DROUGHT STRESS IMPACTS ON WHEAT AND ITS RESISTANCE MECHANISM - A REVIEW

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Wheat is the most commonly grown and used cereal crop due to its economic and social benefits. Nature's vengeance, in the form of numerous biotic and abiotic stress factors, has an adverse impact on plant growth and productivity. Drought is a polygenically managed stress and a major agricultural risk that reduces crop production and restricts effective land potential insight around the world. Drought stress induces a number of morphological, physiological, biochemical, and molecular responses in crops. Drought tolerance is a dynamic trait regulated by polygene, whose expression is affected by a number of environmental factors. We have looked at how drought stress affects development, penology, water and nutrient relationships, photosynthesis, assimilate partitioning etc in wheat plant. Wheat reacts to prevailing water stress in a number of morphological, physiological, and biochemical ways at cellular, and molecular levels, making it a complicated phenomenon. Physiological experiments are being performed to determine the changes that occur in the wheat plant as a result of drought stress. Changes in the root systems such as effects on height, leaf senescence, flowering, and so on, are examples of morphological changes. Changes in cell growth pattern, chlorophyll content, plant water relation, photosynthetic disturbances are all the examples of physiological changes. Different chemicals, biomolecules, enzymes are involved in biochemical changes. Drought escape, drought avoidance, and drought tolerance are three mechanisms that plants use to cope with drought stress. As a result, the focus of this review paper is on the effects of water scarcity on the morphological, physiological, biochemical, and molecular responses of wheat as well as the potential losses caused by drought stress and management strategies.

Keywords: Drought stress, Drought tolerance, Effects, Resistance, Mechanisms.

INTRODUCTION

Wheat (Triticum aestivum), is one of the most widely cultivated cereals, particularly in the mediterranean region and semi-arid regions from temperate to sub-tropical areas of the world (Ahmed et.al., 2019). It is grown on 21% of agricultural land and accounts for 17% of total cereals production (Sharma, 2018) . Wheat was cultivated in 703,992 ha of land in financial year 2018/19 and the production was 2,005,665 metric tons with the productivity of 2.849 tons/hac. (MoALD, 2020). In 2020, wheat production for Nepal was 2,210 thousand tones.

Wheat production of Nepal increased from 193 thousand tonnes in 1971 to 2210 thousand tonnes in 2020 growing at an average annual rate of 5.73%. It contributes highest percentage of calorie and protein to the world diet.It contains 53-74% carbohydrates, 11-20% protein,fat-2%, fiber ,many vitamins (especially B vitamins), calcium, iron and many micro and macro nutrients. Wheat is a global commodity with about 150mt being traded annually (World Agricultural Outlook Board, 2014). Wheat bran and wheat germ can be used as a best source of dietary fiber that helps in the control and prevention of some digestive disorders (Simmonds DH, 1989). The International Grains Council (IGC) released the latest grain market report that the global wheat production is more than 769 millions tones in the 2020/21 marketing year.

DROUGHT STRESS

Drought is considered the single most devastating environmental stress, reducing crop production more than any other environmental stresses(Lambers et al.2008).It has an effect on all stages of plant production, from germination to vegetation and reproductive growth to grain filling and crop maturity (Hossain et al.2012). Nitrogen uptake and utilization by plants is reduced by drought stress. Drought is the most severe abiotic stress, affecting at least 60% of wheat production in high income countries and about 32% of the 99 million hectares in low-income least developed countries (Chen et al.2012). Wheat grain yields could be decreased by 17-70% if there is a shortage of water (Nourin-Gan-balani et al. 2009).Drought stress can reduce leaf water potential, lowering turgour, stomatal conductance, and photosynthesis, and eventually reducing wheat growth and yield (Chen et al.2012).

TaEXPR23	Cell wall expansion: expansin	Water retention ability and osmotic potential	[46]
TaL5	Nucleocytoplasmic transport of 5S ribosomal RNA: ribosomal L5 gene	Drought	[47]
TdPIP1;1, TdPIP1;2	Protective protein: aquaporin	Drought	[48]
TdicATG8	Autophagy: autophagy related gene 8	Drought	[33]
TdicTMPIT1	Autophagy: integral transmembrane protein inducible by TNF-α	Drought	[31]
Era1, Sal1	Enhanced response to ABA, inositol polyphosphate 1-phosphatase	Drought	[49]

Ta: *Triticum aestivum*; Td: *Triticum durum*; Tdic: *Triticum dicoccoides*; DRE: drought related element; SNF: Sucrose nonfermenting; MAP: mitogen activated protein; ABA: abscisic acid; CHP: cysteine histidine proline; TNF-α tumor necrosis factor α; PIMP: pathogen induced membrane protein; CP: cysteine protease; EXPR: expansin; PIP: plasma membrane intrinsic proteins.

