DOI: https://doi.org

EcoBiotics: Journal of Animal & Plant Sciences

journal homepage: https://rjsaonline.org/index.php/EcoBiotics/

Evaluation of Drought-Resistant Wheat and Rice Varieties under Pakistani Agro-Climatic Conditions

Syeda Okasha Javed[1]

[1]Department of Plant Breeding and Molecular Genetics (PBMG), Agriculture, University of Poonch Rawalakot
Email: okashasyed@upr.edu.pk

ARTICLE INFO

Received:
April 04, 2024
Revised:
April 26, 2025
Accepted:
May 11, 2025
Available Online:
May 26, 2025

Keywords:
Drought resistance, Wheat, Rice, Agro climatic condition, Water usage efficiency, Accumulation of proline, Pakistan.

Author:
okashasyed@upr.edu.pk

ABSTRACT

Drought stress is one of the major abiotic stress factors in limiting crop productivity in Pakistan especially of the staple cereal crops (wheat: Triticum Aestivum and rice: Oryza Sativa). This study is an extensive evaluation study of performance of drought resistant wheat and rice varieties in varying agro climatic conditions for the major growing areas in Pakistan. Field trials have been conducted in the current cropping seasons (2024-2025) to estimate the morphological, physiological and yield related parameters. Key drought tolerance indicators like relative water content, stability of chlorophyll, accumulation of proline and grain yield was measured. Results indicate a considerable variation from variety to variety in that some wheat varieties show improved water use efficiencies and both rice and wheat varieties have a similar yield under water limited conditions. The findings highlight the importance of identifying and propagating drought resistant cultivars in order to increase food security and sustainable agriculture in the water scarce areas.

Introduction

Water scarcity is gaining universal recognition as one of the key constraints on agricultural production and particularly so in arid and semiarid regions such as Pakistan. The country is highly reliant on irrigation-based agriculture but the inconsistent rainfalls, declining ground water levels and the climate variabilities has increased the drought stress which has created severe threats to the cereal crop yields (Hussain et al. 2020; FAO, 2021). Wheat and rice being the two major staple cereal crops of Pakistan plays an important role in food security, rural livelihoods and national economy in the country as contribution of 60% more caloric intake of the country's population (Khan et al., 2019). However, both crops are very sensitive to the presence of soil moisture deficits, especially during critical stages of growth namely at tillering, flowering and grain filling, which has led to drought tolerance being an important determinant of stability of yield (Farooq et al., 2017).

Drought stress elicits many different physiologies, biochemical, morphological responses in plants. Water deficit causes the reduced pressure of turgor in the cells, reduction of the photosynthesis process, variation in the conductance of stomata and accelerated aging, ultimately resulting in reduction of the accumulation of biomass and grain formation (Chaves et al., 2003; Hussain et al., 2020). In wheat, drought condition lead to the reduction of leaf relative water content (RWC) and the stability of chlorophyll resulting in lower photosynthetic efficiency and lower potential yield (Ali et al. 2018). Similarly, rice, particularly in upland and rainfed ecosystems, exhibits a reduction in number of tillers, spikelet fertility and grain weight under drought conditions, which underlines the need of incorporating traits related to drought tolerance along with developed breeding strategies (Vikram et al., 2011). Understanding of these physiological responses is very important to evaluate varietal performance and for cultivar selection in Pakistani agro climatic conditions.

Several studies have emphasized role of osmotic adjustment and accumulation of compatible solutes such as proline, glycine betaine and soluble sugars for enhancing drought tolerance in wheat and rice. Proline accumulation in particular has an osmotropectant role, stabilises cell membranes, acts as a free radical scavenger and a maintenance factor for enzymes under water deficit conditions (Ashraf & Foolad, 2007; Farooq et al., 2017). In addition, drought resistant cultivars are also known to possess higher antioxidant enzymes such as superoxide dismutase, catalase and peroxidase to combat oxidative damage caused by drought-induced grasping reactive oxygen products (ROS) (Sairam et al., 2000). These biochemical adaptations as well as morphological adaptations (i.e., deep rooting, leaf area and stomata sensitivity) combine to determine the resilience of plants to water lack.

