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DROUGHT STRESS AND ITS EFFECT AND RESISTANCE IN RICE: A MINI REVIEW

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ABSTRACT

Drought is a major problem in agricultural crops especially in rice which is an important cereal crop in Asian region. Drought stress cases are increasing day by day worldwide. Rice, being a semi aquatic-crop, requires ample water for proper growth and development. Drought stress leads to decrease in economic yields as rice is sensitive to drought. Various resistance mechanisms can be found which lessen yield loss as well provide ideas for new innovations for other crops. Different strategies or activities are performed for drought tolerance such as breeding programs with high yields varieties or molecular level by selecting genes which are responsible for drought tolerance in landraces. The main objectives are to find out the effect, mechanism of resistance shown by rice plants in drought conditions as well as to highlight some methods for durable drought resistance in rice plants. This information can help provide guidelines for some researchers and rice breeders.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major stable cereal crops consumed by more than one-third of the world's population. It provides about 80% daily calories intake of a majority of the human population, especially in Asia (Sahebi *et al*., 2018). The genus Oryza belongs under the tribe Oryzeae, sub family Oryzoideae in the family Gramineae or Poaceae (Lu, 1999). Two species of rice- *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) are known for their commercial value. However, *Oryza glaberrima* is cultivated in limited areas of South Africa. *Oryza sativa* is the most important commercial species of rice that is differentiated into three subspecies- indica, japonica and javanica based on their commercial production zones (Gadal *et al*., 2019).

Oryza sativa is one of the oldest crop species which originated in south east Asia (India or China). As a cereal crop, it is the most widely consumed staple food for more than half of the world population (Felkner *et al*., 2009). It is grown worldwide in more than hundred countries, with total harvested area of approximately 158-million-hectare area, producing more than 700 million tons (about 496 million metric tons of milled rice (Shahbandeh, 2021) with 4.43 million tons per ha productivity, while in Asia 640 million tons of rice which account for 90% of total global production (Ricepedia.org.). It is reported that rice in Nepal (and in India and Southeast Asia) was introduced from mainland China during the late 3rd millennium BC (Ricepedia.org). However, commercial production of rice in Nepal is believed to have started some five hundred years ago (Agrama *et al*., 2010). The productivity growth of rice in Nepal in the last 54 years was 1.5%, and has not kept up with the population growth rate of 2.3%, thereby not producing enough rice in the country (Upadhaya and Joshi, 2020). The total rice production decreased compared to 2018 (5.6 million MT). The total area of paddy planted decreased slightly compared to the last year: it was estimated to be 1,480,288 hectares, against 1,491,744 hectares for 2018 (CRAFT, 2019). Under conditions of unpredictable drought, the production and productivity of rice is affected heavily, especially in the rice growing seasons (Khadka and Paudyal, 2010). Drought stress, during critical developmental stages in rice, creates difficulty to sustain rice production, in terms of yield, its stability and quality (Porter and Semenov 2005). Research and experiences show that small farmers are mainly affected by drought stress during rice production (Jongdee *et al*., 2006; Pandey *et al*., 2007; Prapertchob, 2007) which results in yield losses ranging from 9% to 100% in severe stress (Pandey *et al*., 2007) as well as reduction in the cultivated area (Musila, 2015).

2. DROUGHT STRESS

Drought is defined as limited water available to meet crop water requirements resulting in limited productivity (Pandey *et al*. 2007; Blum, 2011; Musila, 2015). Sinha and Patil (1986) define drought as "the inadequacy of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of a crop to restrict expression of its full genetic yield potential." It is a type of abiotic stress where water availability is lower than that required by rice for the full expression of yield potential (Ceccarelli *et al*., 2007). Meteorologically, drought refers to a condition where a long period of dry weather leads to plant injury (Kneebone *et al*., 2015; Fang and Xiong, 2015). Drought stress during critical developmental stages in rice is among the major challenges faced in rice production, yield, stability and quality (Porter and Semenov 2005; Straussberger 2015). According to Polania et al. (2017) there are two types of drought on the basis of causes, which are classified as terminal and intermittent. Terminal drought is caused when there is a lack of water available to plants or decreases in the amount of water intake by plants. Severe conditions lead to the death of plants. However, intermittent conditions occur due to inadequate rainfall or irrigation which affect plant growth during planting seasons. Terminal drought causes more fatal damage to plants than intermittent ones.

