University of Thi-Qar Journal of agricultural research

Thi-Qar Journal of agricultural research

ISSN Onlin:2708-9347, ISSN Print: 2708-9339 Volume 15, Issue 1 (2026) PP 431-440

https://jam.utq.edu.iq/index.php/main https://doi.org/10.547654/qy8k8l2q22

Genetic Response of Barley under Drought and Heat Stress Conditions

Hussein Tuama Abbood

Department of crop sciences, College of Agriulture, Wasit University

E-mail: coagr26@uowasit.edu.iq

Abstract

This study aims to evaluate the genetic response of barley under drought and heat stress conditions and to identify the most tolerant varieties, thereby contributing to improved breeding and selection programs. The study employed a field experiment with a replicated experimental design, involving several barley varieties exposed to different environmental conditions. Growth and yield characteristics, along with several physiological and genetic indicators related to stress tolerance, were measured. Measurements included plant height, number of spikes, grain weight, seed yield, chlorophyll content, relative moisture in tissues, and indicators of oxidative stress and antioxidant enzymes. Statistical analysis was also conducted to test for differences between varieties and estimate genetic variation. The results showed significant differences in stress response among the varieties, with some varieties exhibiting superior growth and yield compared to others. The study also demonstrated that the more tolerant varieties exhibited better physiological traits related to water use efficiency and reduced damage from heat and drought. These findings indicate the potential for utilizing superior varieties in genetic improvement programs to produce barley varieties more tolerant to harsh climatic conditions.

Keywords: barley, drought, heat, tolerance, genetics

I. Introduction

Barley, belonging to the grass family Poaceae and the genus Hordeum, is considered one of the most important strategic cereal crops essential for achieving food security. It ranks after wheat, maize, and rice in the world's food supply (FAOSTAT, 2018). A reclamation crop improves soil properties, requires minimal fertilizer, and is tolerant of drought and salinity. It can be cultivated in newly reclaimed lands. Barley has high nutritional value, containing vitamin B, minerals such as calcium, phosphorus, potassium, and iron, as well as protein, fats, salts, and carbohydrates (Verstegen et al., 2014).

Barley is a staple cereal crop for humans and is used in various forms, including flour in bread as a substitute for wheat or added to it, or as barley porridge. Barley is also an important forage grain crop linked to the livestock sector. Barley and its derivatives are used as highly beneficial animal feed, increasing milk production and aiding in fattening livestock and increasing their meat yield.

Barley is considered an important forage grain crop in many regions, second only to wheat in economic importance. Large areas, reaching hundreds of thousands of hectares, are cultivated with barley, constituting the majority of production from rainfed areas, with an average yield of approximately 1494 kg/ha (FAO, 2020).

Barley cultivation is concentrated in water-poor, drier soils compared to wheat, resulting in low rainfall. This typically leads to low yields per unit area, prompting some countries to import large quantities of barley to meet their needs. Approximately 496,880 tons of barley grain are imported annually (FAO, 2013). Given climate change and water scarcity, and the severe drought and low rainfall characteristic of arid regions, it became essential to evaluate local varieties and their drought tolerance, as well as to develop improved varieties that yield higher crops under such conditions.