DROUGHT CONDITION IN NEPAL

Agricultural drought has a much greater effect in rainfed agricultural countries, including Nepal (Mayan, 2015, Chen et al. 2016). Due to greater warming in recent years than that of the global average, Nepal has been considered as the most vulnerable country with respect to climate. While the global mean surface temperature rose by 0.6 degree Celsius from 1975 to 2005, Nepal's temperature rose by 1.5 degree Celsius(0.06 degree Celsius per year) over the same time period, from 1980 to 2006 (Biwa et al., 2012). Precipitation and rainfall pattern are becoming more erratic as well (Wang et al., 2013). As a result, average monthly rainfall has decreased by 3.7mm(-3.2%) over the last decade (Ministry of Education, 2010). These ultimately created drought condition particularly for the rain fed farming, where farmer depends on monsoon rainfall for their primary agricultural activities (Ghimire et al.,2010). Furthermore, by the 2060s, the mean annual temperature is expected to rise between 1.3 degree Celsius and 3.8 degree Celsius, and 1.8 degree Celsius to 5.8 degree Celsius by the 2090s, with annual precipitation declination varying from 10 % to 20% across the region (Ministry of Education, 2010).

Droughts are common in Nepal from March to June, when the monsoon season starts, and winter precipitation is almost non-existent, with the land hardly replenished (Joshi, 2018). Drought has caused panic in Nepal's hill farming system, which is dependent on crop production and livelihood support for farmers. Drought, on the other hand, can provide opportunities to learn various adaptations strategies that are a[appropriate in such changing conditions(Dulal et al.,2010)

EFFECTS OF DROUGHT STRESS

Drought stress has a variety of effects on plants, ranging from morphological to molecular, and is harmful to all physiological functions .The various effects of drought stress and their magnitude are described below:

1. Morphological Changes:

1.1 Small plant size

Defective germination and poor crop establishment are the most common effects of water stress (Haris et.al, 2002). Due to the decrease in the turgor pressure, cell growth is an important drought-sensitive physiological process (Taizand Zeigler, 2006). At the stem elongation and booting stages, the plant height was reduced by 35% and 23% respectively, while the plant height was reduced by 7% at grain filling stage(Caverzan et.al, 2016 a). Hence, drought stress is one of the major factors that is responsible for overall decrease in growth of wheat plant.

1.2 Reduced leaf area

Reproductive growth causes a reduction in leaf area index that is equal to or greater than those caused by water stress. The rate of photosynthesis in plants decreases when there is a lack of water. The lack of water induces discoloration and a rise in leaf trichomes and stomata on the leaf surface is increased. While CO2 flow and leaf transpiration decrease, proline accumulation and abscisic acid stress increases (Heidaiy and Moaveni, 2009).

1.3 Leaf Senescence

According to one analysis, if drought occurs during the reproduction stage, the rate of senescence rises as a result of drought stress, resulting a substantial reduction in grain yield (Nawaz et.al, 2013). One of the most visible symptoms of leaf senescence is chlorosis, which triggers a reduction in photosynthesis (Ali et.al, 2020). In most cases, senescence starts in older leaves and spreads to younger.

1.4 Change in root system

Plant root gain nutrients and water from the ground and performs an important position all through condition of drought also. When there is scarcity of water sources plant root goes deep into the soil in order to take in water from soil.In order to survive against drought condition the architecture of root system is considered very important as the good architecture of wheat extracts maximum soil water under drought stress and also improving the yield of grain (Dodd et al., 2011).

