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EFFECTS OF DROUGHT STRESS ON GROWTH, GRAIN FILLING DURATION, YIELD AND QUALITY ATTRIBUTES OF BARLEY (*HORDEUM VULGARE* L.)

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Abstract

A pot experiment was conducted to investigate the effect of drought stress at start of anthesis (applied by adjusting the field capacities at 100, 50 and 30%) on barley growth, grain filling duration, grain shape, yield and quality attributes. The effect of drought stress was more prominent on plant fresh biomass accumulation, grain yield and grain filling duration. However, it produced non-significant effect on total number of tillers and grain protein contents. With the increasing intensity of drought stress, barley growth and yield traits significantly diminished. Water stress gradually shortened the plant height and biomass accumulation but the difference was more prominent in fresh biomass accumulation (– 45%) over dry biomass accumulation. The field capacity of 30% caused 29 - 41% reduction in leaf chlorophyll content and 10 - 27% in grain quality traits. Root fresh and dry biomass accumulation decreased by drought stress while root length increased. Drought stress produced uneven grain size that resulted in lower grain yield (42%) specially at 30% field capacity. This reduction in yield was also due to the decreased grain filling duration (38 d) at 30% field capacity as compared to 100% field capacity. So, it may be concluded that drought stress affected barley yield through impaired grain development and grain filling duration. The results of present study are satisfactory and needed further exploration about the physiological mechanism and management strategies to overcome drought stress related yield losses in barley crop.

Introduction

The population of the world is expanding exponentially and so the demands for food supply. More than 70% increase in current food supplies must be fulfilled for the additional 2.3 billion people by the 2050 (FAO 2009). Land resources are limited and if somehow farmers managed to cultivate agriculture waste lands they will not find any water. The lowered crop yield is due to various abiotic stresses (Rosenzweig *et al.* 2014 and Alghabari *et al.* 2015). In desert areas, aridity and low rainfall are chief contributors that limit crop productivity. These limitations in moisture supplies along with poor management of available resources need special attention to resolve this issue. Cultivation of drought resistant crops is an adoptable option.

Barley (*Hordeum vulgare* L.) is an important annual grain cereal and widely cultivated in dry areas. It is an enriched source of carbohydrates, minerals and vitamins. Barley is used as whole grain or processed in making noodles, porridge and fortified infant foods. It is also used as an animal forage, particularly for sheeps and goats. Due to its stress tolerance nature, it is mostly cultivated in arid zones (Samarah 2005). There are some studies that have reported decreased plant growth and yield under drought stress (Fenta *et al.* 2014). This reduction in growth and yield is subjective to alterations in many plant morph physiological mechanisms. The severity of drought stress is increasing day by day and it has been estimated that it will cause severe losses in global crop production e.g., up to 30% by 2025, compared with current yield (Zhang 2011).

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Drought is undoubtedly most prevalent and damaging abiotic stress (Alghabari *et al.* 2015). Drought stress problem has been raised manyfolds over the last two decades by anthropogenic factors, indiscriminate use of water, conveyance and application losses and the use of inefficient irrigation methods. Bioinformatics tools, molecular breeding and transgenic methods can be adopted to develop drought tolerant crops but, there are many constraints such as, resources management and availability of trained researchers (Ihsan *et al.* 2017).

In Saudi Arabia, there prevails an extreme weather and soil conditions that makes it unfavorable for drought sensitive crops production. Declining fresh water resources, low annual rainfall, lack of water storing bodies and arid features of the region invites extreme drought events especially at crop critical growth stages. This unwelcomed guest sometimes cause unrecoverable damage to field crops especially if intercepted at grain developmental stages. Barley is among those crops that are preferred in dry areas due to its lower water and nutrients requirements. Thus the current experiment was planned to evaluate: (1) effect of drought stress on barley growth, biomass accumulation and root dynamics and (2) to check the effect of drought stress on grain shape, grain filling duration, final yield and grain quality traits. Based on the results of current experiment, future research directions will be marked to develop drought tolerant genotypes or to manage drought by some economical means.

