Development of Drought Resistance in Rice

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ABSTRACT

With the change in the global scenario drought is becoming one of the major problem among other stress and its effect is more severe in rice whose life cycle completely depends on water. Whether it occurs during any stage (early, intermittent and late) it affects crop and its effect is more severe when this stress coincides with reproductive stage of the crop growth. However, rice respond to it by sending signals to shoot which generates signals in terms of physical, chemical and biological form. Hence, screening of plants at this stage is most effective for development of drought resistance. There are several drought resistant traits which have been categorized into primary traits, secondary traits, integrative traits, phenology and plant-type traits. Hence these traits are focussed for the development of drought resistance by adopting conventional and molecular strategy. Varieties like IR-36, IR-64 has been released but through conventional breeding it requires a lot of time to release a variety. Hence molecular strategy has been adopted and focus was given on adopting qtl introgression. Qtls like qDTY_1.1, qDTY_12.1 has pronounced effect on yield potential during drought stress. Some of the cases have been also reported that when combination of several qtls used then it showed more pronounced effect during drought stress.

Keywords
Drought, Reproductive stage, Drought resistant traits, QTLs

Introduction

Rice is grown worldwide covering most of the tropical countries covering an area of 158.85 million hectares with production 472.1 million tonnes and productivity 29.60 quintals per hectare in 2015-16 (World Agricultural Production, USDA, October, 2016). Globally, it covers 31% under rainfed lowland condition and 11% as upland rainfed condition. Rainfed upland and rainfed lowland ecosystems contribute only 21% of the total production from 38% of the cropped area (Vikram et al., 2011). More than 2 billion people around the world depend on it for their survival. It is the staple food for more than 3 billion people (Maclean et al., 2002) in Asia, where more than 90% of the world’s rice is produced and consumed (Babu, 2010; Gomez et al., 2010; Sandhu et al., 2014). With the increase in population and to cope up with the demands of growing population there is need to produce more than 40% of the present to meet the food demand by 2025 (Sandhu et al., 2014; Aravind et al., 2015). By nature it has semiaquatic phylogenetic origin so it depends on ample water supply to complete its lifecycle and thus it is more vulnerable to
water stress which results in drought stress (Pandey et al., 2007; Kumar et al., 2014; Sabar and Arif, 2014; Saikumar et al., 2014) for reduction in yield. Among other abiotic stress affecting it drought is one of the major limitation for rice production which adversely affects the grain quality in rainfed and upland ecosystems (Yang, 2008; Bimpong et al., 2011; Kumar et al., 2012; Afiukwa et al., 2016). Out of 41 m ha of the world’s rainfed lowland rice area, 95% lies in Asia where due to erratic and unpredictable rainfall there is drastic reduction in the yield which ranges from 1.0-2.5 tonnes hectare. It is more frequent in unbunded uplands, bunded uplands and shallow rainfed lowland fields as well as in many parts of South and Southeast Asia, sub-Saharan Africa and Latin America (Serraj et al., 2011). In these regions the spatial and temporal variability of rainfall and coarse-textured soils in some parts exposes the rice plants to frequent drought spells. In sub-Saharan African region it occupies about 9 million hectare which is about 84% of the total rice grown area while in Asia the total drought affected area is 23 million hectare (10 million hectare in upland and 13 million hectare in lowland, Pandey et al., 2005; Usman et al., 2013; Dixit et al., 2014; Kumar et al., 2014; Sellamuthu et al., 2015) with more than half across uplands and rainfed lowlands of India. The 2002 drought in India is described as one of the catastrophic event which reduced rice production by 17 million tons which is about 20% of the trend value (Pandey et al., 2007). During kharif2009 it leads to reduction of about 11 million tonnes (Babu 2010). The recent drought in 2015-16, leads to the reduction in yield of about 1.17 million tonnes (Annual report G.O.I., 2016-17). The eastern Indo-Gangetic Plain is one of the major, drought-prone rice-producing regions in the world (Huke and Huke, 1997). In this plain, losses due to reproductive-stage drought stress are most severe in the key rice-producing states of eastern India: Chhattisgarh, Orissa, Jharkhand, Bihar and eastern Uttar Pradesh (Kumar et al., 2014; Kumar et al., 2015). In eastern Indian states especially in Chhattisgarh, Jharkhand and Orissa which are considered to be the major rice growing states approximately about 13.6 million hectare area is drought prone affected which is considered as the largest drought prone affected region among other rainfed regions of the world (Vikram et al., 2016). In severe drought stress the total loss production in Chhattisgarh, Orissa, and Jharkhand have been reported to be as much as 40%, valued at US$ 650 million (Pandey et al., 2005; Kumar et al., 2014). On an average, the estimated yield lost to drought is 144 kg/ha annually in eastern India (Dey and Upadhyaya, 1996). If drought occurs in such a manner then by 2025, approximately 15-20 million hectares of irrigated rice will experience some degree of water scarcity (Bouman et al., 2007). Many rainfed areas are already drought-prone under present climatic conditions and will experience more intense and more frequent drought events in the future. The green revolution has played a significant role in rice production in irrigated areas but has also limited its impact on rainfed production (Evenson and Gollin, 2003) due to which the gap in yield between irrigated and rainfed rice has increased from 1.7 tonnes per hectare in the late 1960 to 3.6 tonnes per hectare in the late 1990s in Asia (Maclean et al., 2002). The average rice production in eastern India during the normal years still varies between 2-2.5 tonnes per hectare which is still far below the yield potential. High risk in these areas affects severely to small farmers who invests more input on the fertilizers. The overall incidence of poverty is very high in rainfed environment. Although, farmers employ several strategies to cope up with the stress but all goes in vain due to scarcity of rainfall and a consequence farmers has to reduce their food consumption by 15-20% (Pandey et al., 2007). This income loss directly results in the incidence of poverty.
After India this loss is followed by Thailand (8.2 million hectare), Bangladesh (5.1 million hectare), Indonesia (4.0 million hectare), Vietnam (2.9 million hectare), Myanmar (2.4 million hectare), Cambodia (1.6 million hectare) and Philippines (1.3 million hectare (Haefele and Hijmans 2007). Drought stress during the vegetative stage greatly reduced the plant growth and development (Farooq et al., 2009). Yield losses ranging from 15 to 50% has been reported (Srividhya et al., 2011). Chronic dry spells even for a short period affects the crop and it becomes more severe when flowering period coincides with the drought period (Boonjung and Fukai, 1996; Saini and Westgate, 2000; Pantuwan et al., 2002; Lanceras et al., 2004; Venuprasad et al., 2008; Sellamuthu et al., 2011; He and Serraj, 2012; Yadaw et al., 2013; Ha et al., 2016).