2.1. ECONOMIC IMPORTANCE OF DROUGHT

Global warming is one of the main causes of drought which causes greater pressure on water availability and irregular rainfall resulting from pollution, population growth, land use changes and others (Kang *et al.*, 2009). Drought, occurring for a long period during the critical growth stages of the crop, significantly reduces crop productivity (Serraj *et al.*, 2011; Musila, 2015). Surveys from different countries in Asia drought stress affect rice production of small farmers (Jongdee *et al.*, 2006; Pandey *et al.*, 2007; Prapertchob, 2007) and also yield losses ranged from 9 to 45% (Ding *et al.*, 2007) and 100% in severe stress (Pandey *et al.*, 2007). Moreover, in drought, there is a reduction in the cultivated area as well as reduction in the use of agricultural inputs such as fertilizer as well as labor (Pandey *et al.*, 2007; Ding *et al.*, 2007; Bernier *et al.*, 2008; Musila, 2015).

2.2. EFFECT OF DROUGHT STRESS

Drought stress occurs when low levels of water are available in soil, which may be defined as the inability of plants to meet the evapotranspiration demand (Singh, 2001). Generally, drought stress in plants is characterized by reduction in plant water content, low availability to be absorbed by plants, a decrease in cell elongation and growth, closure of stomata, reduction in gaseous exchange, and disruption of enzyme-catalyzed reactions (Ozga *et al.*, 2017). Furthermore, it is measured by morphological, physiological and biochemical response (Figure 1). Moreover, under severe drought conditions, there is a gross disruption in photosynthesis and metabolism which eventually leads to the death of the plant (Oladosu *et al.* 2019). According to Yang *et al.* (2001), rice sometimes shows accelerated grain filling due to enhanced remobilization of pre-stored carbon reserves to grain during grain filling period (Farooq *et al.*, 2009b).

2.3. EFFECT OF DROUGHT STRESS ON RICE DURING REPRODUCTIVE STAGES

Rice is most sensitive to drought stress and any drought stress occurring at the reproductive stage can cause significant yield losses (Liu *et al.*, 2006). At the booting stage water stress reduces peduncle length and rate of elongation. Reduced peduncle elongation primarily predisposes reduction in the rate of panicle exsertion (Rang *et al.*, 2011; He and Serraj, 2012) resulting in either incomplete or failure of the panicles to exert from the boot (Ekanayake *et al.*, 1989). As mature spikelets are retained inside the flag leaf sheath, growth, maturation, opening of spikelets and pollination is prohibited, increasing the flowering period (O'Toole and Namuco, 1983). As drought stress progresses, desiccation of exposed lemma, palea, and the anthers is observed. Severe desiccation of glumes which appear as shrivelled and dry and anthers turn white which contribute to reduced flowering hence high spikelet sterility (Ekanayake *et al.*, 1989; Liu *et al.*, 2006; Rang *et al.*, 2011). High spikelet sterility may also result from damaged and abnormal development of the reproductive organs caused by stress (He and Serraj, 2012). Drought stress causes a 50-

