

Biotechnological Options for Enhancing Water Use Efficiency of Rice

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Rice is the staple food in Asia, the most populous continent, which accounts for almost 90 per cent of the global production and consumption. This demand is likely to increase by 70 per cent in the next three decades for the ever-increasing Asian population (Hossain, 1997). Asia produces more than 530 million tonnes of paddy rice every year. More than 75 per cent of this comes from the irrigated area, which accounts for 55 per cent of the total rice area (Bouman, 2001). Irrigated low land rice constitutes the major economic activity, source of employment and income for the rural population. In India out of the 43 million hectares under rice cultivation, almost 50 per cent is irrigated which consumes almost 50 per cent of the irrigation water resources. The growing water shortage has threatened the sustainability of irrigated low land rice production systems, which consumes up to 5000 liters of water to produce 1 kg of grain (Bhuiyan, 1992). Fresh water consumption for irrigated low land transplanted rice in most Asian countries is, therefore, very high. Fresh water is a scarce resource and getting scarcer every passing day (Tuong and Bouman, 2003).

Since rice is the staple food of billions, it is imperative to devise technologies of growing rice with less water, reducing dependence on

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traditional methods of growing rice, without any compromise on production. Breeding rice varieties for enhanced water use efficiency and drought tolerance using the modern tools such as Marker Assisted Selection (MAS) breeding and genetic engineering is necessary to enhance and sustain the rice production at a higher level. It is now the need of the hour. Water use efficiency (WUE) is generally defined as the amount of dry matter (or grain yield) produced per unit of water consumed. It can also be defined as the ratio of photosynthetic carbon assimilation to transpirational water loss. Total biomass produced is, therefore, equal to total water use \times WUE. The total water use and WUE of crop plants can be improved by 1) maximization of water uptake from the soil to support maximal photosynthetic rates, 2) minimizing water loss through plant architecture such as modified stomata and cuticle (stomatal and cuticle) without reducing photosynthesis, 3) enhancing the production per unit quantity of water used, and 4) cellular tolerance to water deficit.

Maximization of Water Uptake from the Soil

The roots play pivotal role in water and nutrient uptake, and act as sensors of water and nutrient status of the soil. Under rainfed unirrigated/inadequately irrigated conditions, possession of a deep and thick root system and other root morphological traits that allow access to water and nutrients from deeper soil layers will be one of the most promising of traits for improving WUE. In addition to it, the ability of plants to cool their canopy temperature through transpiration needs efficient functioning of the root water uptake system. The actual measurement of root morphological and other traits, that contribute to enhanced water uptake under field drought conditions, require a whole crop season in addition to other resources. Hence efforts were made to identify the quantitative trait loci (QTL, genomic locations of genes controlling a quantitative trait) for root traits and tag it with molecular markers. Once QTLs are tagged with molecular markers, these markers can be used to screen and select the desired plant type (with desired QTLs) from the segregating population even in the seedling stage in the lab conditions. Thus MAS of genotypes help in increasing the accuracy of breeding and at the same time reduces the time and other resources requirement. QTLs controlling root morphological traits in rice (Babu *et al.* 2003; Courtois *et al.* 2003; Zheng *et al.* 2003) have been identified by using molecular markers. Currently efforts are being

made to introgress QTLs for root traits in MAS breeding for enhanced drought tolerance and WUE (Steele *et al.* 2002).

Minimization of Water Loss

Water loss from the plant to the atmosphere occurs through transpiration mediated by stomata and direct evaporation of water from epidermal cell surface. Of these two, water loss through stomata accounts for majority of the water loss. Stomatal pores allow CO₂ influx for photosynthetic carbon fixation and water loss via transpiration to the atmosphere. Thus, the rate of transpiration and photosynthesis depends upon the plants ability to regulate its stomatal pores. The stress hormone, Abscisic acid (ABA) synthesized by root under receding soil water conditions or by leaf when the transpiration exceeds water uptake act as signal to control stomatal responses. Genetic analyses of stomatal regulation in *Arabidopsis* have led to the identification of genes that control stomatal response to water deficit (Schroeder *et al.* 2001). QTLs for traits that minimize water loss through plants such as controlling stomatal regulation (Price *et al.* 1997), leaf ABA accumulation (Quarrie *et al.* 1997) and leaf rolling (Courtois *et al.* 2000) have been identified and tagged with molecular markers in rice. These QTLs and genes involved in minimization of water loss can be used to genetically modify the stomatal regulation and improve WUE.