2. Physiological Change

2.1 Yield loss

Drought stress (water deficit) is the primary abiotic stress that severely reduces yield and productivity in the current and future climate change scenarios. The decline in yield, productivity and quality, according to the IPCC (2014) report, is primarily due to severe water deficit condition and possess a serious threat to agriculture. Drought has a complex effect on grain yield, involving processes such as nutrient assimilation and mobilization to various reproductive organs, stem reserves accumulation, gametogenesis, fertilization, embryogenesis, endosperm and seed growth. Presence of these stresses at any stage of growth can affect the yield of crop, the seed filling stage is important for calculating average seed weight, seed composition and therefore the final quantitative and qualitative yield reduces(Cakir,2004; Otegui and Slafer, 2004; Prasadet. al,2017).

2.2 Diminished growth rate

It affects nearly all plants growth processes, though the response varies depending on the intensity rate and length of the stress, as well as the stage of crop growth.(Simane et al,1993,EI HAFID et al,1998 a).

2.3 Changes in cell wall integrity

Drought stress induces mycological changes in higher plants , such as turgor loss , osmotic adjustment and a decrease in leaf water capacity . Turgor potential is the physical force necessary to drive cell expansion , which is primarily determined by the cell walls extensibility . By reducing cell extensibility , a low turgor pressure cause by water stress causes a reduction or cessation of growth.

2.4 Leaf water potential reduction

The water balance of plants is impaired during a water shortage

, resulting in a decrease in a Relative water content (RWC) and water capacity of the leaves(Siddique et al., 2000; Gupta et al., 2001; Baijjii et al., 2001). Drought stress is thought to be detected by changes in the Relative Water Content of leaves. (Strauss and Agenbag, 2000).

2.5 Reduction in the rate of photosynthesis

Drought stress causes the stomata to close, decreasing the amount of CO2 available for photosynthesis and thereby lowering the rate of photosynthesis . Reduced photosynthesis rates can lead to decrease starch accumulation and invertase activity , which can eventually result in pollen sterility and the ovary abortion.(Cattivelli et al., 2008: Farooq, Hussain, and Siddique, 2014). This leads to the reduction of yield.

2.6 Reduced chlorophyll content

Chlorophyll is a good indicator of a plants photosynthesis capacity, which explicitly reflects the plants health and indirectly reflects its response to water stress. It is the main photosynthetic pigment of plants and plays a critical role in photosynthesis and plants physiological conditions, so it is a good indicator of plants photosynthesis capability, which directly reflects the plants health and indirectly reflects its response to water stress (Guo, et al. 2003: Hailemichael et al.

2016). Optimal soil moisture condition increase the chlorophyll content in leaves.

3. Biochemical changes

3.1 Antioxidant properties

Reduced carbon assimilation during drought stress induces an imbalance between electron excitation and consumption by photosynthesis , resulting in the development of reactive oxygn species (ROS) , mainly superoxide and hydrogen peroxide H_2O_2 (Reddy,2004). These ROS induce oxidative stress by destroying cell membrane proteins and nucleic acid (Liu,H.et al.,2015). The presence of Malondialdehyde (MDA) in the intracellular environment indicates the absence of oxidative stress(Sabra,2012) . To detoxify ROS, the plant have both enzymatic and nonenzymatic activity(Abid, M et al.,2016) . Superoxide dismutase (SOD) catalyzes the conversion of $O_2^{.-}$ to the less reactive H_2O_2(Helena,2008). Through the action of catalase (CAT) and ascorbate peroxidase (APX) , this H_2O_2 is further detoxified to O_2 and H_2O. The enzymes described above when combined, ensure alow intercellular level of O_2^- and H_2O_2(Sgherri, 2000). Non enzymatic anti oxidant such as glutathione(GSH) and carotenoid plays a role in cellular protection(Asensi-Fabado,2010).GSH protects the chloroplast from ROS damage by increasing the ratio of reduced to oxidized glutathione(Sairam, 2005), while carotenoid protects the photosynthetic apparatus by converting excess excitation energy into heat(Verma,2005).

3.2 Proline content

Proline aggregation and catabolism play important role in drought stress adaptation. Plants have been shown to be capable of degrading proline through an oxidation mechanism. Adjustment, detoxification of ROS and memberane intergrity protection are all aided by proline. Proline accumulation has been suggested to act as a compatible osmolyte and a way to store carbon and nitrogen, and it is throught to play an adaptation role in plant stress tolerance. It has an osmoregulatory function.