Pakistan has wide ranging agro-climatic zones from the arid south plains of Punjab and Sindh to the more temperate northern highlands of the country offering different level of agro-ecological drought stress, which also require varietal evaluation specific to each region of the country (Ahmad et al., 2019). Field based evaluation of drought resistant cultivars under local conditions not only help to get critical information on the genotype x environment interactions, but also help to identify varieties having consistent performance under water limited environments. Traditional breeding and modern molecular approaches i.e. Marker- assisted selection, genomic prediction have helped in breeding of drought tolerant varieties for wheat and rice; however their validation under Pakistan agro-climatic conditions is necessary for the acceptance of these varieties by the farmers (Jaleel et al., 2009; Vikram et al., 2011).

This yield stability in a drought stressed situation is correlated to the extent of the physiological efficiency and resource utilization to. Water use efficiency (WUE) which is defined as the ration between the yield of biomass or grains to the amount of water us is a selection criteria in drought prone environments (Blum, 2009). Varieties with higher WUE have sustained photosynthetic activity with sustained accumulation of biomass in conditions of limited water availability, which translates into greater stability of grain yield. Similarly, some of the traits such as stay green phenotype, early maturation and improved root/shoot ratio are adaptive traits under drought conditions (Farooq et al., 2009). Integration of these physiological and morphological traits in the framework of evaluation can be of use in finding the cultivars with drought tolerance and high productivity for sustainable cereal production in Pakistan.

Previous studies of drought resistant wheat and rice in Pakistan have reported that there is significant variation in performance among cultivars. For instance, some wheat varieties such as 'Bakhtawar-92' and 'Faisalabad-2008' have a enhanced RWC, chlorophyll retention and grain yield in water deficit conditions than traditional varieties (Ali et al. 2018). Similarly, rice cultivars like 'Super Basmati' and 'IRRI-9' have manifested its tolerance towards drought stress in rainfed lowland and upland ecosystem (Vikram et al., 2011). Despite these improvements, little information is present about the comparative performance in multiple agro-climatic zones especially under field conditions simulating the stress scenarios in the field. Such knowledge is very important for the formulation of the context, varietal specific recommendations and policy interventions to improve cereal productivity under climate variability.

In conjunction with the physiological and biochemical evaluation, a consideration of resting agronomic parameters of performance such as plant height, number of tillers, spikelet fertility and grain weight is also useful to evaluate a fuller performance indicator for varietal adaptation to drought stress. Integrating biochemical, physiological and agronomic parameters helps in taking a comprehensive view on drought resistance, in helping select for better cultivars for research and practical purposes (Farooq et al., 2017). This multi-trait approach manifests in a certain situation like ours in Pakistan with the diversity of agro-climatic conditions and water scarcity calling for the cultivars that have the traits of resilience and productivity.

The increase in the occurrences of drought in Pakistan due to climate changes and the monsoon setting influx, make it imperative to develop and adopt of residue resistant genotypes for wheat and rice to create food security and eliminate the unsustainable agricultural practices (FAO, 2021; Hussain et al., 2020). The present study aims to fill some existing gaps as it has been planned to be conducted a comparative evaluation of drought resistant cultivars under representive agro climatic conditions with their physiological, biochemical, yield response. The results are expected to feed into breeding programs as well as farmer adaptation strategy and result in climate resilient cereal consequent production in Pakistan.

Literature Review

Drought stress is a universal environmental constraint for agricultural production having serious impacts on agricultural production worldwide particularly in arid and semi-arid areas including Pakistan. The susceptibility of staple cereals like

wheat (Triticum aestivum) and rice (Oryza sativa) to water deficit situation has led to the conduction of extensive researches on the mechanism of drought tolerance and varietal improvements (Farooq et all, 2017; Hussain et all, 2020). Physiological, biochemical and morphological adaptations are widespread in plants to deal with drought stress and, thus, understanding these mechanisms is important for the breeding and selection of drought resistant cultivars that could be cultivated under agro-climatic conditions situated in very diverse environments (Blum, 2009; Chaves et al., 2003).

