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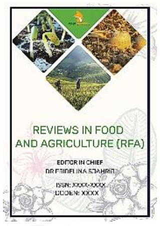

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REVIEW ARTICLE

EFFECT OF DROUGHT STRESS ON WHEAT AND DROUGHT BREEDING STATUS FOR IT IN NEPAL WITH THE WAY FORWARD: A REVIEW

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ABSTRACT

Wheat is the third most important crop in Nepal that is grown in a dominant rice wheat cropping pattern. The productivity of wheat is at a standstill for the past decade primarily due to abiotic stress like drought and high temperature. Changing climate pattern and high vulnerability of Southeast Asian countries in the future demands extensive work under plant breeding to cope with the challenges. Wheat requires about 266.8-500mm of water for normal attainable yield, but prolonged drought has a serious effect on photosynthesis as it hampers the carbondioxide assimilation rate. It also has a pronounced effect in the reproductive and grain filling period of the wheat. This results in the reduction of yield, and this is expected to increase in the future because of climate change. Varieties like Gautam and Vijay have been reported to show positive drought adaptive traits. Vast resources of biodiversity and landraces have been underutilized in Nepal which can be useful when coupled with advanced biotechnological tools to produce drought adaptive crop.

KEYWORDS

Drought stress, wheat, breeding in Nepal

1. INTRODUCTION

The third most important cereal crop in Nepal, wheat (*Triticum aestivum L.*) is grown in an area of 206843 hectare(ha) with the total national production of 1949001 metric ton (t) and productivity of 2.75 t/ha in the year 2018/2019 (MoALD, 2020). Total global production of 765.41 million metric tons is estimated for wheat in 2019-2020 (Shahbandeh et al., 2020). Globally it is the number one crop in terms of cultivation and constitute and important one fifth calorie portion of human diet (Asseng, 2020; Appels et al., 2018). There is an estimated to a 70% incline in the global wheat demand by the year 2050 (Chenu et al., 2017). It is a major winter cereal crop in Nepal and more than 80% of wheat is grown in rice-wheat cropping pattern (Kandel et al., 2018). The productivity of wheat in Nepal has remained at a standstill since the past 15 years and is very low as compared to global average at around 1.9 to 2.5t/ha (Poudel et al., 2020a).

Limiting factors like drought and heat stress are the main cause in reduction of cereals worldwide (Lesk et al., 2016). Drought is a global and recurring natural phenomenon which results in yield losses when the soil moisture does meet the crop water requirement. This phenomenon vary from place to place within a country too (Pandey et al., 2007). Climate change is expected to increase the frequency of extreme drought in the future (Tombesi et al., 2018). Nepal is the world's fourth most vulnerable nation in terms of climate change (Khadka, Torkamaneh, et al., 2020). Global wheat production decreases by 6% per degree increase in temperature which shows the high sensitivity of wheat toward heat (Asseng et al., 2011). Changing climate has caused a severe effect in the overall wheat production in the country (Gairhe et al., 2021). Plant breeding is one of the solutions for proper adaptation of wheat at the present challenge of climate change under various cropping patterns (Atlin et al., 2017). Plant breeders are facing immense pressure to develop cultivars suitable under varying environment with a great deal of uncertainty because of climate change (Semenov and Halford, 2009).

Drought sensitivity has increased in the central and eastern Nepal while decrease in the western region has been observed in past couple of decades (Hamal et al., 2020). Drought impede the sustainable agriculture all over the world by affecting the growth and development of the crop (Osmolovskaya et al., 2018). Thirty wheat varieties were under cultivation in Nepal and thirteen varieties have been denotified till 2017 under Nepal Agriculture Research Council (NWRP, 2017). Six improved wheat varieties have been released by NARC on December 11, 2020 (CIMMYT, 2020). Climate change is expected to affect 67% of the total world population though water shortages by 2050 especially in the most vulnerable Southeast Asia and Central America region. Breeding for drought resistance traits in crops including wheat is going to be one of the biggest challenges for plant breeders around that region to ensure food security (Ceccarelli et al., 2015).

2. OBJECTIVES

The objective of this paper is to provide a brief overview of, (i) Various effect of drought in a wheat crop (ii) Status of drought related breeding in Nepal (iii) Ways that the country must imply for successful drought related breeding program in future.

3. METHODOLOGY

Secondary sources of data were used for this paper. They were taken from various research and review article authorized by known journals. Preference was given to those research paper in which the research was conducted in recent years along similar agro meteorological condition to that of Nepal.

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4. Result and Discussion

The primitive wheat varieties are being replaced by the modern high yielding varieties in Nepal that has led to a narrowed genetic diversity of wheat and making the wheat more susceptible to abiotic stress like drought (Poudel et al., 2020 a). Many key genes and transcription factors have been identified through recent advances in drought tolerance research governing the morpho-physiological traits of plants (Kulkarni et al., 2017).