Materials and Methods

A pot experiment was conducted to evaluate the effect of drought stress on barley crop growth, root development and grain traits at Had al Sham Research Station, Department of Arid Land Agriculture, King Abdulaziz University Jeddah, Saudi Arabia. The pot experiment was performed in a completely randomized design (CRD) with four replications.

In the second week of November, 2016 the soil was prepared by mixing with organic amendments at 1 : 1 ratio to increase the fertility and biological activity of the used soil. After that each pot was filled by adding 3 kg soil. Water was applied in equal amounts to maintain moisture contents at field capacity for seed germination period. Ten barley seeds were sown in each pot.

Water stress was applied by adjusting the soil field capacities at 100, 50 and 30%. Half kg soil was taken and weighed on electric balance. After that soil was oven dried and weighed again. Soil saturation paste was prepared by pouring the water and continuously stirring with scapula. The point at which water starts accumulating over soil surface as a thin layer was considered as saturation point. Half of the saturation point was taken as 100% field capacity. Similarly, a field capacity of 50 and 30% were adjusted (Ihsan *et al.* 2016).

After 15 days of seed germination, the plant population was set to 3 plants per pot. Plants were left to grow normally until the anthesis stage. Levels of field capacities (100, 50 and 30%) were adjusted by maintaining the different amounts of water to each pot. These field capacities were maintained throughout the grain filling duration.

The NPK was applied at a rate of 45 : 80 : 50 kg per acre and dose was calculated on individual pot bases before application. The NPK was mixed with water and fertigated. No pests/diseases were reported. Crop was harvested at full maturity and plant growth characteristic, root traits and grain characteristics were measured.

Plant height (cm) and root length (cm) were simply recorded by using meter rod at plant harvest. Number of tillers per plant was taken by counting. Plant fresh weight (g), plant dry weight (g), root fresh weight (g) and root dry weight (g) were recorded by using electric balance. Whole plant grains weight was measured in grams. Grain filling duration was taken as number of days required to develop mature grains. Grain shape was identified with naked eye as normal or uneven grains from a sample of 20 grains per pot. All these traits were taken from three plants per pot and their average was taken as a single value. Then the average value of all three replications for each treatment was compared for statistical analysis.

Grain proximate analysis was performed to check the effect of drought stress on grain quality. Total starch content was determined by phenol sulfuric method (Dubois *et al.* 1956) and grain protein content by using Micro-Kjeldahl digestion and multiplication factor (AOAC 1990). To measure the ash contents, 100 g seed were set in an oven at 80ºC for three days and later at 750ºC for five hrs that turned it into ash. Chlorophyll a and b were measured with chlorophyll meter. Relative water content was determined by using Dhopte and Manuel (2002) equation.

RWC = (FW – DW/TW – DW) ×100

where, FW is fresh weight, DW is dry weight and TW is turgor weight of leaf samples.

Simple completely randomized design was used to analyse the data. Analysis of variance was performed by using SAS software. Treatment means were compared by using LSD test at 95% confidence interval to estimate their significance under different drought stress levels.

Results and Discussion

Effect of drought stress was studied on barley agronomic and grain quality traits (Table 1). Water stress significantly affected shoot and root fresh and dry biomass accumulation while non-significant effect was observed on number of tillers per plant. Similarly, drought stress exhibited significant negative effect on grain shape/weight and grain filling duration. Water stress also impaired leaf chlorophyll content, relative water percentage and grain quality except for grain protein content that reported non-significant effect (Table 2).

Table 1. Analysis of variance for barley growth and grain yield parameters.

Variables	df	PH	SFW	SDW	RL	RFW	RDW	NTP	GYP	GS	GFD
Field capacity	2	*	*	*	*	**	**	NS	*	*	**
Error	9										
Total	11										
CV		8.62	6.97	6.35	8.42	8.50	9.11	1.61	6.55	5.44	8.32
LSD		2.66	1.46	1.06	1.77	1.41	0.41	1.00	1.47	1.43	2.33

PH; Plant height (cm), SFW - Shoot fresh weight (g), SDW - Shoot dry weight (g), RL - Root length (cm), RFW - Root fresh weigh (g), RDW - Root dry weight (g), NTP - Number of tillers/plant, GYP - Grain yield per plant, GS - Grain shape, GFD - Grain filling duration (days).