Water deficit gives affect mainly on the growth of plants by lowering turgor of the cell, impede of photosynthesis and metabolic processes. Drought induced reduction of relative water content (RWC) and chlorophyll content is the direct limiting factor to the photosynthetic efficiency causing reduction in accumulating biomass and grain yield (Ali et al., 2018; Farooq et al., 2009). In wheat, drought stress during critical stages of development, likes tillering and anthesis stage can reduce grain number and weight, however in rice reduced tillering, spikelet fertility and reduced grain filling under water limited conditions was recorded (Vikram et al., 2011; Khan et al., 2019). These physiologic impairments establish the need for choosing drought tolerant varieties that have adaptive characteristics to help alleviate the effects of the water deficit.

Osmotic adjustment is one of the world's significant biochemical mechanisms of cell turgor maintenance in plants under drought stress. Accumulation of compatible solutes such as proline, glycine betaine, soluble sugars which stabilize the order of cell structures, protection of enzymes and scavenging of reactive oxygen species (ROS) (Ashraf & Foolad, 2007; Farooq et al., 2017). Accumulation of proline in particular has been reported by many, as a good biochemical marker for drought tolerance of wheat and rice (Kumar et al., 2014; Hussain et al., 2020). Additionally, oxidation through the production of ROS (reactive oxygen species) due to drought is ameliorated by antioxidant systems of defense that consists of superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) - contributing to the drought resilience (Sairam et al., 2000; Jaleel et al., 2009).

Morphological characteristics are also of great importance to drought tolerance. Deep and more extensive root systems occur as part of root architecture which allow for efficient water uptake from deeper soil layers which helps retain turgor and photosynthesis during water scarcity (Lopes & Reynolds, 2010; Rehman et al., 2017). Molecular regulatory response: Reduced leaf area, thicker cuticles having stomatal regulation which further restricts transpiration losses improves water-use-efficiency (WUE) (Blum, 2009; Farooq et al., 2017). Genotypic variability in these traits has enabled to identify wheat and rice cultivars with better drought adaptation and is necessary to breeders in their breeding programs towards water-limited environment.

Agronomic management practices, such as optimized planting density, mulching and scheduling irrigation time, have been shown to act in addition to genetic improvements to optimize soil moisture retention, as well as decrease evapotranspiration (Ahmad et al., 2019; FAO, 2021). Studies in the agro-climatic zones of Pakistan have shown that drought resistant wheat variety like 'Bakhtawar-92' and 'Faisalabad-2008' had higher RWC, chlorchol retention and yield with water limitation (Ali et al., 2018). Similarly, rice cultivars including 'Super Basmati' and 'IRRI-9' have adaptive traits for the drought stress as they have early maturation, efficient root systems and osmotic adjustments to sustain drought stress yield (Vikram et al. 2011; Rehman et al. 2017).

Molecular approaches have developed in the breeding for drought resistance by the identification of quantitative trait loci (QTLs) and genes of the water-use efficiency, root architecture, osmotic adjustment and hormonal regulation. For example, DREB (dehydration-responsive element-binding) transcription factors have been implicated to enhanced drought tolerance in wheat and rice with the interventions in stress-responsive genes (Lata & Prasad, 2011; Zhang et al., 2014). Similarly, target fixing genes that produces aquaporins, late embryogenesis abundant proteins (LEA) or genes that establish the biosynthesis of osmoprotectants have been aimed at improving the drought resilience (Sharma et al., 2013; Khan et al., 2019). These molecular insights, though, are complementary for the field-based examination of the phenotypic evaluations for a more holistic approach to cultivar development.

The hormonal regulation is also an important component of drought adaptation. Abscisic acid or ABA has been known to mediate stomatal closure, root production & triggering of stress-responsive genes under water-deficit conditions (Cutler et al., 2010; Farooq et al., 2017). Cross-talk between ABA and other hormones including ethylene, jasmonic acid and salicylic acid is responsible for fine-tuning the response to drought under ABA influence of antioxidant activity, osmotic adjustment and gene expression (Pieterse et al., 2014; Zhang et al., 2014). Understanding these mechanisms mediated by hormones allows to identify cultivars that are able to adapt very quickly and efficiently to drought.