**Types of drought**

Mainly three types of drought (early, intermittent and late drought stresses) are recognized for rainfed lowland rice on the basis of nature and severity and timing of drought in relation to crop development. In case of early drought there is delayed sowing or transplanting. Yield reductions from early droughts (occurring during vegetative growth, after establishment but before maximum tillering) are often minimal as a result there is only reduction in tiller numbers. Intermittent or continuous droughts (occurs between tillering and flowering) significantly reduces yield despite no apparent drought symptoms (leaf rolling) mainly as a result of reduced leaf expansion and photosynthesis. When drought occurs during later growing stages (panicle initiation and flowering) spikelet fertility is reduced. Terminal drought especially during the flower initiation stage in rice causes severe impact on the yield which on its extreme results in complete failure of crop. Recently, IRRI has given a new classification system according to which there are four major classes of drought prone rainfed environments (1) Early season drought risk in lowland (non-flooded soils and root zone below saturation for at least 10 consecutive days before flowering. (2) Flowering stage drought risk in lowland (non-flooded soils and root zone below saturation for at least 7 days around anthesis). (3) Late season drought risk in lowland (non-flooded soils and root zone below saturation for at least 10 consecutive days after flowering. (4) Flowering stage drought risk in upland (field without rainfall or irrigation for at least 7 days around anthesis and groundwater table deeper than 100 cm).

**Response of plant to water deficit**

When drought appears numerous changes occurs at the physiological, biochemical and molecular levels (Atkinson and Urwin, 2012; Bargaz et al., 2015). In response to drought conditions roots respond to it by sending signals to the shoot which results in producing various responses like stomatal closure, decrease in leaf expansion and gas exchange. Such types of plant response to water stress can be described in three stages. Stage I occurs when water is freely available and there is no limit in transpiration. Stage II occurs when plants reaches the threshold value of available water and rate of water uptake can’t match the potential transpiration rate.