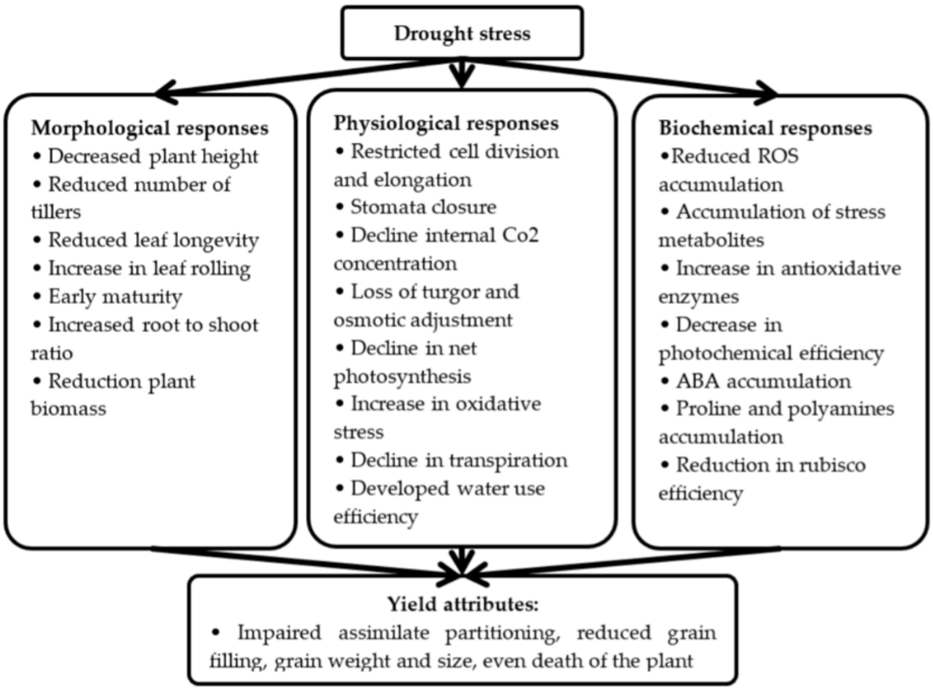

Figure 1. Annotation mechanisms of growth/yield decline in plants under drought stress conditions (Source: Oladosu *et al.*, 2019).

60% decrease in flag leaf water content (Rang *et al.*, 2011), as well as peduncle length decrease of about 24% and the number of germinated pollen on the stigma reduced to 59%. Sometimes there may be combined stress of drought and heat which cause spikelet fertility to decline under combined stress (71%) while due to water stress conditions (21%) (Rang *et al.*, 2011; Straussberger, 2015). Under drought stress conditions, the succession of events in pollen and ovule development that lead to fertilization and eventual formation of seed are irreversibly affected, significantly reducing grain yield (Ekanayake *et al.*, 1989; Liu *et al.*, 2006). Water stress occurring before and during heading inhibits the processes of pollen development at meiosis stage and anther dehiscence. At meiosis stage, water stress interferes with development of the microspores into mature pollen grains. The number of pollen grains produced per stigma is reduced (Liu *et al.*, 2006; Rang *et al.*, 2011) into a ratio of 8:1 compared to 31:1 under optimal conditions (Liu *et al.*, 2006). Anther dehiscence is related to a series of processes including floret opening, dehiscence, pollen - shedding, germination, pollen tube growth and fertilization and drought influences each of these steps (He and Serraj, 2012: Musila, 2015). According to (Liu *et al.*, 2006), inhibition of anther dehiscence seems to be due to a combination of degeneration of the endothelial cells and failure of the pollen to reach the critical size. These two events preclude the opening of the apical and basal pores of the anther thus pollen grains are not released from the pollen sac. In addition, due to water deficits in tissues, anther dehiscence is prohibited by low turgor condition of the floral parts: Lodicule, filaments, anthers and stigma (Ekanayake *et al.*, 1989). For the few pollen grains that may be shed, these may fail to germinate on landing on desiccated stigmatic surface. If germination occurs, the pollen tube may never reach the micropyle (Liu *et al.*, 2006). Likewise, the dehydration of the stigma results in arrest of the events that lead to production of female gametes. Fertilization and eventual formation of seed is therefore inhibited resulting in spikelet sterility thereby decreasing the number of grains produced per panicle and reducing the sink size during grain filling (Lilley and Fukai, 1994; Boonjung and Fukai, 1996; Musila, 2015).