Due to differences in cystosolic synthesis and mitochondrial degradation rates, proline accumulates in response to water stress and disappears quickly once the stress is removed (Kiyosue et al.,1996). It has been discovered that when wheat is subjected to water stress the maximum amount of proline increases in the heading stage (Moralian et al.,2010).

DROUGHT TOLERANCE

Drought avoidance is a crucial adaptation for survival in a water scarce environment. Drought tolerance refers to a plants ability to survive in a dry environment (Ashley,1993). Drought tolerance is a complex polygenic trait, so a variety of factors play a role in the plants ability to tolerate drought. Drought has an effect on the plants cellular, tissue and organ levels (Beck et.al, 2007). Drought tolerant plants respond to drought by triggering a variety of protection mechanisms, which most be understood in order to breed for drought tolerant cultivars(Chaves and Oliveira,2004; Zhou et.al, 2007). Drought resistance mechanisms may be morphological, physiological, or molecular in nature(Bohnert et.al, 1995, Farooq et.al, 2009).

A. Morphological Mechanisms:

Drought escape, which is the ability of plants to complete their life cycle before the start of drought season is one of the morphological mechanisms(Mitra,2001). Drought avoidance is the ability of a plant to retain water by increasing uptake and reducing loss through reduced transpiration,which is facilitated by the plants long and thick root network, as well as leaf and stomatal characteristics(Blum, 1988; Turner et.al,2001; Lzanloo et.al,2008; Agbicodo et.al, 2009).

B. Physiological Mechanisms:

Osmotic adjustment(OA) is perhaps the most important factors that allows the cell to decrease osmotic potential while maintaining turgor, allowing the plant to survive in a low- water environment(Blum, 2005; Farooq et.al, 2009; Taiz and Zeiger, 2006). Abssissic acid causes the stomata to close in water – stressed environment,reducing water transpiration(Turner et.al, 2001). Glucousness(a waxy covering over the cuticle) is also thought to be a reliable parameter for increasing water use efficiency in wheat plants, providing a drought tolerance mechanisms(Richards et.al, 1986).

C. Molecular Mechanisms:

It entails the activation of a series of genes that result in the plants desiccation tolerance(Agarwal et.al, 2006; Umezawa et.al, 2006). Many research on wheat gene expression in wheat are conducted at the seeding stage , although it is junction stage that is susceptible to drought . This is because the junction phase serve as a link between vegetative and blooming stages of growth and it is critical for development and reproduction.

CONCLUSION

Different years of drought in Nepal have been identified, and the effects of those stresses on crop production have been assessed. Historical evidence has shown that there has been a significant loss in crop yield in the past. Drought stress slows crop growth and development, resulting in changes in the crop's morphological, physiological, and biochemical characteristics . The identification of plant genomic responses to water stress is important. To begin, it complies extensive data on plant transcriptional responses to drought stress. Secondly, it helps researchers to learn about the role of genes in stress and related cis- components, which are also important for pre-clinical research and crop engineering (J. Zhou, X. Wang, Y. Jiao et al.,). As a result of this, there is a greater economic loss in wheat production all over the world. Drought is one of the major problems for obtaining potential yield because it prevents proper plant growth and production, hampering fruiting and grain filling, and consequently reducing the size and amount of wheat grains. Drought-induced biochemical reactions are one of the most important growth inhibitors. It is critical to understand the physiological responses of wheat in drought conditions in order to improve yield. To cope with drought stress, plants have developed a variety of resistance mechanisms. Understanding wheat's physiological, morphological, and biochemical responses in this situation assists in the identification of drought tolerance mechanisms and the production of drought-tolerant wheat varieties.

REFERENCE

1.https://www.nature.com/articles/s41598-018-21441-7

2.Reddy, A.R., Chaitanya, K.V. and Vivekanandan, M.Drought-induced responses of photosynthesis and antioxidant metabolism in higher Plants J .Plant Physiol. 161, 1189-1202(2024).

3.Liu, H. et al. Physiological and comparative proteomic analysis reveals different drought responses in roots and leaves of drought-tolerant wild wheat (Triticum boeoticum). PLoS One 10, e0121852(2015).

4.Sabra, A., Daayf, F. and Renault, S. Differential physiological and biochemical responses of three Echinacea species to salinity stress. Scientia Hort. 135,23-31(2012)

5.Abid, M.et al. Improved tolerance to post-anthesis drought stress by pre-drought priming at vegetative stages in drought-tolerant and –sensitive wheat cultivars.