There is decline in transpiration, stomatal conductance, reduction of leaf expansion and growth of the plant (Serraj et al., 1999). In stage III all the metabolic process restricts its activity and no further growth of the plant occurs due to interruption of water flow from the xylem to the surrounding elongating cells. In this stage plants responds by osmotic adjustment and increased production of ABA has been reported (Price et al., 2000; Bimpong et al., 2011) for its survival. Hence, it produces drought adaptation mechanism for its survival (Serraj and Sinclair, 2002).
Consequences of drought to rice grain formation

Although drought effect at different stages of the growth of rice plant but its severe form appears when its period strikes with the reproductive stage (Boonjung and Fukai, 1996) resulting in the reduction of spikelet fertility and panicle exertion. Some of the cases have also reported that meiosis in the spore mother cells to fertilization and early seed formation is extremely sensitive to drought which leads to several structural and functional disruptions in reproductive organs, leading to failure of fertilization or premature abortion of the seed (Saini, 1997; Saini and Westgate, 2000). It also inhibits the development of reproductive organs, such as the ovary (Saini et al., 1983) and the pollen at meiosis stage (Saini, 1997). Apart from that it can also inhibit processes such as anther dehiscence, pollen shedding, pollen germination, and fertilization (Satake and Yoshida, 1978; Ekanayake et al., 1990). It has been also found that there is decrease in peduncle elongation, which can ultimately accounts for 70–75% spikelet sterility under water deficit (O’Toole and Namuco, 1983).

A reduction in grain filling occurs due to a reduction in the assimilate partitioning and activities of sucrose and starch synthesis enzymes (Farooq et al., 2009). Recent studies at IRRI has reported that drought significantly delayed the peduncle elongation, trapped a significant fraction of panicle within the flag leaf sheath due to the repression of the expression of cell-wall invertase genes. The spikelet’s left inside the leaf sheath are usually sterile, resulting in a poor yield, which indicates that peduncle elongation may play a major role in panicle exertion and spikelet fertility under stress. Therefore, screening for tolerance at the reproductive stage is considered to be the most fruitful in breeding for improved drought resistance.

Drought resistance trait

Different types of drought resistant trait have been identified based on the interaction of drought with the rainfed rice field. Such types of drought resistant traits have been categorized into primary traits, secondary traits, integrative traits, phenology and plant-type traits. Primary traits includes constitutive traits (rooting depth, root thickness, branching angle and root distribution pattern; Lafitte et al., 2001; Kato et al., 2006) and induced traits (hardpan penetration, cell membrane stability and osmotic adjustment). Constitutive root traits help in the extraction of water from soil during drought stress (Lilley and Fukai, 1994). Secondary trait includes relative water content, leaf water potential, canopy temperature, panicle exertion, leaf death and rolling. Integrative trait includes yield harvest index, spikelet sterility, grain number per panicle, 1000 grain weight, biomass, drought response index, flowering delay. Phenology (flowering) interact with timing of drought has a large effect on yield through integrative traits. Plant-type traits include tiller number and plant height which modify the expression of secondary and integrative traits by affecting transpiration demand. Water deficiency is considered as one of the major challenge for sustainable rice production in future due to progressive climate change processes. Selection and use of these traits in breeding programmes could lead to sustainable production in drought prone regions (Nguyen et al., 1997).

Strategy for improving drought resistance

Conventional breeding

Conventional breeding has been based on observed selection for yield. Most of the high-yielding varieties—IR36, IR64, MTU1010, BR11, Swarna and Samba Mahsuri are grown in rainfed areas are preferred by the farmers
due to their yield potential but are not tolerant to drought. These varieties gives high yield during non-drought years, but there is drastic reduction when moderate drought appears and collapse completely in severe drought stress (Kumar et al., 2008).

As yield is a complex character and its improvement depends on several characters which are directly or indirectly associated with it which has been assessed at protein level also (Kumar et al., 2018; Mishra et al., 2018; Kumar et al., 2016; Mishra et al., 2015a, b; Smriti et al., 2015) In the absence of high-yielding, good-quality drought-tolerant varieties, farmers in the rainfed ecosystem continue to grow these drought-susceptible varieties. Genetic enhancement of rice for drought tolerance is a cost-effective approach to further increase its productivity, stabilize production and contribute to food security.