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Barley is known to be more environmentally tolerant than other cereal crops in terms of pH levels and water availability (Goyal and Ahmed, 2012). Climate changes in recent decades have led to a decrease in rainfall and its distribution in arid and semi-arid regions worldwide, including the Middle East, resulting in changes in the frequency and intensity of droughts. Therefore, scientists have collaborated to find suitable strategies to reduce the gap between actual crop yield and crop potential in these regions (Ort, 2002). Furthermore, the 48% increase in carbon dioxide levels since the Industrial Revolution (1760–2019) has led to higher temperatures (Walker et al., 2021), resulting in an increase in extreme weather events, such as droughts, in many regions of the world with valuable agricultural land. Drought stress is a global problem affecting agricultural production (Jaleel et al., 2009) due to its morphological and physiological effects on various indicators, such as plant height, stomatal closure, reduced turgor pressure, decreased water content, and loss of suitability, which can lead to plant death due to disrupted photosynthesis (Jaleel et al., 2008). The severity and duration of drought stress depend on the variety and its growth stage, as crops respond differently to drought stress depending on their growth stage. Crops also vary in their ability to overcome drought stress through water conservation, turgor effort, or efficient water use (Patrignani et al., 2014). Drought is a major environmental stressor, limiting plant production in most agricultural regions worldwide. Therefore, crop yield and yield characteristics are evaluated in agricultural research (Hasan et al., 2010). Ali (2008) reported that water stress combined with high temperatures during critical grain growth stages leads to a reduction in the average thousand-grain weight. Experiments on barley showed that drought stress significantly reduced barley grain yield, and barley varieties were more sensitive to drought stress than plant standards (Rajala et al., 2011)

The problem lies in the severe impact of drought and heat on barley in arid regions, which affects its growth and yield. The importance of this research stems from its study of a strategic crop and its contribution to selecting varieties that are more tolerant of harsh conditions. Therefore, the study aims to evaluate genetic response of barley under drought and heat stress conditions.

II. Materials and Method

This study was conducted on a group of barley varieties with varying degrees of drought and heat tolerance to evaluate their genetic, physiological, and biochemical responses under environmental stress conditions in winter season 2024-2025. The temperature was 19 °C and humidity 65%. The varieties were selected to represent a clear contrast between tolerant and sensitive varieties, allowing for a precise comparison of plant performance under harsh conditions. The experiment was carried out in a controlled field environment with an appropriate experimental design that ensured repeatability of treatments and minimized the effect of random factors. Plants were then subjected to drought and heat treatments at critical growth stages. Standardization of cultivation and agricultural practices, such as planting dates, planting density, irrigation, and fertilization, was also maintained to ensure that the observed differences were attributed to the effects of stress and genetic variations among the varieties. Figure (1) illustrates the overall methodology, from variety selection to interpretation of the final results.

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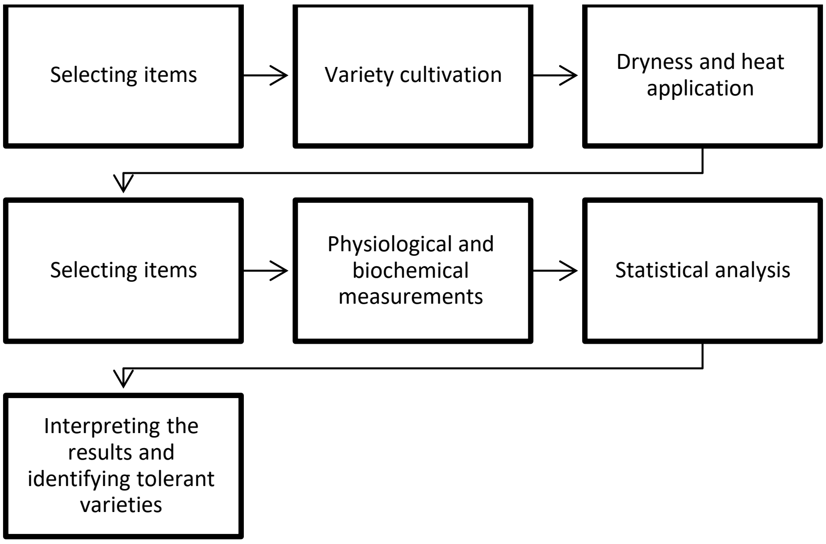

Figure 1. Study Methodology

Measurements included morphological and productive traits such as plant height, number of spikes, number of grains per spike, and grain yield, along with physiological indicators such as chlorophyll content, stomatal permeability, and relative water content. Biochemical indicators were also measured, including proline, antioxidant enzyme activity, and some indicators related to protection against oxidative damage. Samples were collected at specific growth stages to ensure measurement accuracy and then analyzed in the laboratory according to established procedures for each indicator. The data were subsequently subjected to statistical analysis to determine the significance of differences between varieties and treatments and to identify the indicators most strongly associated with tolerance. This is illustrated in Table 1, which lists the study materials; Table 2, which lists the measured indicators; Table 5, which presents the statistical analysis; and Table 3, which shows the correlation of the indicators with the measurement objective.

