Genetic manipulation of this trait is also possible (Rahimian et al. 2004). Transfer of photosynthetic materials is affected by drought stress, which means that the produced materials in stem and peduncle were transmitted to the grains with a lower rate. As a result, the remobilization of the produced material decreases due to the accumulation of these materials in the stem and peduncle. Therefore, a genotype with more remobilization is better in drought stress conditions (Moaveni et al. 2005). Numerous studies have shown that drought stress reduces biological performance by reducing leaf area and disrupting the process of uptake and transfer of nutrients in cereals (Albacete et al. 2014; Abdoli et al. 2013). According to different studies, drought stress after pollination reduced harvest index in different bread wheat genotypes by 24.8%. The probable cause for the decrease in harvest index is that at the end of the growing season due to lack of available water, the transfer of nutrients to the grain is reduced and leads to a decrease in grain yield. Therefore, genotypes with higher harvest index can have better retransfer than other genotypes in drought stress conditions (Abdoli and Saeedi 2013; Moradi et al. 2008). Study on grain filling rate and remobilization of soluble carbohydrates of stem under end-of-season drought stress in barley cultivars showed that the response of cultivars was different in terms of remobilization and remobilization efficiency and there were significant differences in remobilization and remobilization efficiency traits in between cultivars (Pour Issa et al. 2019). Other studies showed that thousand-kernal weight, biological yield, number of fertile tiller, number of grains per spike and harvest index had a positive and significant correlation with grain yield in barley under terminal drought stress conditions (Najib and Vani 2004; Nikkhah et al. 2010; Mohammadi nia et al. 2014; Kumar et al. 2014; Irvani et al. 2008). Karami (2005) in the study of 22 barley genotypes under non-stress and drought stress conditions, using multivariate statistics, concluded that traits such as number of grain per spike, a thousand-kernel weight, biological yield and harvest index, explains about 97% of grain yield changes in both conditions Other researchers found that wheat cultivars with the high biological yield and harvest index had high grain yield under drought stress conditions (Saeidi et al, 2015; Ahmadizadeh et al, 2011). Remobilization of storage materials before flowering is altered by various environmental factors and varieties. Current photosynthesis in the grain filling period is strongly dependent on light absorption. Water stress reduces the rate of grain filling. Growing grains are in high demand for photosynthetic material in grain filling stage. Therefore, reserved assimilates in vegetative tissues can be considered as an important source of carbohydrates during the grain filling period (Lopez pereia et al. 2008). Ebadi et al (2011) stated that lack of irrigation increased the remobilization rate of dry matter from various plant organs to grains in spring barley genotypes. The share of dry matter remobilization in the conditions of cut of irrigation at the flowering stage was 36.5% in production. Xu et al (2006) showed that grain yield depends not only on dry matter accumulation, but also on the effective allocation of dry matter to economically important parts of the plant, and this is the key to sustainable yield under moisture stress conditions. According to Blum (2005), the role and importance of material transferred from the stem in grain filling is more than other aerial parts. Bodakli et al (2007) while pointing to the significant difference in terms of dry matter remobilization efficiency between barley cultivars, stated that cultivars with higher rate of dry matter remobilization also have higher efficiency. Ehdaie et al. (2008), while pointing to the genotypic differences in wheat, breeding to have more stem stock participation in grain yield considered it inevitable in order to stable yield in stressful environments. Rezaei et al (2013) in their study on wheat genotypes under terminal drought stress, stated that high harvest index was the most important reason for the high grain yield of Pishgam cultivar in water stress conditions. Pishgam cultivar with 41% share of photosynthetic material remobilization had the highest value in severe drought stress treatment and Shahriar cultivar with 5% remobilization share had the lowest value. So, our results are in agreement with the results obtained in other experiments. According to the results of this experiment, the highest values of number of fertile tillers, peduncle weight, remobilization of assimilates to grains, biological yield and harvest index in water deficit conditions belonged to 4, 11 and 16 genotypes and these genotypes produced higher grain yield under severe water scarcity. Therefore, it seems that these traits are important in the breeding and selection of drought tolerant genotypes. In addition, these genotypes can be used for cultivation in areas facing water shortage stress at the end of the growing season. According to the results of this study and other studies conducted in similar cases, it can be stated that to increase grain yield in terminal drought stress conditions, special attention should be paid to the important traits such as early maturity, peduncle weight or length, remobilization, biological yield and harvest index, in addition to the grain yield, these traits should be considered as well and be used in promoting barley breeding programs.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42976-022-00286-x.

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