The wild species of rice, though phenotypically inferior in agronomic traits, are important reservoirs of many useful genes for drought stress which can be used to improve the cultivated species for these desired traits through breeding (Ali et al., 2010). Several traditionally grown landraces such as KhaoDawk Mali, Azucena, Dular, Rayada, Bala, Apo, Nam Sagui 19, Nagina 22, AdaySel, Dehula, Moroberekan, Huma Wangi Lenggong, Siam Pilihan, ChianungSen Yu, Kashmir Basmati, MR142, FR13A, KDML 105, Azucena and Dular have great adaptability to survive in drought and their hidden genetic potential offers a better opportunity to improve drought tolerance in mega varieties (Pantuwan et al., 2002; Venuprasad et al., 2007; Venuprasad et al., 2009; Henry et al., 2011; Vikram et al., 2012; Swamy and Kumar 2013; Shamsudin et al., 2016).

These traditional donors possess genes for better ability to tolerate drought than high-yielding semi-dwarf varieties. Some of the varieties tolerant to drought stress (Azucena from the Philippines and Moroberekan from Guinea) have been reported in japonica varieties from upland ecosystems cultivated in hilly Southeast Asia and Africa (Mackill et al., 1996).

Other varieties which show some degree of resistance to drought reported from plateau region of Eastern India. Nam Sagui 19 reported from Thailand, has both tissue tolerance and grain yielding ability in an indica which is one of the important parental lines in breeding programs. Some of the successful cases of direct selection for grain yield under drought have been reported at IRRI (Kumar et al., 2008; Venuprasad et al., 2008). This breakthrough resulted in the development of several promising breeding lines for the rainfed lowland and upland (Mandal et al., 2010; Verulkar et al., 2010). Some of the varieties of rice for grain yield under drought conditions has been also released through direct selection Sahbhagidhan (India), Sukha dhan-1, Sukha dhan-2 and Sukha dhan-3 (Nepal), BRRI Dhan-56 (Bangladesh), Sahod ulan-3, 5, 6, 8 and Katihan-8 (Philippines), Tarharra 1. These varieties perform well even during favourable years and can provide upto 1 tonnes per hectare under stress.

**Marker assisted breeding**

As drought is one of the complex situation which is very difficult to manage through phenotypic selection but it can be managed through transgenics and marker assisted breeding (Collins et al., 2008) which helps to judge more precisely the target trait in same genotype with fewer loss in selection cycle. Many transgenic plants have been developed through introgression of stress related genes to increase tolerance against drought. But due to enhanced expression of these genes plants
generally shows retarded growth which further limits its practical application (Farooq et al., 2009). The advent of molecular markers has revolutionized the screening of complex traits like drought tolerance in crop plants. Development of molecular markers and their use for the genetic dissection of agronomically important traits has become a powerful approach for studying the inheritance of complex plant traits such as drought tolerance (Suji et al., 2011). The use of molecular markers for the selection of complex breeding traits offers greater selection accuracy with less labour and time inputs and enables assemblage of different target traits into a single cultivar. Molecular markers such as RFLP and SSRIs are very reliable and have been extensively used in rice (Mohan et al., 1997; Kumar et al., 2015). The very first RFLP map for rice was constructed by McCouch et al., 1988. Microsatellite markers have been also widely applied for rice genome mapping for abiotic stress tolerance (Temnykh et al., 2000). Recent developments in DNA marker technology coupled with MAS provide efficient means to plant breeders to carry out selection of rice cultivars under drought prone environments.