Table 1. Study Materials

Item	Details
Plant Material	Barley varieties with varying tolerance levels
Number of Varieties	A range of tolerant and sensitive varieties
Study Environment	Field/Controlled
Factors Understood	Drought, Heat
Application Phase	Critical growth stages
Objective	Comparison of genetic and physiological responses

Table 2. Measured Indicators

Type of indicator	Examples
Morphological characteristics	Plant height, number of spikes
Productive characteristics	number of grains, grain yield
Physiological indicators	Chlorophyll, stomatal permeability, relative water content
Biochemical indicators	Proline, antioxidant enzymes;
Analytical indicators	Significant differences, correlations betw

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Table 3. Statistical Analysis

The tool	Purpose
Comparing means	To identify differences between varieties
Analysis of variance	To test the significance of the treatment effect
Correlation coefficients	To demonstrate the relationship between traits
Graphical interpretation	To clarify general trends in the results

Table 4. Correlation of indicators to the measurement objective

Indicator	The purpose of measuring it is to:
Plant height	Assess growth vigor
Number of spikes	Estimate productivity
Chlorophyll content	Measure photosynthetic efficiency
Proline	Estimate stress response
Antioxidant enzymes	Measuring internal defense mechanisms

III. Results and Discussion

The study results showed clear and significant differences between barley varieties under drought and heat conditions in most of the studied traits, indicating variations in genetic, physiological, and biochemical responses between tolerant and sensitive varieties. Variety V2 recorded the highest plant height at 95.1 cm, followed by variety V1 with an average of 92.4 cm, while variety V5 recorded the lowest at 78.3 cm. Variety V2 also outperformed other varieties in the number of spikes per plant (17.5 spikes), the number of grains per spike (an average of 45.2 grains), and the average grain yield (4.18 tons/hectare). In contrast, variety V5 recorded the lowest values in these traits (12.8 spikes/plant, 35.4 grains/spliff, and 2.91 tons/hectare, respectively). Table (5) illustrate the differences between varieties in growth and yield characteristics.

Table 5. Growth and Yield Characteristics under Drought and Heat Conditions

Category	Plant height (cm)	Number of ears/plant	Number of grains/ear	Grain yield (tons/hectare)
Al-warka	92.4	16.2	43.8	3.92
Rayhan	95.1	17.5	45.2	4.18
Aksad	88.7	15.1	40.5	3.61
Numar	80.6	13.4	36.7	3.05
Arivat Local	78.3	12.8	35.4	2.91
LSD 0.05	0.90	1.01	1.55	2.43