Water stress gradually decreased the plant height and biomass accumulation but the difference was more prominent in fresh biomass accumulation (–45%) over dry biomass accumulation among drought stressed treatments (–24%) (Fig. 1). The maximum plant height, fresh and dry biomass accumulation was observed at 100% field capacity. The difference in drought stress treatments was more prominent between 50 and 30% field capacity as compared to 100 and 50% field capacity. A field capacity of 30% produced almost 30 - 50% decrease in plant growth. The minimum biomass accumulation was recorded at 30% field capacity for both fresh and dry biomass accumulation. Ihsan *et al.* (2016) reported 57% reduction in wheat biomass accumulation at severe drought stress. Al-Ajlouni *et al.* (2016) reported significant reduction in barley growth and subsequent grain filling duration in drought sensitive genotypes under severe drought stress applied prior to anthesis stage. The genotypes that acquired early flowering under drought stress produced higher yield because they have longer photosynthetic period that had contributed in grain filling for higher number of days as compared to those genotypes that delayed their flowering stage.

Table 2. Effect of different field capacities on barley grain and leaf characters.

Field capacity (FC)	Protein content (g/100 g)	Ash content (g/100 g)	Starch content (g/100 g)	Chlorophyll a (mg/g fw)	Chlorophyll b (mg/g fw)	Water content (%)
FC-100%	10.4	2.5	67	6.3	3.2	81
FC-50%	10.5	2.1	63	5.7	2.8	67
FC-30%	9.8	1.8	60	4.5	1.9	43
FC	ns	*	*	*	*	**
LSD	-	0.4	2.1	0.8	0.3	6.3
CV	4.2	5.3	7.9	5.6	5.2	8.6

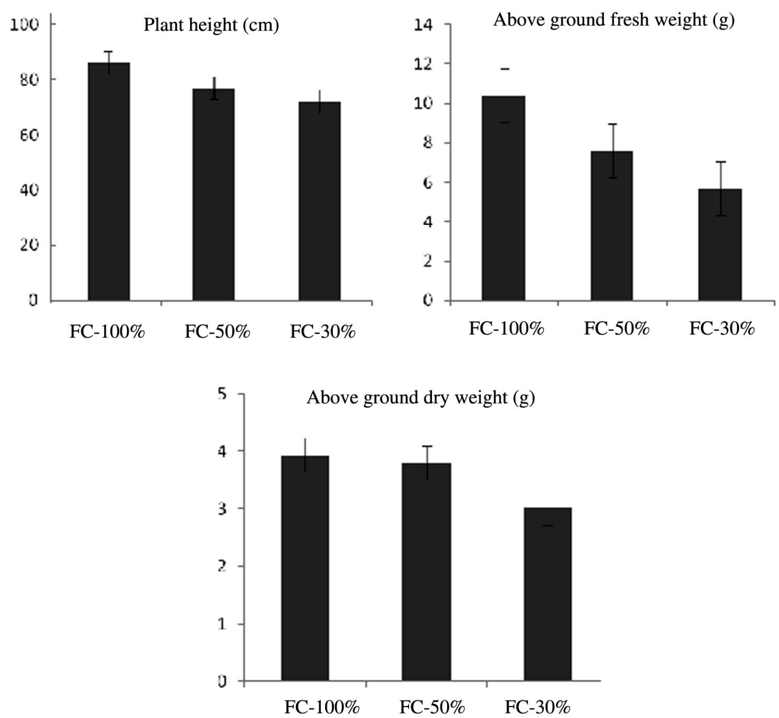

Fig. 1. Effect of drought stress on barley growth and biomass accumulation.