6.Plant physiol. Biochem. 106, 218-227 (2016)

7. Helena, M. and Carvalho, C.D. Drought stress and reactive oxygen species. Plant Signal. Behav. 3, 156-165(2008)

8.Sgherri, C. L. M., Maffei , M. and Navari – Izzo, F. Antioxidative enzymes in wheat subjected to increasing water defecit and re-watering J .Plant . Physiol.157,273-279(2000) 9.Asensi-Fabado, M . A. and Munne-Bosch , S. Vitamins in plants: occurrence , biosynthesis and antioxidant function. Trends Plant Sci 15, 582-592(2010)

10.Sairam , R.K., Srivastava , G.C., Agarwal, S. A. and Meena, R.C., Differences in antioxidant activity in response to salinity stress in tolerant and susceptible wheat genotypes. Biol. Plant. 49, 85-91 (2005)

11.Verma, S. and Mishra , S.N Putrescina allevation of growth in salt stressed Brassica Juncea by including antioxidative defense system. J Plant Physiol. 162, 669-677 (2005).

12.https://www.researchgate.net/publication/324056485_Physiological_Responses_of_Wheat_ to_Drought_Stress_and_its_Mitigation_Approaches

13.https://link.springer.com/article/10.1051/agro:2008021

14.https://www.hindawi.com/journals/tswj/2013/610721/

15.Bawa, K.S.U.B.,Gautam, SP.Widespread climate change in himalays and associated changes in local ecosystems.

16.Wang, S.-Y.,Yoon, J.-H.,Gillies, R.R.CHO,C.What Caused the winter drought in western Nepal during recent years? J.Clim.2013,26,8241-8256.

17.Ministry of Education.National Adaptation Programme of Action to Climate Change, Ministry of Environment:Kathmandu, Nepal, 2010

18.Ghimire, Y.N.,Shivakoti, G.P.,Perret,S.R.Household-level Vulnerability to drought in hill agriculture of Nepal.

19.Joshi,G.R Agricultural Economy of Nepal:Development Challenges and Opportunities,Sustainable Research and Development Centres; Kathmandu, Nepal, 2018

20.United Nation Development Program. Country Report Climate Risk Management in Nepal.Regional Integrated Multi-hazard Early Warning System for Africa and Asia, UNDP:New York,NY,USA,2013

21.Central Bureau of Statistics. National Climate Changes Impact Survey 2016, a Statistical Report, Central Bureau of Statistics:Kathmandu,Nepal,2017

22.J.Bernier,G.N. Atlin, R.Acrraj, A.Kumar, and D.spaner, Review:breeding upland rice for drought resistance in Sorghum(Sorghum bicolour L..Moench),Plant Molecular Biology vol.48,no.5-6,pp.713-726,2002.

23.J.Z hou,X.Wang, Y.Jiao et al.,Global genome expression analysis of rice in response to drought and high- salinity stresses in shoot, flag leaf and the panicle, Plant Molecular Biology,vol.63, no.5, pp.591-608,2007

24.Anjum S.A., Xie X.,Wang L.,Salem M.F.,Man CandLei W. (2011). Morphological, Physiological and Biochemical Responses of Plants to Drought Stress. African Journal of Agriculutural Research, 6(9), 2026-2032.

25.WU X, Bao W(2011), Influence of water deficit and genotype on Photosynthetic activity,dry mass partitioning and grain yield changes of winter wheat. African Journal of Agricultural

Research, 6(25), 5567-5574.MATH

26.B.A.Kimbll,J.P.PINTER,R.L.GARCIA et.al., Prouductivity and water use of wheat under free-air CO2 enrichment,Global Changed Biology, vol.I,pp499-442,1995.

27.J.M.Clark and T.N.McCAIG, Evaluation of technique for screening for draught resistance in wheat,Crop Science, vol.22,pp.5003-5006,1982

28.Earl, H., Davis , R.F., 2003. Effect of drought stress on leaf and whole canopy radiation use efficiency and yield of plant. Agron. J.,95, Pp.688-696

29.Paulsen,G.,2002. Application of Physiology in wheat breeding.Crop Science,42(6).

30.Nouri-Ganbalani, A., Ganbalani, G., Hassanpanah , D.,2009. Effects of drought stress condition on the yield and yield components of advanced wheat genotypes in Ardabil, Iran.