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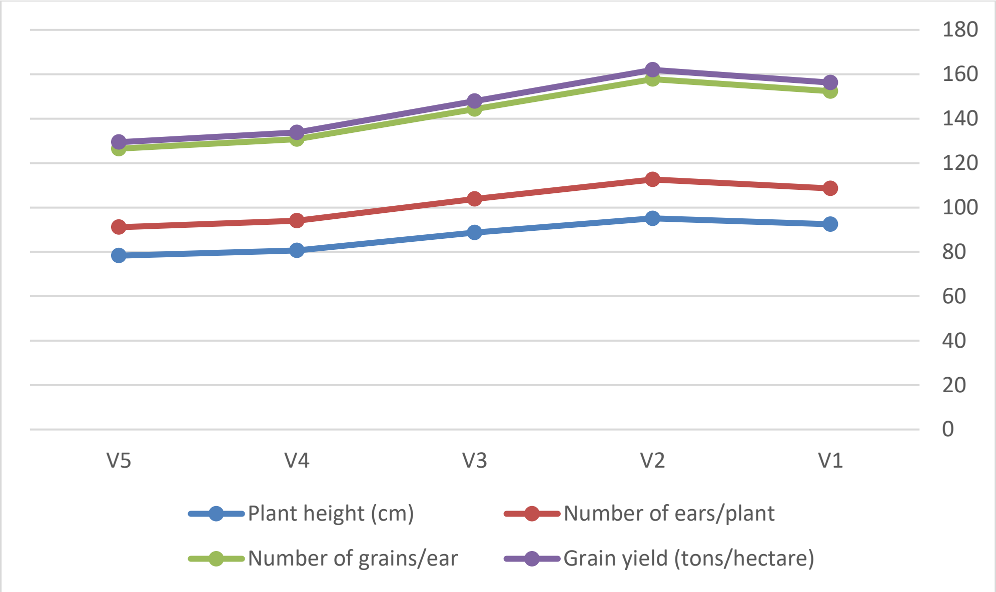

Figure 2. Comparison of growth and yield characteristics between varieties.

On the physiological side, variety V2 showed the highest chlorophyll content at 39.8 SPAD, the highest relative water content at 79.1%, and the lowest stomatal permeability at 1.79. Conversely, variety V5 recorded the lowest chlorophyll value at 30.5 SPAD, the lowest relative water content at 69.8%, and the highest stomatal permeability at 2.35. These results indicate that the more tolerant varieties maintained better water balance and photosynthetic efficiency, as shown in Table 6 and Figure 3.

Table 6. Physiological indicators under stress

Category	chlorophyll (SPAD)	Relative water content (%)	Bulging permeability
Al-warka	38.6	78.4	1.84
Rayhan	39.8	79.1	1.79
Aksad	35.4	74.2	2.08
Numar	31.2	70.3	2.31
Arivat Local	30.5	69.8	2.35
LSD 0.05	2.22	2.10	0.79

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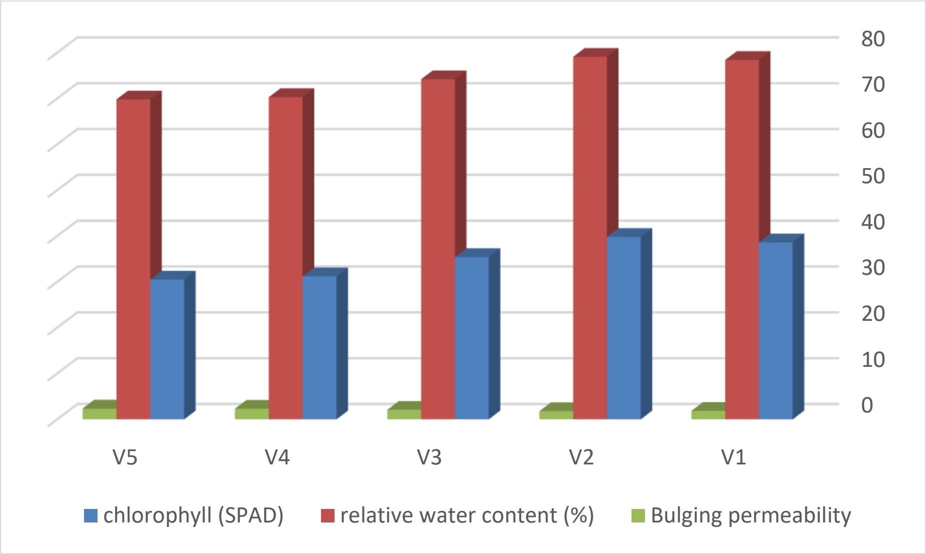

Figure 3. Physiological Indicators Among Varieties

From a biochemical perspective, the less tolerant varieties showed a marked increase in proline content and the activity of some antioxidant enzymes. Proline in variety V5 reached approximately 8.1 µmol g^{-1} FW compared to 5.6 µmol g^{-1} FW in variety V2, while Superoxide dismutase (SOD) activity was 22.1 in variety V2 compared to 15.2 in variety V5. Catalase (CAT) activity was approximately 20.3 in V2 compared to 14.1 in V5, and Peroxidase (POD) activity was approximately 16.8 in V2 compared to 12.1 in V5. Table 7 and Figure 4 clearly illustrate these differences.