The only prerequisite requirement for effective MAS program is the stable and continued expression of QTLs under different environments. QTLs linked to drought resistance have been mapped in different populations and is found that most of the mapping populations were derived from indica x japonica parents, in which alleles for drought-resistance traits are contributed by japonica lines. Since indica and japonica ecotypes are grown in different environments so they are used in most of the breeding programs to improve the locally adapted germplasms. Therefore, it is desirable to look for genetic variation among indica ecotypes (IR58821/IR52561; Ali et al., 2000) as well as among japonica ecotypes (Akihikari x IRAT109, Otomemochi x Yumenohatamochi; Horii et al., 2006; Ikeda et al., 2007) and to map QTLs using populations derived from lines adapted to target environments. Other wild species which acts as a source of suitable donor which can be further used in the breeding programme for developing drought resistant variety are Oryza rufipogon, Oryza australiensis, Oryza glaberrima, Oryza officinalis and Oryza nivara. Several QTLs for yield has been identified in rice for secondary traits associated with drought response including rooting traits (depth, volume, thinness, penetration ability), leaf rolling and death, membrane stability and osmotic adjustment (Lafitte et al., 2006) which has been incorporated into high yielder but drought sensitive variety and has been tested on farmers field (Singh et al., 2009; Thomson et al., 2010; Mackill et al., 2012) plays significant role in developing drought tolerant varieties. Extensive efforts have been made towards the identification of QTLs underlying traits associated with drought tolerance in rice chromosomes using molecular markers. Zheng et al., 2000 identified two QTLs for root penetration ability and root thickness that colocalizes with rice SSR markers RM252 on rice chromosome 4 and RM60 on chromosome 3. Rice QTLs for root growth rate and root penetration ability have also been mapped using RFLP and AFLP markers (Price et al., 2000; Price and Tomas, 1997). The co-location of QTLs for root traits with those of yield under drought has allowed combined selection of both traits (Salunkhe et al., 2011). Courtois et al., 2003 used MAS to transfer a number of QTLs related to deep rooted character from the japonica upland cultivar “Azucena” to the lowland indica variety “IR64”. MAS selected lines showed a greater root mass and higher yield in drought stress. Steele et al., 2006 used marker assisted breeding program to improve some root traits related to drought tolerance in an Indian rice cultivar Kalinga III (Table 1–3).
### Table 1: Effect of drought in rice at different stages of the crop growth

| Crop | Stage                        | Yield reduction | Reference                      |
|------|------------------------------|-----------------|--------------------------------|
| Rice | Reproductive (mild stress)   | 53–92%          | Lafitte et al., 2007           |
|      | Reproductive (severe stress) | 48–94%          | Lafitte et al., 2007           |
|      | Grain filling (mild stress)  | 30–55%          | Basnayake et al., 2006         |
|      | Grain filling (severe stress)| 60%             | Basnayake et al., 2006         |
|      | Reproductive                 | 24–84%          | Venuprasad et al., 2007        |

### Table 2: Traits affecting the drought conditions

| Trait                              | Function                                                                 | Reference                     |
|------------------------------------|--------------------------------------------------------------------------|-------------------------------|
| Deeper, thicker roots              | To explore a greater soil volume                                         | Yadav et al., 1997           |
| Root pulling resistance            | Root penetration into deeper soil layers                                 | Pantuwan et al., 2002        |
| Greater root penetration ability   | To explore a larger soil volume                                          | Ali et al., 2000             |
| Osmotic adjustment                 | To allow turgor maintenance at low plant water potential                | Lilley et al., 1996          |
| Membrane stability                 | Allows leaves to continue functioning at high temperature               | Tripathy et al., 2000        |
| Leaf rolling score                 | Reduce transpiration                                                     | Courtois et al., 2000        |
| Leaf relative water content        | Indicates maintenance of favourable plant water status                   | Courtois et al., 2000        |
| Water-use efficiency               | Indicates greater dry weight gain per unit of water lost by transpiration| Specht et al., 2001          |