Journal of Food, Agriculture and Enviroment,Pp.7.

31.Siddique, M.R.B., Hamid , A., Islam, M.S.,2001. Drought stress effects on water relation of wheat , Bot.Bull.Acad.Sinica., 41,Pp.35-39.S. Lucas, E. Dogan, and H. Budak, "TMPIT1 from wild emmer wheat: first characterisation of a stress-inducible integral membrane protein," Gene, vol. 483, no. 1-2, pp. 22–28, 2011.View at: Publisher Site | Google Scholar

32. S. Lucas, E. Durmaz, B. A. Akpnar, and H. Budak, "The drought response displayed by a DRE-binding protein from Triticum dicoccoides," Plant Physiology and Biochemistry, vol. 49, no. 3, pp. 346–351, 2011.View at: Publisher Site | Google Scholar

33 .D. Kuzuoglu-Ozturk, O. Cebeci Yalcinkaya, B. A. Akpinar et al., "Autophagy-related gene, TdAtg8, in wild emmer wheat plays a role in drought and osmotic stress response," Planta, vol. 236, no. 4, pp. 1081–1092, 2012.View at: Google Scholar

34. H. Liu, X. Zhou, N. Dong, X. Liu, H. Zhang, and Z. Zhang, "Expression of a wheat MYB gene in transgenic tobacco enhances resistance to Ralstonia solanacearum, and to drought and salt stresses," Functional & Integrative Genomics, vol. 11, no. 3, pp. 431–443, 2011.View at: Google Scholar

35 .X. He, X. Hou, Y. Shen, and Z. Huang, "TaSRG, a wheat transcription factor, significantly affects salt tolerance in transgenic rice and Arabidopsis," FEBS Letters, vol. 585, no. 8, pp. 1231–1237, 2011.View at: Publisher Site | Google Scholar

36. H. Cai, S. Tian, C. Liu, and H. Dong, "Identification of a MYB3R gene involved in drought, salt and cold stress in wheat (Triticum aestivum L.)," Gene, vol. 485, no. 2, pp. 146–152, 2011. View at: Google Scholar

37. Y. Tang, M. Liu, S. Gao et al., "Molecular characterization of novel TaNAC genes in wheat and overexpression of TaNAC2a confers drought tolerance in tobacco," Plant Physiology, vol. 144, no. 3, pp. 210–224, 2012.View at: Google Schola

38.,Y. Qin, M. Wang, Y. Tian, W. He, L. Han, and G. Xia, "Over-expression of TaMYB33 encoding a novel wheat MYB transcription factor increases salt and drought tolerance in Arabidopsis," Molecular Biology Reports, vol. 39, no. 6, pp. 7183–7192, 2012.View at: Google Scholar

39. C. F. Niu, W. Wei, Q. Y. Zhou et al., "Wheat WRKY genes TaWRKY2 and TaWRKY19 regulate abiotic stress tolerance in transgenic Arabidopsis plants," Plant, Cell & Environment, vol. 35, no. 6, pp. 1156–1170, 2012.View at: Google Scholar

40. C. Wang, R. Jing, X. Mao, X. Chang, and A. Li, "TaABC1, a member of the activity of bc1 complex protein kinase family from common wheat, confers enhanced tolerance to abiotic stresses in Arabidopsis," Journal of Experimental Botany, vol. 62, no. 3, pp. 1299–1311, 2011.View at: Publisher Site | Google Scholar

41. .X. Mao, H. Zhang, S. Tian, X. Chang, and R. Jing, "TaSnRK2.4, an SNF1-type serine/threonine protein kinase of wheat (Triticum aestivum L.), confers enhanced multistress tolerance in Arabidopsis," Journal of Experimental Botany, vol. 61, no. 3, pp. 683–696, 2010.View at: Publisher Site | Google Scholar

42..H. Zhang, X. Mao, R. Jing, X. Chang, and H. Xie, "Characterization of a common wheat (Triticum aestivum L.) TaSnRK2.7 gene involved in abiotic stress responses," Journal of Experimental Botany, vol. 62, no. 3, pp. 975–988, 2011.View at: Publisher Site | Google Scholar

43. I. Zaïdi, C. Ebel, M. Touzri et al., "TMKP1 is a novel wheat stress responsive MAP kinase phosphatase localized in the nucleus," Plant Molecular Biology, vol. 73, no. 3, pp. 325–338, 2010.View at: Publisher Site | Google Scholar

44. C. Li, J. Lv, X. Zhao et al., "TaCHP: a wheat zinc finger protein gene down-regulated by abscisic acid and salinity stress plays a positive role in stress tolerance," Plant Physiology, vol. 154, no. 1, pp. 211–221, 2010.View at: Publisher Site | Google Scholar.