Table 7. Biochemical Indicators

Category	Proline (µmol g-1 FW)	Superoxide dismutase	Catalase	Peroxidase
Al-warka	5.8	21.4	19.7	16.2
Rayhan	5.6	22.1	20.3	16.8
Aksad	6.7	18.6	17.9	15.1
Numar	7.8	15.9	14.8	12.6
Arivat Local	8.1	15.2	14.1	12.1
LSD 0.05	2.20	0.90	1.11	0.89

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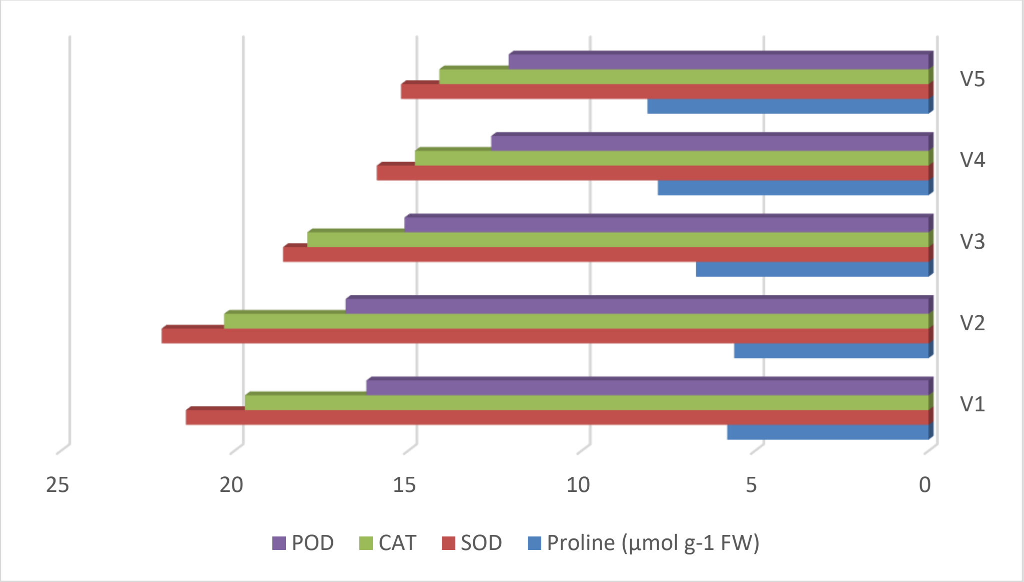

Figure 4. Proline and Defense Enzymes

Correlationship analysis showed a strong positive relationship between chlorophyll content and relative water content with grain yield, while the relationship between proline and grain yield was negative, indicating that higher proline was associated with increased stress intensity rather than improved production. The highest positive correlation coefficients were recorded between chlorophyll and grain yield (0.89), between relative water content and grain yield (0.87), while the correlation between proline and grain yield was -0.84. Table 8 presents these relationships, and Figure 5 shows the strength of the correlation between the variables.