### Table 3: QTLs obtained from their respective donors

| QTL | Donor      | Recipient | Marker Interval       | R² | Reference           |
|-----|------------|-----------|-----------------------|----|---------------------|
| qDTY₁₁ | Dhagaddeshi | Swarna    | RM431–RM104           | 32 | Ghimire et al., 2012|
| qDTY₁₁ | Dhagaddeshi | IR64      | RM104–RM12091         | 9  | Ghimire et al., 2012|
| qDTY₁₁ | N22        | Swarna    | RM11943–RM12091       | 13 | Vikram et al., 2011 |
| qDTY₁₁ | N22        | IR64      | RM11943–RM12091       | 17 | Vikram et al., 2011 |
| qDTY₁₁ | N22        | MTU1010   | RM11943–RM12091       | 13 | Vikram et al., 2011 |
| qDTY₁₂ | Kali Aus   | MTU1010   | RM259–RM315           | 7  | Sandhu et al., 2014 |
| qDTY₁₃ | Kali Aus   | IR64      | RM488–RM315           | 5  | Sandhu et al., 2014 |
| qDTY₂₂ | Aday Sel.  | IR64      | RM236–RM279           | 11 | Swamy et al., 2013  |
| qDTY₂₂ | Kali Aus   | MTU1010   | RM211–233A            | 16 | Palanog et al., 2014|
| qDTY₂₃ | Kali Aus   | IR64      | RM573–RM250           | 9  | Palanog et al., 2014|
| qDTY₃₁ | IR55419-04 | TDK1      | RM168–RM468           | 15 | Dixit et al., 2014  |
| qDTY₃₂ | Aday Sel.  | Sabitri   | RM569–RM517           | 23 | Yadaw et al., 2013  |
| qDTY₃₂ | N-22       | Swarna    | RM60–RM22             | 19 | Vikram et al., 2011 |
| qDTY₄₁ | Aday Sel.  | IR64      | RM551–RM16368         | 11 | Swamy et al., 2013  |
| qDTY₆₁ | IR55419-04 | TDK1      | RM586-RM217           | 36 | Dixit et al., 2014  |
| qDTY₆₂ | IR55419-04 | TDK1      | RM121-RM541           | 20 | Dixit et al., 2014  |
| qDTY₉₁ | Aday Sel.  | IR64      | RM105-RM434           | 13 | Swamy et al., 2013  |
| qDTY₁₀₁| MTU1010    | N22       | RM216–RM304           | 5  | Vikram et al., 2011 |
| qDTY₁₂₁| Way Rarem  | Vandana   | RM28048–RM28166       | 12 | Bernier et al., 2007|
There are several QTLs governing grain yield under drought conditions has been identified (Bernier et al., 2007; Kumar et al., 2007; Venuprasad et al., 2009; Vikram et al., 2011; Ghimire et al., 2012; Venuprasad et al., 2012; Mishra et al., 2013; Yadaw et al., 2013; Vikram et al., 2016). The development of drought tolerance varieties could be made more efficient through the introgression of drought yield QTLs through marker assisted breeding. This approach has been successfully proven with Vandana lines introgressed with qDTY$_{12.1}$ where production of about 500 kg ha$^{-1}$ has been obtained over its donor parent under drought conditions which is similar to Vandana under non-stress condition (Kumar et al., 2014). Efforts have been also made to introgress the identified qDTYs into the drought-susceptible variety IR64 through MAB (Swamy et al., 2013) and it was found that there is yield gain of 10 to 30% and a yield advantage of 150 to 500 kg ha$^{-1}$. However, there is still need of at least 1000 kg ha$^{-1}$ to meet the present needs of farmers. Among other QTLS qDTY$_{12.1}$ was the first reported large-effect QTL for grain yield under reproductive stage drought (Bernier et al., 2007). This QTL was identified among 436 random F$_3$-derived lines from a cross between upland rice cultivars Vandana and Way Rarem. This QTL shows $R^2$ of 33% under severe upland reproductive-stage drought conditions (Kumar et al., 2014) and approximately 23.8% of the phenotypic variance under severe lowland drought for lowland-adapted variety Sabitri (Mishra et al., 2013). Later on, qDTY$_{12.1}$ was also identified to show a similar high effect in lowland reproductive-stage drought in an IR74371-46-1-1/Sabitri population (Mishra et al., 2013). Another QTL, qDTY$_{2.1}$ and qDTY$_{3.1}$ are the two large-effect QTLs affecting grain yield under lowland reproductive-stage drought, were identified in a BIL population derived from a cross between lowland rice variety Swarna and upland rice variety Apo. Both QTLs showed a very high effect under severe lowland reproductive-stage drought ($R^2$=16.3% and 30.7%). The rice grain yield QTL region on chromosome 2 was reported to contain QTLs for leaf rolling, leaf drying, canopy temperature, productive tiller number and stress recovery in this mapping population (Gomez et al., 2010). qDTY$_{3.1}$, identified in a cross between Apo and Swarna population, expressed 31% of the genetic variance in lowland drought conditions. Two other QTLS, qDTY$_{1.1}$ and qDTY$_{3.1}$, were identified for lowland drought conditions. qDTY$_{1.1}$ showed a constant effect in three different genetic backgrounds, Swarna, IR64 and MTU1010 with phenotypic variance up to 16.9%. Babu et al., 2003 obtained double haploids rice lines and subjected it to water stress which results in identification of 47 drought related QTLs with phenotypic variation ranged from 5 to 59%. Obara et al., 2010 mapped qRL$_{6.1}$ for root length under hydroponic conditions.