2.4. DROUGHT RESISTANCE AT THE REPRODUCTIVE STAGES OF RICE

Drought resistance may be defined as the mechanisms which result in minimum loss of yield in drought conditions related to the maximum yield in a constraint-free or optimum for the crop. According to May (1962) drought resistance is "the ability of plants to thrive well when exposed to water deficient conditions". Drought resistance is the ability of species or cultivars for growth and production in drought conditions (Fathi and Tari, 2016).

Drought resistance on a crop acts as a trait which involves different changes such as, morphological, physiological and biochemical changes. While, at tissue and cellular levels, those changes include earliness, reduced leaf - area, leaf rolling, efficient rooting system, reduced tillering, reduced transpiration, stomatal closure and accumulation of osmoprotectants such as proline and trehalose (Figure 2) (Guo *et al.*, 2006; Nakashima *et al.*, 2007; Wang *et al.*, 2007; Jin *et al.*, 2010; Islam *et al.*, 2009; Hadiarto and Tran, 2011).

2.5. MECHANISM OF DROUGHT RESISTANCE

Plants use a mechanism of drought resistance to survive drought conditions, used in balance known as drought escape, drought avoidance and drought tolerance (Hadiarto and Tran, 2011). Drought escape describes the situation where drought period is avoided by susceptible variety (Singh, 2001). In this mechanism, rice plants are exposed to drought for a short period or not exposed to stress during the plant cycle (Musila, 2015.) Escape is also possible through employing a short life cycle where flowering time comes before drought conditions which leads to less decreases in yield in drought stress (Araus *et al.*, 2002). Developing short duration crop or early -

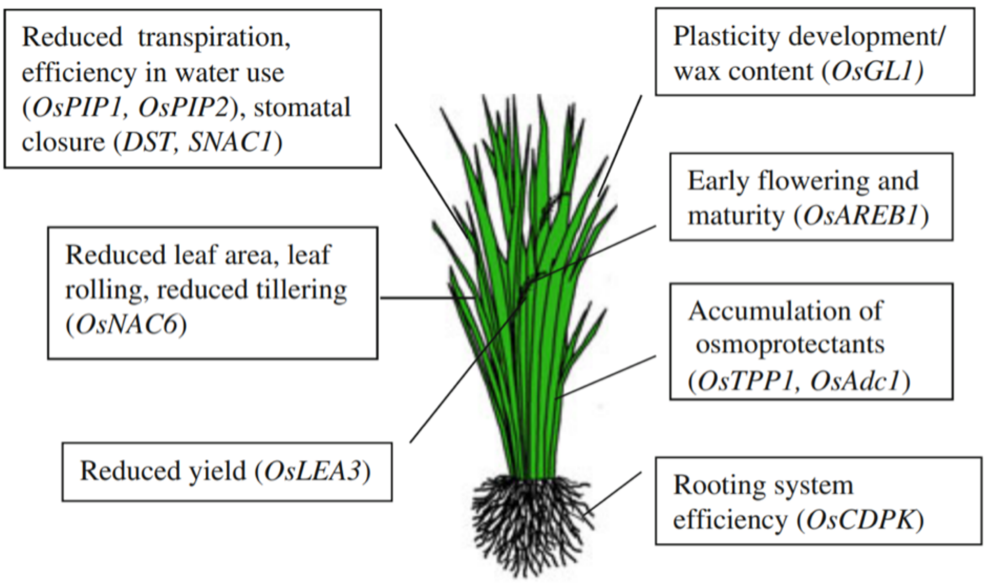

Figure 2. Schematic diagram of physiological and biochemical responses of rice under drought and examples of identified drought responsive genes (Source: Hadiarto and Tran, 2011)