4.1 Effect of drought in a wheat crop

4.1.1 Role of water

Water plays a major role in overall growth and development of crops. Wheat requires 266.8-500mm water for overall good returns and the moisture content in soil has been found to have a positive co-relation with various physiological and phenological stages of crops (Poudel et al., 2020 a). Evaporative cooling can be done by irrigation to alleviate local water stress even at large spatial scales and help in the mitigation of higher temperatures also (Mueller et al., 2016). Excess water can also cause huge yield loss in wheat through leaching, higher incidence of pests and disease problem, root suffocation, interrupted agronomic practices. For example, the yield anomaly during the 2016 wheat cropping season in France is thought to be because of it however exact reasons for it is still not clear (France24, 2016). There is a decrease in leaf water potential and relative water content in a plant facing drought stress along with a substantial increase in leaf temperature. During the vegetative and reproductive stages the leaf canopy temperature is higher in drought stressed wheat crop (Siddique et al., 2000).

4.1.2 Physiological effect

Physiological studies and traits have the capacity to increase the productivity and grain yield of wheat under drought through the establishment of precise screening technique (Olivares-Villegas et al., 2007). Water relations can be altered under drought condition to maintain cellular functions in the plant (Izanloo et al., 2008). The turgor pressure and cell volume are osmotically adjusted at low water potential for maintaining proper metabolism. This adjustment helps in recovery of the metabolism after the stress has passed (Souza et al., 2004). Recovery of photosynthesis from drought has been widely studied but the studies addressing antioxidative process, osmolyte dynamics, membrane stability at drought recovery are rare (Yi et al., 2016). Photosynthesis is the first process to be affected by the abiotic stress like drought and heat on the plant (Suzuki et al., 2014).

In C3 plants like wheat long drought stress causes diffusional limitations to photosynthesis (Perdomo et al., 2017). There is a decrease in electron transport rate under prolonged drought (Galmés et al., 2007). This causes impaired ATP synthesis and acts as a metabolic limitation to photosynthesis and as a result of this the regeneration of Ribulose-1,5-phosphate (RUBP) is affected which in turn limits the CO2 fixation (Singh et al., 2014). Reduced carbon assimilation causes an imbalance between electron excitation and utilization by photosynthesis under drought stress resulting in the development of reactive oxygen species (ROS), mainly superoxide and hydrogen peroxide which cause oxidative stress by damaging cell membranes, proteins, and nucleic acids and also the amount of malondialdehyde (MDA) in the intercellular space shows the degree of oxidative stress (Abid et al., 2018).

There is an increase in ethylene concentration during drought that retards plant growth, reduced yield and reduces root elongation (Danish and Zafar-ul-Hye, 2019). The central regulator of water use has been found to be the abscisic acid (ABA) through direct regulation of stomatal opening and transpiration from previous findings. The high conservation of the ABA signaling pathway can be used to increase the water productivity of plants (Mega et al., 2019). Various plant responses are detected ranging from whole plant responses to biochemical responses after the removal of stress that have a significant effect on overall physiology of plant (Abid et al., 2018).

4.1.3 Phenological effect

Drought can affect wheat growth at any stage of the phenological cycle, but the reproductive and grain-filling phases are the most vulnerable (Farooq et al., 2014). In both (drought and well-watered) conditions, there were substantial differences in number of days to heading, GFP, number of days to maturity, plant height, number of spikes per m-2, chlorophyll content, peduncle length, spike length, grains per spike, spikelets per spike, 1000 grain weight, and SDS sedimentation, while there were no significant differences in protein content and spikelets per spike (Kiliç and Yağbasanlar, 2010). Drought limits root system growth during the vegetative process (e.g., tillering stage), resulting in lower leaf area, leaf number per plant, leaf size, and leaf longevity. This is consistent with a meta-analysis of wheat biomass and yield reductions in response to elevated O3 (Zhang et al., 2018). Tillers accumulated linearly at a mean rate of 26 degree-days per tiller under non-stress conditions until they reached about 300 degree-days before heading. Stressed plants tillered at a similar pace until tillering ceased as a result of the stress (Blum et al., 1990).

4.1.4 Loss in Yield

Rate of photosynthesis on the plant leaf determines the yield in plant and this rate decreases under drought stress condition (Kabiri et al., 2014). Drought is responsible for a great amount of plant yield reduction upto 50% among the wheat farmers especially those most vulnerable to climate change (Akpinar et al., 2013). Underweighted analysis in wheat using the log response for calculating the bootstrapped confidence limits of yield responses and calculation of drought sensitivities in regards to co-varying factors from the data between 1980 to 2015 that gave wheat responses to drought under field conditions on various peer reviewed publications showed a global yield reduction of 20.6%.(Daryanto et al., 2016).