45. Li, J. Lv, X. Zhao et al., "TaCHP: a wheat zinc finger protein gene down-regulated by abscisic acid and salinity stress plays a positive role in stress tolerance," Plant Physiology, vol. 154, no. 1, pp. 211–221, 2010.View at: Publisher Site | Google Scholar

46. Q. W. Zang, C. X. Wang, X. Y. Li et al., "Isolation and characterization of a gene encoding a polyethylene glycol-induced cysteine protease in common wheat," Journal of Biosciences, vol. 35, no. 3, pp. 379–388, 2010.View at: Publisher Site | Google Scholar

47. Y. Y. Han, A. X. Li, F. Li, M. R. Zhao, and W. Wang, "Characterization of a wheat (Triticum aestivum L.) expansin gene, TaEXPB23, involved in the abiotic stress response and phytohormone regulation," Plant Physiology and Biochemistry, vol. 54, pp. 49–58, 2012.View at: Google Scholar

48. G. Z. Kang, H. F. Peng, Q. X. Han, Y. H. Wang, and T. C. Guo, "Identification and expression pattern of ribosomal L5 gene in common wheat (Triticum aestivum L.)," Gene, vol. 493, no. 1, pp. 62–68,

2012.View at: Google Scholar

49. M. Ayadi, D. Cavez, N. Miled, F. Chaumont, and K. Masmoudi, “Identification and characterization of two plasma membrane aquaporins in durum wheat (Triticum turgidum L. subsp. durum) and their role in abiotic stress tolerance,” Plant Physiology and Biochemistry, vol. 49, no. 9, pp. 1029–1039, 2011.View at:

Google Schola

50. rH. Manmathan, D. Shaner, J. Snelling, N. Tisserat, and N. Lapitan, “Virus-induced gene silencing of Arabidopsis thaliana gene homologues in wheat identifies genes conferring improved drought tolerance,”

Journal of Experimental Botany, vol. 64, no. 5, pp. 1381–1392, 2013.View at: Google Scholar

51.M. Reynolds and R. Tuberosa, “Translational research impacting on crop productivity in drought-prone environments,” Current Opinion in Plant Biology, vol. 11, no. 2, pp. 171–179, 2008.View at: Publisher Site | Google Scholar.

[52] S. I. Milad, L. E. Wahba, and M. N. Barakat, “Identification of RAPD and ISSR markers associated with flag leaf senescence under water-stressed conditions in wheat (Triticum aestivum L.),” Australian Journal of Crop Science, vol. 5, no. 3, pp. 337–343, 2011.

[53] J. Schneekloth, T. Bauder, and N. Hansen, “Limited irrigation management: principles and practices,” 2012, http://www.ext.colostate.edu/pubs/crops/04720.html.

[54] F. Rizza, F. W. Badeck, L. Cattivelli, O. Lidestri, N. di Fonzo, and A. M. Stanca, “Use of a water stress index to identify barley genotypes adapted to rainfed and irrigated conditions,” Crop Science, vol. 44, no. 6, pp. 2127–2137, 2004.

[55] R. Tuberosa and S. Salvi, “Genomics-based approaches to improve drought tolerance of crops,”Trends in Plant Science, vol. 11, no. 8, pp. 405–412, 2006.

[56] E. Sivamani, A. Bahieldin, J. M. Wraith et al., “Improved biomass productivity and water use efficiency under water deficit conditions in transgenic wheat constitutively expressing the barley HVA1 gene,” Plant Science, vol. 155, no. 1, pp. 1–9, 2000

57. M Seki, M Narusaka. H. Abe et. al, “Monitoring expression pattern of 1300 Arabidopsis gene under drought and cold stresses by using full length cDNA microarray , “ Plant cell, vol 13 no. 1 pp. 61-72, 2001

.