Several studies identified the importance of multi-environmental testing to Europeans genotype x environment interaction in drought resilient wheat and rice. Field trial conducted in different agro-climatic regions of Pakistan have shown a significant difference in varietal performance, which is an indication of local-specific recommendation (Ahmad et al., 2019; Hussain et al., 2020). Integration of physiological, biochemical and yield-related parameters gives an all round evaluation scheme, thus paving the way to the determination of excellent drought resistant cultivars for sustainable cereals production.

Water-use efficiency (WUE) has come to be an important selection criteria for production of drought tolerant cultivars. Varieties with high values for WUE maintain biomass production and grain yield with little water application which is particularly important under the water-limited conditions of Pakistan (Blum, 2009; Farooq et al., 2009). Traits such as stay-green phenotype, early time of maturity and increased root/shoot ratios are responsible for increased WUE and an overall drought resistance (Lopes & Reynolds, 2010; Kumar et al., 2014). The combination of assessment of WUE in the breeding programs will make sure that cultivars being selected are both productive and resource efficient.

Recently, however, there have also been various research interests, for which the model to approach and increase the drought resilience using molecular and physiological methods has been presented by the combination of traditional breeding. Marker assisted selection (MAS) of drought related QTLs and field based evaluation of RWC, chlorophyll stability & proline accumulation help in identification of superior genotypes under water deficit (Lata and Prasad, 2011; Sharma et al., 2013). Such integrative strategies are needed to achieve the double challenge of the maintenance of stability of crop yields and ecology in drought prone areas.

In a nutshell, literature brings out the fact that the trait of drought tolerance in wheat and rice is a multifactorial trait and involves physiological, biochemical, morphological and molecular components. Effective drought resistant cultivars combine the traits of osmotic adjustment, antioxidant defense mechanism, hormone regulation mechanism, root architecture and, optimized agronomic traits for yield stability in water limited conditions (Farooq et al., 2017; Hussain et al., 2020). However, there still remains need for region specific evaluation of these cultivars under Pakistani agro-climatic conditions in order to provide food security, sustainable agriculture and resilience against climate vagaries. The present study extends these results by conducting an in-depth evaluation of drought resistant wheat and rice cultivars in various agro-climatic regions using biochemical and physiological as well as agronomic parameters based on finding out high potential cultivars with the potential of large scale cultivars adoption

Methodology

Study Location

The study has been conducted under the current cropping season of 2024-2025 at an experimental research farm situated in the region south of Punjab region of Pakistan with the climatic conditions of arid to semiarid region, low and erratic rainfall conditions, high temperature during summer season and medium to high fertility range (sandy loam to clay) of soil. This site has been selected as representative of common water limited conditions experienced by the farmers of the wheat and rice of the region.

Selection of Varieties

Six varieties of wheat namely 'Bakhtawar-92', 'Faisalabad-2008', 'Punjab-2011', 'Sehar-2006', 'Galaxy-2013' and 'Siran-2015' and six varieties of rice 'Super Basmati', 'IRRI-9', 'Shaheen Basmati', 'Faisal Basmati', 'Pak Basmati' and 'IRRI-10' were chosen for further screening based on the earlier screening results obtained from physiological, molecular and physiological

Experimental Design

A randomised complete block design (RCBD) with 3 replications made of each variety. Plot size was 5 x 5 meters in size while wheat was sown with 20 cm row spacing and rice is transplanted with spacing of 25 cm and 20 cm between rows and seedlings respectively. Uniform agronomic practices such as fertilization, weed control and pest management measures were followed for all plots so as to be consistent between treatments.

Irrigation Treatments

Two irrigation regimes were adopted viz. (i) Normal irrigation based on the normal crop water requirement and (ii) Stressed conditions, induced by avoiding irrigation at critical growth stages i.e. tillering and anthesis in case of wheat and panicle

initiation and flowering in rice (Farooq et al., 2017; Rehman et al., 2017). Soil moisture should be monitoring by gravimetric techniques and use of soil moisture sensor on regular basis in order to maintain uniform stress condition over drought plots.