maturity varieties having lower leaf area index, lower total evapotranspiration, lower yield potential and time of flowering for minimizing yield loss from terminal drought or avoiding the period of drought stress (Kumar and Abbo, 2001). Flowering time is a major trait of crops restricted by terminal drought as well as high temperature (Farooq *et al.*, 2009b). Early flowering varieties help to increase yield in such conditions because varieties which flower earlier tend to have higher numbers of fertile spikelet's than those flowering late (Mackill, Coffman, and Garrity, 1996; Musila, 2015). In rice cultivated areas drought escape mechanisms have been massively used for yield components in drought prone areas (Fukai and Cooper, 1995; Jongdee *et al.*, 2006). Drought avoidance uses enhanced water uptake and reduced water loss and drought tolerance applies osmotic adjustment, antioxidant capacity and desiccation tolerance (Zhang 2007). Drought avoidance is the ability of a plant to retain a relatively higher level of water under conditions of water stress. Drought avoidance is one of the resistance mechanisms which tries to reduce water loss from plants or ability of plants to retain water in plants under drought conditions (Blum, 2011). This mechanism in plants occurs due to stomatal control of transpiration, abscisic acid affecting stomata closure (Singh, 2001), leaf characteristics and also maintain water uptake through deep prolific root systems (Turner *et al.*, 2001). Modulation of root is a robust ability to increase root length at an early stage of stress to go deeper under soil to absorb the water. Different root characters like length, weight, volume, biomass as well as depth were reported for drought resistance in crops or avoidance of drought to contribute to yields (Turner *et al.*, 2001; Hammer *et al.*, 2009; Fang and Xiong, 2015). A deep and thick rooted system having more branches is helpful for extracting water from considerable depths during drought environment conditions (Kavar *et al.*, 2008).

In drought avoidance, rice plants use strategies like stomata closure during stress condition cause by ABA (Abscisic acid), leaf rolling or decreasing leaf expansion (Singh, 2001) and increasing wax accumulation that reduce transpiration in plants (Islam *et al.*, 2009; Fang and Xiong, 2015). Drought tolerance enables plants to sustain under severe drought through some plant physiological activities like regulation of gene or metabolic pathways to reduce or maintain stress damage (Ogburn and Edwards, 2010). In rice plant phenology (delay heading) may be used as an index of tolerance under stress (Singh, 2001). Drought tolerance can be achieved through traits like cell membrane stability, translocated stem reserve, plant phenology (Singh, 2001), osmotic adjustment and stability of flowering process (Dixit *et al.*, 2014).

2.6 BREEDING METHOD OF RICE FOR DROUGHT RESISTANCE

Success of breeding programs depend upon various factors including the availability of genetic resources, selection, and selection criteria. Sources of resistance genes available in cultivated varieties, landraces, related wild species or introduced by genetic engineering (Singh, 2005). Landraces have high genetic compatibility which help in drought tolerance than improved varieties (Blum 2011). Using conventional breeding methods to increase population using crosses between drought-tolerance landraces and high yielding drought susceptible varieties (Serraj *et al.*, 2011; Dixit *et al.*, 2014). General steps of conventional breeding used for developing drought tolerance lines are shown in figure 3. In Nepal, Kataush and Guthanisaro are the most drought tolerant landraces of rice (Puri *et al.*, 2013). Conventional breeding with local landraces and high yielding susceptible varieties of selected regions help to develop many genotypes which on varietal screening in different regions help in development of different varieties or lines having high quality grains. Different varieties are being released through this procedure in South and Southeast Asia (Dixit *et al.*, 2014). Line IR74371-70-1-1 was released under three different names in three countries in South Asia: India, Bangladesh, and Nepal (Dixit *et al.*, 2014). Similarly, in conventional breeding different QTLS traits are identified for drought resistance in rice. Different QTLs for different purposes like grain yield, water stress indicators, drought avoidances are found in rice which help in development of genotypes by selecting trait or gene through biotechnology (Singh, 2001). Different genes are associated with drought responsiveness as well and 125 genes have been found associated with drought (Hadiarto and Tran, 2011). QTL mapping approaches are also used to detect genes which affect drought - resistance, found or identified through resistant and susceptible crosses (Venuprasad *et al.*, 2009).