Table 8. Correlation Coefficients Between Traits

First attribute	Second attribute	Correlation coefficient r
Chlorophyll	Grain crop	0.89
Proline	Grain crop	-0.84
SOD	Grain crop	0.81
CAT	Grain crop	0.79
Relative water content	Grain crop	0.87

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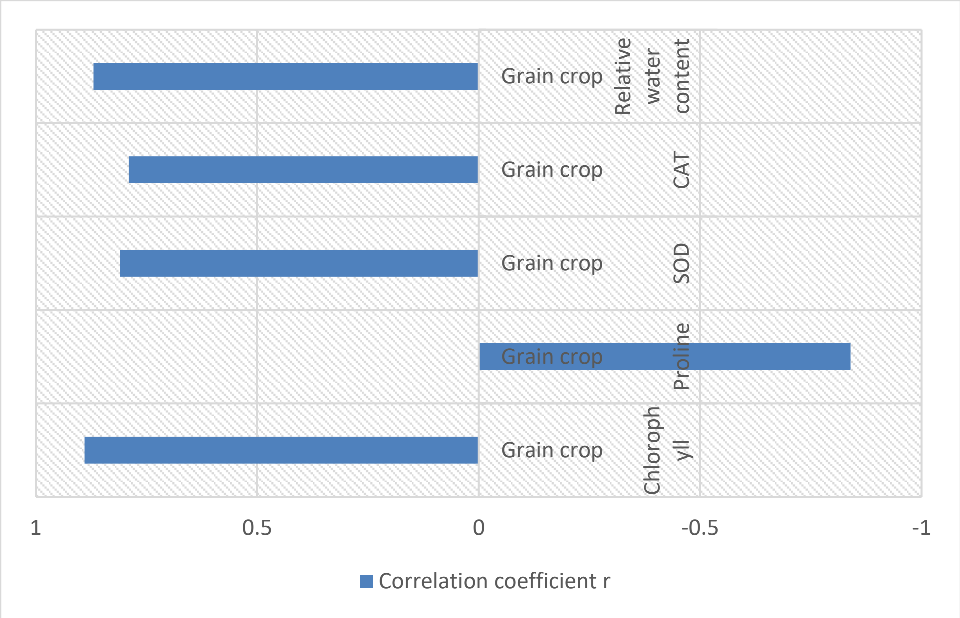

Figure 5. Correlation between indicators and grain yield.

In the final ranking, V2 and V1 were found to be the most tolerant, while V4 and V5 recorded the lowest tolerance levels, as shown in Table (9).

Table 9. Ranking of varieties by tolerance level

Order	Category	tolerance level
1	V2	High
2	V1	High
3	V3	Medium
4	V4	Low
5	V5	Low

These results are interpreted as follows: drought and heat acted as stressors that affected growth efficiency, photosynthesis, and water balance within the plant, which in turn impacted the overall performance of the varieties. It is observed that the more tolerant varieties were able to maintain a better level of physiological balance, indicating that they possess more efficient internal mechanisms for adapting to harsh conditions, such as reducing water loss, maintaining photosynthetic activity, and activating systems that protect against oxidative stress (Alsamadany et al., 2024; Bahrami et al., 2025) .

Furthermore, the elevated levels of certain defense indicators in the tolerant varieties are not merely transient responses, but rather reflect a genetic capacity to regulate stress responses more effectively, thus helping the plant overcome the negative effects of heat and drought (Sallam et al., 2019; Thabet et al., 2023). This interpretation aligns with studies suggesting that barley's tolerance to these conditions is not linked to a single trait, but rather to the integration of a set of physiological and biochemical characteristics that work together to maintain plant survival and productivity (Janiak et al., 2018; Kavi et al., 2013).

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On the other hand, the relationship between physiological indicators and productivity supports the idea that adaptive efficiency is not separate from agricultural performance, but rather forms its foundation (Elakhdar et al., 2022; Elakhdar et al., 2023). Therefore, varieties that exhibited relative stability in their traits under stress can be considered promising genetic resources for breeding programs, as they combine resilience with the ability to maintain an acceptable level of yield, making them more suitable for arid and semi-arid environments. Accordingly, the study's findings are not merely descriptive but also provide an important practical indicator for future variety selection and improvement.

IV. Conclusion:

The study concluded that drought and heat clearly affect barley growth and yield, and that varieties differ in their resilience. The results also indicated that certain physiological and biochemical indicators can be relied upon to distinguish and select resilient varieties for improving cultivation in harsh environments.

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