Yield QTLs which shows consistent effect in target environment over seasons has been identified on chromosomes 1, 4 and 6 could stabilize the productivity in high-yielding rice lines in a water-limited ecosystem. These yield QTLs governs secondary traits, such as leaf drying, canopy temperature, panicle harvest index and harvest index (Prince et al., 2015). Some of the QTLs combinations were also used to study the effect of their interactions with respect to reproductive stage drought stress. Combinations of qDTY$_{1.1}$, qDTY$_{2.1}$, qDTY$_{3.1}$, qDTY$_{11.1}$ were used and it was found that they give higher yield than normal in reproductive stage stress conditions (Sandhu et al., 2018).

**Problems in developing drought resistant rice**

In spite of the direct link with development issues, there has been little success in
developing drought-tolerant rice cultivars though, conventional breeding for drought tolerance in rice has met little success (Fukai and Cooper, 1995). Some of the varieties has been developed by keeping focus on high grain yield but were never selected for drought tolerance (Kumar et al., 2008). Still today large part of rainfed ecosystems is planted with the varieties that were developed particularly for irrigated lowland ecosystems. These varieties need a continuous supply of water throughout the season and risk heavy yield loss if drought occurs (Dixit et al., 2014). The donors used in breeding programmes is linked with some undesirable traits and has also low yield potential. Several studies have been done to improve drought tolerance pre-breeding lines by crossing traditional drought-tolerant donors with drought susceptible varieties (Swamy and Kumar, 2013). This progress is further slowed down due to irregular timing, duration, severity of drought occurrence and difficulty of establishing screening environments. Hence, more number of breeding generations is required to develop drought resistant variety. Still, at present most of populations has been derived from intra specific crosses. Focus should also be given to go for inter specific crosses to explore novel alleles and their incorporation in to the breeding programs for drought tolerance in rice. It has also been found that when a rice plant is screened for drought stress then it affects its secondary traits which has direct effect on yield contributing traits like reduction of leaf area, restriction in opening of stomatal (Babu et al., 2003; Abbate et al., 2004; Lanceras et al., 2004). Focus should be given on selection of suitable secondary traits which are genetically associated with grain yield under drought conditions. It should be heritable and can be easily measurable but should not be associated with yield loss (Edmeades et al., 2001). However, selection for such types of traits is very difficult for critical situations like drought. Another reason for slow progress in breeding has been the failure to identify QTL with large and consistent effects that could be used for marker-assisted breeding. The most suitable QTL for drought would be one that can overcome QTL × genetic background, QTL × environment and QTL × ecosystem effects. To identify genomic regions with a consistent effect across environments, enormous mapping populations need to be screened in different environments. Further problem arises with the high cost which is to be incurred in genotyping and phenotyping of large mapping. Progress in mapping QTL for secondary traits associated with drought tolerance is studied (Bernier et al., 2008; Price and Courtois, 1999; Price et al., 2002) but marker assisted selection for such QTL has not been successfully used to improve yield under drought stress in rice. Some of the populations which has been developed by crossing CT9993 with IR62266 and IR64 with Azucenafor secondary drought-related traits (root morphology and osmotic adjustment) but few loci with large effects on either of these traits have been identified (Yadav et al., 1997; Hemamalini et al., 2000; Tripathy et al., 2000; Zheng et al., 2000; Zhang et al., 2001; Kamoshita et al., 2002; Babu et al., 2003). Last but not the least is the problems which are encountered with the QTLs which were having minor effect on the phenotype possess a great challenge for the breeders to discover major QTLs functioning independently to their genetic background (Gowda et al., 2011).

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