Root penetration was measured by the root length. Opposite to the other studied traits, root length increased with the severity of the drought stress (Fig. 2). The maximum root length (13 cm) was recorded at the lowest field capacity. Both root fresh and dry weights were considerably reduced by the application of water stress. The highest and lowest root fresh (7 - 4 g) and dry weight (3 - 1.8 g) were recorded at 100 and 30% field capacities respectively. Zeid and Shedeed (2006) studied the inverse trend of root length to the rest of the studied root characteristics. It increased with the decrease in water supply, while water stress decreased root fresh and dry biomass accumulation. By increasing the water stress severity, root volume decreased that also disturbed the root to shoot ratio (Afshari-Behbahanizadeh *et al.* 2014).

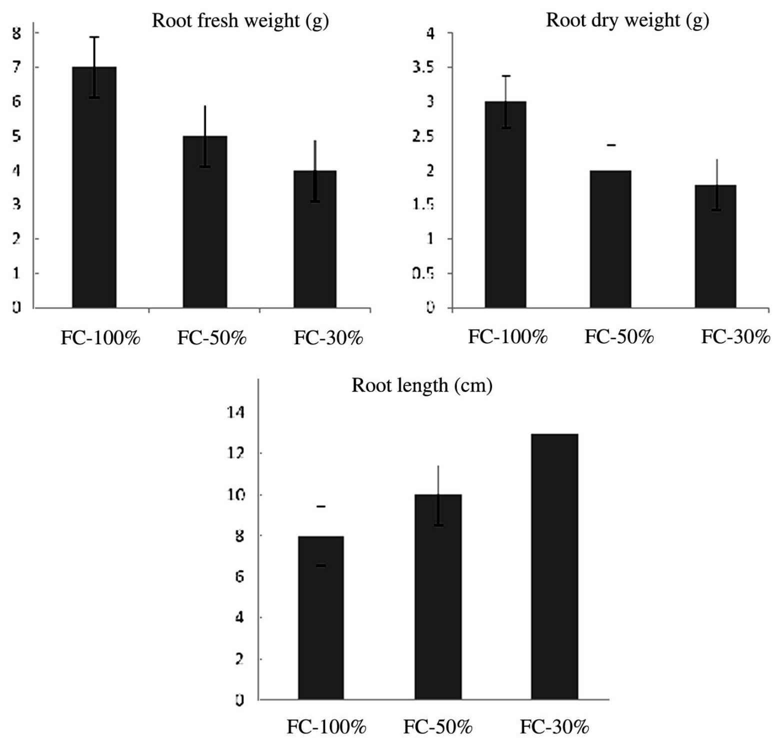

Fig. 2. Effect of drought stress on barley root dynamics.

Water stress posed non-significant effect on total number of tillers however slight reduction observed in barley tillering capacity with the increasing intensity of drought stress. With decreasing field capacity, a significant reduction was observed in grain shape, weight and grain filling duration (Fig. 3). The maximum grain yield per plant (12 g) was achieved at 100% field capacity while the minimum (7 g) was attained at 30% field capacity. Among ten mature seeds observed for drought impression, three were de-shaped at 50% field capacity and six at 30% field capacity. This 60% impaired filling of seeds directly contributed in final yield reduction. Similarly, the severe water stress (30% field capacity) decreased the grain filling duration up to 38% that has also contributed in impaired photo-assimilates translocation and final yield reduction. Plant tillering capacity was unaffected when stress was applied at anthesis stages (Ihsan *et al.* 2016). Grain shape and filling duration were very sensitive to drought stress. Severe drought stress may reduce grain filling duration up to 71% in drought sensitive wheat genotypes (Ihsan *et al.* 2016). Samarah (2005) calculated 57% reduction in barley grain yield at severe drought stress. This reduction in grain yield might be due to shortening of crop growth cycle that leads to early flowering under drought stress. This early flowering not only shortened the grain filling period but also affected plant vegetative growth period. Thus, resulted lower plant height and biomass accumulation failed to provide sufficient photosynthates to developing grains at grain filling stage.