Physiological Assessments

Leaf relative water content (RWC) was calculated by the following formula: RWC = [(FW - DW) / (TW - DW)] x 100 where FW is fresh weight, TW is turgid weight and DW is dry weight, (Ali et al., 2018). Chlorophyll content was determined using a SPAD meter and the canopy temperature was determined using an infrared thermometer to determine the water status and stress levels of the plant. These parameters gave a good evaluation of physiological response of plant to drought stress.

Biochemical Assessments

Proline accumulation was determined following Bates et al (1973) method while soluble sugar using anthrone reagent method. Antioxidant enzyme activities Superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) were measured by standard spectrophotometry methods (Ashraf and Foolad 2007; Jaleel et al. 2009). These biochemical indicators have been selected on the basis of the relevance in terms of osmotic adjustment, oxidative stress mitigation and drought tolerance.

Morphological Evaluations & Yield Evaluations

Morphological characteristics such as plant height, number of tillers per plant leaf area and panicle length were measured at maturity. Yield related parameters viz, spikelet fertility, 1000 grain weight and g/plot were determined. Observations were obtained for the ten randomly selected plants/plot and the mean values were calculated for statistical analyses.

Statistical Analysis

The data collected for all of these was analysed by using analysis of variance (ANOVA) to determine the significant effects of these factors on physiological, biochemical, morphological and yield parameters. Mean comparisons using the least significant difference (LSD) test at the five percent level of probability were made. Correlation and regression analysis to determine relations between physiological and biochemical characteristics and grain yield were performed (Farooq et al., 2017; Blum, 2009). Statistical analyses were made using statistical package, version 25.0, of computer program Statistical Package and the statistic program R.

Data Analysis & Findings

The data obtained from field experiment in the southern area of the province showed that the information about the performance of drought resistant wheat and rice varieties under normal and drought stressed condition are complete. Physiological analysis revealed that there were significant differences among varieties in terms of the relative water content (RWC), the concentration of chlorophyll and the temperature in canopy. For wheat 'Bakhtawar-92' and 'Faisalabad-2008' had maximum RWC under drought stress that is 78.4% and 76.9% respectively as compared to the susceptible one 'Galaxy-2013' that declined to 62.5% (Table 1). In case of rice, 'Super Basmati' and 'IRRI-9' had better RWC under water deficit that reveals better water retention ability. A similar trend was also found in chlorophyll content with a higher SPAD reading in stressed plant in drought resistant varieties suggesting a better photosynthetic capacity in these varieties. Canopy temperature, obtained at peak afternoon time of day heat was lower in drought pathogenesis tolerant varieties which demonstrated a better transpirational cooling and stomatal regulation.

Table 1. Physiological parameters of wheat and rice varieties under drought stress and control conditions

Crop	Variety	RWC (%)	Chlorophyll (SPAD)	Canopy Temp (°C)
Wheat	Bakhtawar-92	78.4	45.3	31.2
Wheat	Faisalabad-2008	76.9	44.1	31.8
Wheat	Galaxy-2013	62.5	35.8	34.7
Rice	Super Basmati	81.2	46.5	30.5
Rice	IRRI-9	79.6	45.0	31.0
Rice	Faisal Basmati	66.8	37.4	34.2

Biochemical analysis of the critical role of osmoregulation and antioxidant defense in drought tolerance of the crop. Proline accumulation in wheat varieties increased significantly under drought i.e. 'Bakhtawar-92' showed maximum accumulation

3.45 umol gm-1 FW as compared to 1.92 umol gm-1 FW in 'Galaxy-2013'. Similarly there was accumulation of 3.62 umol/g FW and 3.40 umol/g FW of proline in rice 'Super Basmati' and 'IRRI-9' varieties whereas susceptible 'Faisal Basmati' recorded 2.05 umol/g FW of proline. Soluble sugars and antioxidant enzyme activities (SOD, CAT and POD) were also significantly higher in drought tolerant varieties as a result of their improved capabilities to scavenge reactive oxygen species and preserve intracellular homeostasis under water deficit (Table 2). These results suggest both wheat and rice varieties have biochemical mechanisms that have a direct role in drought resistance.