A meta-analysis study on wheat from 60 published studies incorporating the quantitative assessment of the effect of drought on the agronomic traits in combination with various moderators demonstrated a 27.5% decrease in wheat yield.(Zhang et al., 2018).Grain yield is usually the basis for selection in drought tolerant breeding program however it is a complex, late-stage trait and is affected by many other factors too (Khadka et al., 2020). In wheat breeding nations, breeding for early flowering has been observed and is expected to continue in upcoming years. This is good for modern varieties in the context of combating climate change with minimization of risk leading to higher yield potential (Shavrukov et al., 2017).

4.2 Drought stress varietal trails and breeding in Nepal

Lerma-52 was the first wheat variety to be recommended by the variety recommendation system in 1960 (Joshi and Bank, 2017). Wheat that is being cultivated in Nepal are wild landraces, diploid, spring and winter type. It has been recorded that 540 landraces, 10 wild relative and 35 improved cultivars are found in Nepal (Joshi et al., 1970). Local landraces found from mid and far western hills of Nepal have been found to be have faster germination as well as drought tolerant (Devkota, 1994). Nepal has been able to use only 5% of its landraces on research and breeding (Joshi et al., 2020). The slow increment in the productivity and production of wheat is obtained due to the investment in wheat technologies and breeding programs (Koirala, 2019). Out of 20 genotypes which consisted of 17 advanced lines and 3 commercial varieties of Nepal it was found that NL 1327 had maximum yield of 2ton/ha while NL1326 matured earliest (Poudel et al., 2020 a). Genotype-Environment Interaction (GEI) of 20 wheat genotypes were examined through AMMI analysis of additive main effect and multiplicative interaction effect.

The result was found to be significant for grain yield where NL1244 genotype was best under drought condition (Poudel et al., 2020b). 20 genotypes of wheat varieties released or in pipeline of Nepal were accessed using SSR markers for drought stress which found that among the 4 clusters, BL-4707 and NL-1325 were most divergent as compared to other genotypes. This study is expected to be helpful in wheat breeding for drought tolerance in Nepal (Poudel et al., 2019). 60 different genotypes including landraces, advanced lines of NWRP, drought check international cultivars, advanced commercial cultivars derived from CIMMYT were experimented in a greenhouse which showed that NPGR 7504 landrace showed drought adaptive traits including high water use efficiency (WUE) and among the Nepalese cultivars Gautam showed the superior drought adaptive traits (Pokhrel et al., 2013). Vijay cultivar of Nepal has been characterized as drought sensitive while Gautam cultivar has been found to show various positive drought related traits in an experiment conducted within a greenhouse comprising of local landraces, advanced commercial CIMMYT derived cultivars and three international check cultivars (Pokharel and Pandey, 2012).

4.3 Way forward for Nepal

The breeding of drought tolerant wheat cultivars is difficult because of the complex multi-trait and polygenic control of high genotype and environment , drought tolerance, difficulty in mass screening of plant traits , low heritability (Cattivelli et al., 2008; Fleury et al., 2010; Hu and Xiong, 2014). Interpretation of genotype and environment interaction by the breeders require low cost, phenotype based techniques (Desclaux et al., 2000). Nepal should explore and utilize the huge diversity present in the country for better genotype designs and harvest the economically important genes suitable for stress tolerance specially drought tolerance .This can be achieved through the cooperation between researchers, private stakeholders, biotechnological tools, universities, government in plant breeding through proper documentation (Joshi and Bank, 2017).

Nepal hasn't properly documented the information on the genetic diversity and population structure of its spring wheat (Khadka et al., 2020). Studying genetic stability of wheat varieties under abiotic stresses and experimental conditions, the information on genetic variation and clustering is useful to identify genes and the mechanism involved in stress tolerance (Poudel et al., 2019). Improved biotechnological breeding methods such as genomic selection, genome editing, diagenesis and intragenesis, RNA based DNA methylation, agroinfiltration and reverse breeding have become increasingly common in recent decades. This provides opportunities for plant breeders to manipulate the response to various stress the plant faces and accelerate the crop improvement efforts (Savadi et al., 2018).

Various strategies like classical breeding, molecular markers, introgression have been more advantageous while developing drought tolerant wheat. DNA markers have significantly increased the ease, efficacy and reliability in developing stress tolerant crops and in selecting desirable traits while breeding within a short duration (Budak et al., 2015).Use of marker-assisted selection (MAS) has been a important tool for developing stress tolerant traits in crops (Mishra, 2017). Traditional breeding methods have been extremely successful in the production of heat and drought resistant wheat cultivars around the world (Zulkiffal et al., 2021). Under drought stress the opportunity for the use of traits produced by the fixable additive gene action for proline, chlorophyll and total soluble proteins can be used on a drought tolerant related breeding program in wheat (Saleem et al., 2017).

5. Conclusion

Changing climate & weather pattern is the burning issue of the world at present and for the future. Nepal is expected to be highly vulnerable to prolonged drought which can result in seriously lowered yield. Breeders should focus on using the diverse genetic resource available in the country along with modern breeding technologies. Investment by the government in the breeding program with co-operation among stakeholders is essential in developing effective breeding for drought tolerant wheat.

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