

Review Article

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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

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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, banded 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 *kharif*2009 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 give 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 up to 1 tonnes per hectare under stress.

Marker assisted breeding

As drought is one of the complex situations 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 losses 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 SSRs 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 has 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 co-localizes 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 <i>et al.</i> , (2007)
	Reproductive (severe stress)	48–94%	Lafitte <i>et al.</i> , (2007)
	Grain filling (mild stress)	30–55%	Basnayake <i>et al.</i> , (2006)
	Grain filling (severe stress)	60%	Basnayake <i>et al.</i> , (2006)
	Reproductive	24–84%	Venuprasad <i>et al.</i> , (2007)

Table.2 Traits affecting the drought conditions

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

Table.3 QTLs obtained from their respective donors

QTL	Donor	Recipient	Marker Interval	R ²	Reference
<i>qDTY_{1.1}</i>	Dhagaddeshi	Swarna	RM431–RM104	32	Ghimire <i>et al.</i> , 2012
<i>qDTY_{1.1}</i>	Dhagaddeshi	IR64	RM104–RM12091	9	Ghimire <i>et al.</i> , 2012
<i>qDTY_{1.1}</i>	N22	Swarna	RM11943–RM12091	13	Vikram <i>et al.</i> , 2011
<i>qDTY_{1.1}</i>	N22	IR64	RM11943–RM12091	17	Vikram <i>et al.</i> , 2011
<i>qDTY_{1.1}</i>	N22	MTU1010	RM11943–RM12091	13	Vikram <i>et al.</i> , 2011
<i>qDTY_{1.2}</i>	Kali Aus	MTU1010	RM259–RM315	7	Sandhu <i>et al.</i> , 2014
<i>qDTY_{1.3}</i>	Kali Aus	IR64	RM488–RM315	5	Sandhu <i>et al.</i> , 2014
<i>qDTY_{2.2}</i>	Aday Sel.	IR64	RM236–RM279	11	Swamy <i>et al.</i> , 2013
<i>qDTY_{2.2}</i>	Kali Aus	MTU1010	RM211–233A	16	Palanog <i>et al.</i> , 2014
<i>qDTY_{2.3}</i>	Kali Aus	IR64	RM573–RM250	9	Palanog <i>et al.</i> , 2014
<i>qDTY_{3.1}</i>	IR55419-04	TDK1	RM168–RM468	15	Dixit <i>et al.</i> , 2014
<i>qDTY_{3.2}</i>	Aday Sel.	Sabitri	RM569–RM517	23	Yadaw <i>et al.</i> , 2013
<i>qDTY_{3.2}</i>	N-22	Swarna	RM60–RM22	19	Vikram <i>et al.</i> , 2011
<i>qDTY_{4.1}</i>	Aday Sel.	IR64	RM551–RM16368	11	Swamy <i>et al.</i> , 2013
<i>qDTY_{6.1}</i>	IR55419-04	TDK1	RM586–RM217	36	Dixit <i>et al.</i> , 2014
<i>qDTY_{6.2}</i>	IR55419-04	TDK1	RM121–RM541	20	Dixit <i>et al.</i> , 2014
<i>qDTY_{9.1}</i>	Aday Sel.	IR64	RM105–RM434	13	Swamy <i>et al.</i> , 2013
<i>qDTY_{10.1}</i>	MTU1010	N22	RM216–RM304	5	Vikram <i>et al.</i> , 2011
<i>qDTY_{12.1}</i>	Way Rarem	Vandana	RM28048–RM28166	12	Bernier <i>et al.</i> , 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 F₃-derived lines from a cross between upland rice cultivars Vandana and Way Rarem. This QTL shows R² 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 (R²=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 \times genetic background, QTL \times environment and QTL \times 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 Azucena for 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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