Table 2. Biochemical parameters of wheat and rice varieties under drought stress

Crop	Variety	Proline (µmol g^{-1} FW)	Soluble Sugars (mg g^{-1} FW)	SOD (U mg^{-1} protein)	CAT (U mg^{-1} protein)	POD (U mg^{-1} protein)
Wheat	Bakhtawar-92	3.45	6.8	42.5	28.7	30.2
Wheat	Faisalabad-2008	3.12	6.4	41.2	27.9	29.5
Wheat	Galaxy-2013	1.92	4.1	28.6	18.3	19.7
Rice	Super Basmati	3.62	7.0	44.8	29.5	32.1
Rice	IRRI-9	3.40	6.7	43.5	28.9	30.5
Rice	Faisal Basmati	2.05	4.3	29.4	18.7	20.3

Morphological observations showed that the plant height, more tillers per plant and greater leaf area of drought-tolerant than susceptible wheat and rice varieties was maintained under drought conditions. These two cultivars 'Bakhtawar-92' and 'Faisalabad-2008' produced an average of 5.8 and 5.5 productive tillers per plant while 'Galaxy-2013' produced only 3.7 tillers. Similar adaptive morphology in rice varieties 'Super Basmati' and 'IRRI-9' was observed with higher number of panicle maintenance and spikelet fertility under water deficit.

Drought stress produced yield analysis confirming the arguments for use of drought tolerant varieties. Wheat varieties 'Bakhtawar-92' and 'Faisalabad-2008' showed grain yield of 4.2 t ha-1 and 4.0 t ha-1 under drought stress, reduction which were quite little than their irrigated yield of 4.8 t ha-1 and 4.7 t ha-1; respectively. On the other hand, 'Galaxy-2013' had a sharp reduction from 4.5 t/ha under irrigation to 2.8 t/ha under drought. In rice 'Super Basmati' and 'IRRI-9' showed 4.6 t ha^-1 and 4.4 t ha^-1 yield under drought with negligible reduction of irrigated yield whereas 'Faisal Basmati' showed reduced from 4.2 t ha^-1 to 2.9 t ha^-1. These results suggest that drought-tolerant varieties maintain a stability of yield via a combination of physiological, biochemical and morphological adaptations (Table 3).

Table 3. Grain yield of wheat and rice varieties under normal and drought conditions

Crop	Variety	Yield (t ha^{-1}) Control	Yield (t ha^{-1}) Drought	% Reduction
Wheat	Bakhtawar-92	4.8	4.2	12.5
Wheat	Faisalabad-2008	4.7	4.0	14.9
Wheat	Galaxy-2013	4.5	2.8	37.8
Rice	Super Basmati	4.8	4.6	4.2
Rice	IRRI-9	4.6	4.4	4.3
Rice	Faisal Basmati	4.2	2.9	31.0

Correlation analysis revealed a good positive correlation among the RWC, proline accumulation, chlorophyll content and the grain yield, which was finding that these physiological and biochemical traits can be assumed to be reliable indicators to drought tolerance in both wheat and rice. Furthermore, the yield was also positively correlated with antioxidant enzyme activities in drought conditions emphasizing the importance of ROS scavenging during maintenance of plant productivity under water limited conditions.

Overall the results show that the drought tolerant varieties of wheat and rice have a combination of several adaptive mechanisms (high RWC, chlorophyll stability, proline accumulation, antioxidant activity and preferred morphological traits) to sustain yield under the water deficit condition. These results recommend the use of "Bakhtawar-92" and "Faisalabad-2008" in wheat and "Super Basmati" and "IRRI-9" in rice in drought prone areas of southern Punjab and are potential for food security and sustainable production of cereals under the conditions of climate variability.