Different strategies are used for developing drought tolerances in rice plants. IRRI performed different location or region genotype trials and laboratory screening for developing of new varieties for respected areas in the South Asia region (Bernier *et al.*, 2009; Farooq *et al.* 2010; Parent *et al.*, 2010; Serraj *et al.*, 2011). Different strategies for inducing drought are seed priming i.e osmopriming with 4% KCL solution and saturated CaHPO4 solution (Du and Tuong, 2002), plant growth regulators, osmoprotectants, and silicon (Farooq *et al.*, 2009a). In the context of Nepal, different genotypes available through IRRI are used for screening in different locations having different environments or creating drought conditions for performing varietal trials to release a variety of drought tolerance.

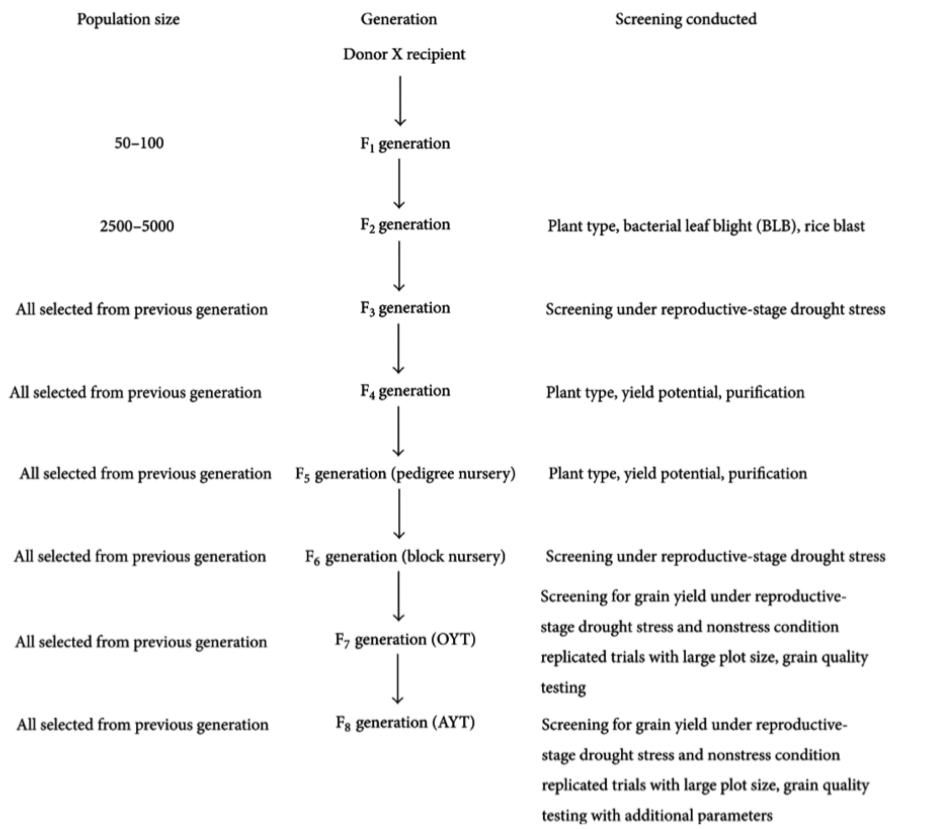

Figure 3. A breeding approach used in IRRI in a conventional breeding program to develop high- yielding drought-tolerance lines (Source: Dixit *et al.*, 2014).

3. CONCLUSION

The timing of drought occurrence is highly unpredictable and so is its duration. Drought resistance should be evaluated in association with heat stress and other abiotic stress. Different approaches or strategies should be taken for drought resistance. All methods should be available and the idea of breeding methods should be provided to all regions. Conventional methods are time consuming and modern methods through biotechnology may provide ways of drought resistance that are not available in developing countries. Genetic resources should be evaluated including the different QTLs responsible for drought should be identified and application of these QTLs for developing drought resistance in rice should be initiated. Different mechanisms should also be taken into action for developing resistance in plants.

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5. FUNDING

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