Grain protein contents were unaffected at different field capacities but ash content and total starch content displayed a gradual decline with the increase in water stress (Table 2). The 100 g of barley dry grain produced 2.5 g of ash and 67 g of starch. Leaf chlorophyll and relative water content significantly decreased at 30% field capacity. The field capacity of 30% produced a reduction of 29 - 41% in leaf chlorophyll content and 47% in relative water content. Drought stress remarkably decreased grain quality traits in maize (Naeem *et al.* 2017). Abiotic stresses damaged rice grain quality by reducing grain length, grain protein and starch contents (Ihsan *et al.* 2014). Under drought stress chlorophyll content suppressed in barley leaf (Anjum *et al.* 2003).

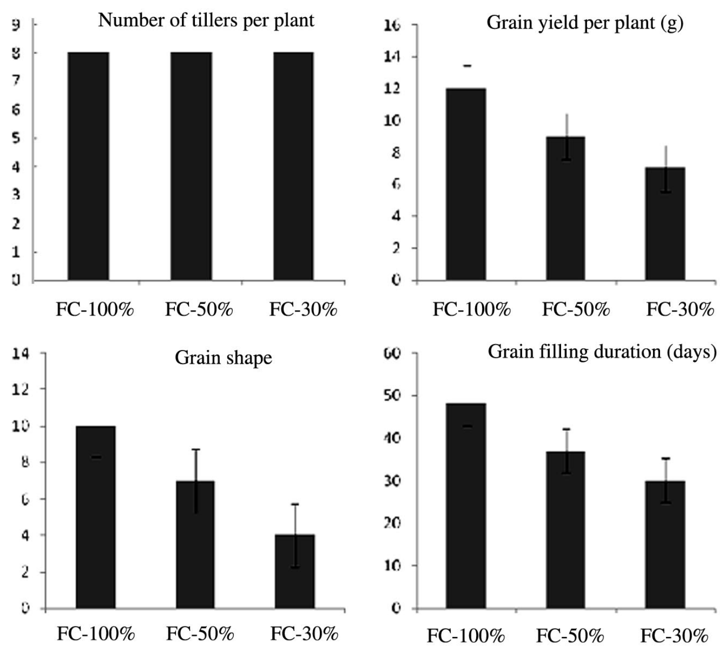

Fig. 3. Effect of drought stress on barley grain yield and grain filling duration.

All treatments produced similar number of tillers due to the drought stress application after tillering stage. However, the number of fertile tillers was different for stressed and non-stressed plants. This difference was due to the application of drought stress at anthesis stage (Ghotbi-Ravandi *et al*. 2014). Many yield contributing traits responded to the time of water stress application. For instance, water stress applied at pre-anthesis reduced time to anthesis, while at post-anthesis it shortened the grain-filling period in triticale genotypes (Estrada-Campuzano *et al.* 2008). In barley (*Hordeum vulgare*L.) drought stress reduced grain yield by reducing the number of tillers, spikes and grains per plant and individual grain weight. Severely stressed plants reached maturity earlier than non-stressed plants (Ihsan *et al*. 2016). It is expected that severely stressed plants have higher rate of grain filling. This higher rate and shorter grain filling period resulted in improper translocation of photosynthates that caused a yield decline. Ihsan *et al* (2016) had reported that genotype Faisalabad-2008 had 38% longer grain filling period over sensitive wheat genotypes under severe drought stress. So, grain filling duration is a genetically controlled trait and can be used for drought resistant genotypes selection.

Drought stress adversely affected barley growth and grain quality. Reduction in biomass accumulation, grain weight, shape and filling duration played important role in final yield reduction. With the declining water resources, the future research must focus on the introduction and screening of the drought tolerant barley cultivars. One must focus on cultivars grain filling duration trait as a genotype selection tool in future breeding and variety development programs. The results of current study are satisfactory and needed further exploration about the physiological mechanism and management strategies to overcome drought stress related yield losses in barley crop.

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