Discussion

The results of the present study shows that drought resistant wheat and rice varieties show physiological, biochemical and morphological adaptation of corals, which make them productive under water limited environment. Physiologically the varieties like 'Bakhtawar-92' and 'Faisalabad-2008' in case of wheat and 'Super Basmati' and 'IRRI-9' of rice had more relative water content with increased concentration of chlorophylls with their better water retention and photosynthesis stability under the stress of drought. These results are in congruence with earlier results showing that RWC as well as chlorophyll stability are critical indicators of drought tolerance in cereals (Ali et al., 2018; Farooq et al., 2017). Canopy temperature measurements supported these findings as the drought tolerant varieties had a lower temperature as a result of better regulation of stomata and transpirational cooling confirming their ability to deal with heat stress associated with water deficit.

Biochemical responses such as high proline accumulation, soluble sugars, and antioxidant enzyme activities (SOD, CAT and POD) played an important role in alleviation of the drought induced oxidative stress. These biochemical mechanisms allow plants to ensure an osmotic balance within the plant cells, prevention of damages to cell structures and detoxification of reactive oxygen species which leads to subsequently support plant growth and yield (Ashraf & Foolad, 2007; Jaleel et al., 2009). The aforementioned enhanced content of such compounds was highly associated with the stability of the yield of drought tolerant varieties showing that such characteristics can be useful indicators of drought resilience. Morphological traits such as increased tiller number, increased plant height and increased leaf area also further contributed to enhanced drought adaptation by the enhanced photosynthetic capacity and nutrient acquisition.

Yield analysis results showed that the variety are drought tolerant and yield productivity is maintained under water stress yielding reduction little from irrigated conditions. In contrast, substantial amount of yield losses were observed among susceptible varieties such that it underlines the importance of varietal selection to reduce consequences of drought. These results are similar to other previous results showing a possible significant increase in yield stability with water limitation as a result of the combination of physiological, biochemical and morphological adaption (Blum 2009, Vikram et al. 2011). The high correlations which are existing between RWC, proline accumulation, antioxidant activity and grain yield support the integrative nature of the mechanisms of drought tolerance in wheat and rice.

Conclusion

This study shows that the drought resistant wheat and rice cultivars, viz. 'Bakhtawar-92' and 'Faisalabad-2008' (wheat) and 'Super Basmati' and 'IRRI-9' (rice) had better physiological, biochemical and morphological characteristics to sustain the yield under water limited conditions. The results confirm that relative water content, stability of chlorophyll, osmotic adjustment of proline accumulation and antioxidant enzyme activities are important factors of drought tolerance. These results emphasise the importance of incorporation of different adaptive traits in selection and breeding of drought resilient cereal varieties of south Punjab and similar agro-s climatic**.**

Recommendations

Based on the results of the present study, it is recommended that the drought tolerant wheat and rice varieties identified in the present study be promoted for their cultivation in drought prone areas of SCP for the stability of the yield and food security. Future breeding programmes should be based upon integration of physiological and biochemical traits along with high potential yield in order to create cultivars capable of coping with more erratic rainfall and climate variability. In addition, farmers are recommended to practice some complementary agriculture techniques, such as optimized irrigation schedule, mulching and soil moisture conservation to increase melting of the crops in water limited conditions further. Continuous monitoring of the drought adaptive traits and multi-environment testing is also recommended to assure the continued performance of these varieties under the variable agro-climatic scenarios.

References

1. Ahmad, M., Hussain, S., & Khan, S. (2019). Agro-climatic zones of Pakistan and crop suitability assessment. *Pakistan Journal of Agricultural Sciences, 56*(3), 245–258.

2. Ahmed, N., & Ali, M. (2020). Antioxidant enzyme activity in wheat under water deficit conditions. *Journal of Plant Interactions, 15*(1), 56–64.
3. Ali, Q., Abbas, A., & Anwar, F. (2018). Physiological evaluation of wheat genotypes for drought tolerance under field conditions. *Journal of Agronomy, 17*(2), 89–99.
4. Ashraf, M., & Foolad, M. R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. *Environmental and Experimental Botany, 59*(2), 206–216.
5. Bates, L. S., Waldren, R. P., & Teare, I. D. (1973). Rapid determination of free proline for water-stress studies. *Plant and Soil, 39*(1), 205–207.
6. Blum, A. (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Research, 112*(2–3), 119–123.
7. Chaves, M. M., Maroco, J. P., & Pereira, J. S. (2003). Understanding plant responses to drought—from genes to the whole plant. *Functional Plant Biology*, 30(3), 239–264.
8. Cutler, S. R., Rodriguez, P. L., Finkelstein, R. R., & Abrams, S. R. (2010). Abscisic acid: Emergence of a core signaling network. *Annual Review of Plant Biology*, 61, 651–679.
9. Farooq, M., Hussain, M., Wakeel, A., & Siddique, K. H. M. (2017). Drought stress in plants: An overview. In A. Ahmad, M. Rasool, & M. Hussain (Eds.), *Plant responses to drought stress* (pp. 1–33). Springer.
10. Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2009). Plant drought stress: Effects, mechanisms, and management. *Agronomy for Sustainable Development, 29*(1), 185–212.
11. Farooq, S., Basra, S. M. A., & Wahid, A. (2010). Physiological mechanisms of drought tolerance in wheat. *Plant Growth Regulation, 60*(2), 123–138.
12. Hussain, S., Rehman, A., & Khan, M. (2020). Climate change and its impact on wheat and rice productivity in Pakistan. *Environmental Science and Pollution Research, 27*(22), 28145–28157.
13. Jaleel, C. A., Gopi, R., & Panneerselvam, R. (2009). Antioxidant defense responses in crop plants under drought stress. *Plant Stress, 3*(1), 42–57.
14. Kaur, P., & Kaur, R. (2019). Physiological and biochemical adaptations in wheat under drought stress. *Journal of Stress Physiology & Biochemistry, 15*(4), 105–118.
15. Khan, S., Ahmad, S., & Ali, M. (2019). Staple cereals and food security in Pakistan: A review. *Journal of Food Security*, 7(2), 45–57.
16. Kumar, S., Kumar, S., & Singh, R. (2014). Role of proline and soluble sugars in drought tolerance of wheat and rice. *Journal of Plant Physiology, 171*(3–4), 236–244.
17. Li, X., Wang, F., & Chen, Y. (2015). Proline metabolism and drought tolerance in cereal crops. *Plant Science, 239*, 72–81.
18. Lata, C., & Prasad, M. (2011). Role of DREB transcription factors in drought tolerance. *Plant Biotechnology Reports*, 5(4), 305–317.
19. Lopes, M. S., & Reynolds, M. P. (2010). Root architecture and drought adaptation in wheat. *Plant Physiology*, 153(4), 1740–1755.
20. Rehman, A., Hussain, S., & Ali, M. (2017). Comparative evaluation of rice cultivars under drought stress in Pakistan. *Pakistan Journal of Botany, 49*(2), 725–734.
21. Raza, A., & Qureshi, R. (2018). Water-use efficiency and drought tolerance in rice genotypes. *International Journal of Agriculture and Biology, 20*(6), 1275–1284.
22. Shah, T., & Iqbal, M. (2017). Effects of drought on grain yield and biochemical traits in rice. *Asian Journal of Crop Science, 9*(3), 130–142.
23. Sairam, R. K., Srivastava, G. C., & Saxena, D. C. (2000). Increased antioxidant activity in tolerant wheat genotypes: Response to drought stress. *Biologia Plantarum*, 43(4), 245–249.
24. Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2013). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stress. *Journal of Botany*, 2013, Article 1–26.
25. Vikram, P., Swamy, B. P. M., Dixit, S., Singh, R., & Kumar, A. (2011). Breeding drought-resistant rice: Physiological and molecular approaches. *Journal of Plant Biology, 54*(4), 255–270.
26. Zhang, H., & Li, S. (2018). Evaluation of wheat genotypes for drought resistance using physiological and biochemical parameters. *Journal of Plant Research, 131*(5), 839–851.
27. Zhang, J., Liu, X., & Wang, Y. (2016). Drought stress effects on physiological and biochemical traits in wheat. *Journal of Agronomy and Crop Science, 202*(6), 499–510.

2025 by the authors; EcoBiotics: Journal of Animal & Plant Sciences. This is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (http://creativecommons.org/licenses/by/4.0/).