Enhancing the Production per Unit Quantity of Water Used

The WUE of plants can be enhanced by genetic modification of plants for higher harvest index, spikelet fertility, stay green traits, seedling vigour, and short duration and reduced photorespiration. Now QTLs have been identified for some of these traits in rice and efforts are being made to identify the genes and understand the molecular basis. Molecular markers that are linked to QTLs that control panicle sterility and reproductive traits (Lanceras *et al.* 2004) have been identified in rice. Since WUE is a complex trait and determination of WUE under field condition needs accurate measurement of water and carbon budget of plants. During photosynthesis, plants with high water use efficiency show less discrimination to ¹³CO₂ to ¹²CO₂. Hence, ¹³C-isotope discrimination by photosynthesis has been successfully established as surrogate for WUE. Breeding for ¹³CO₂ discrimination trait in wheat lead to the release of wheat variety with enhanced drought tolerance ([http://www.csiro.au/proprietary Documents/PI_info_Rees.pdf](http://www.csiro.au/proprietary_Documents/PI_info_Rees.pdf)). High

water use efficiency has been found to be associated with low ^{13}C -isotope discrimination in rice (Peng *et al.* 1998). Identification and molecular marker tagging of QTLs controlling $^{13}\text{CO}_2$ discrimination and application of this approach in rice will therefore help in enhancing WUE.

Cellular Tolerance to Water Deficit

Cellular water deficit stress tolerance in plants depends upon the expression of genes involved in production of organic compatible solutes (proline, sugars, polyols, betaine, etc.), late embryogenesis abundant (LEA) proteins and antioxidants. They protect plants from stress by (1) osmotic adjustment which helps in turgor maintenance, (2) detoxification of radical oxygen species, (3) stabilization of the quaternary structure of proteins, and 4) allowing the plant to extract water at low soil water potential. Transgenic rice plants engineered to over-produce organic compatible solutes such as glycine betaine (Sakamoto *et al.* 1998), proline (Su and Wu, 2004) and trehalose (Garg *et al.* 2002) showed enhanced tolerance abiotic stresses including drought. In addition to that, QTLs that confer osmotic adjustment have been identified in rice using molecular markers (Zhang *et al.* 2001).

Transcriptome engineering or overexpression of a master switch gene (such as stress sensors, protein kinases or transcription factors) that regulate several target genes coding for osmolyte biosynthesis enzymes and LEA proteins is emerging as an important tool to combat abiotic stresses. Transgenic overexpression of a stress inducible calcium dependent protein kinase (OsCDPK7) in rice increased cold salinity and drought tolerance (Saijo *et al.* 2000). The *Arabidopsis* DREB1A transcription factor controls the expression of several LEA genes and genes code for osmolyte biosynthesis enzyme. Wheat transgenic plants overexpressing *DREB1A* gene showed lower canopy temperature (1-2°C less), relatively higher water content and enhanced drought tolerance under field condition (Pellegrineschi *et al.* 2004). Transgenic rice plants overexpressing of *DREB1A* gene has been shown to impart abiotic stress tolerance under lab conditions (Oh *et al.* 2003). IRRI is currently developing transgenic rice plants with *RD29A* promoter driven *DREB1A* gene from *Arabidopsis* (Datta, 2002).

MAS appears to be successful in producing promising plant type for enhanced WUE and drought tolerance (Steele *et al.* 2002). However, QTLs can vary from population to population and are influenced by

the growing environment. Therefore identification of QTLs under near realistic field stress conditions will enhance pace of its use in molecular breeding and genetic engineering. Map based cloning of major genes that control the QTLs involved in WUE and drought tolerance and validating their function in rice transgenic will be an important step towards genetic engineering and molecular breeding to enhance WUE in Rice. Since the preliminary field test results of *DREB1A* transgenic wheat at CIMMYT (Pellegrineschi *et al.* 2004) and result from *DREB1A* transgenic plants of rice (Oh *et al.* 2003) showed that transcriptome engineering can enhance the drought tolerance, transcriptome engineering appears to be a promising method to engineer drought tolerance in rice.

Non-biotechnological Options for Improving WUE

As stated earlier, water is currently the most limiting input for crop production and the most vital resource for all developmental related activities in general, and agriculture, in particular. Undoubtedly, judicious management of water is critical for the sustainability and dependability of rice production. Developing rice varieties that have higher water productivity is one aspect of the strategy but it can be targeted to only one component of the field water balance, i.e. transpiration. At the field level, there are several other processes that contribute to non-productive water losses. Therefore reduction in water losses due to other components of the field water balance will result in an increase in WUE and can contribute significantly to overall water productivity of a system. Laser leveling, mulching and following an optimum irrigation regime are options that can enhance water productivity significantly. Contrary to the earlier belief, rice does not

Table 1. Management Options and Strategies for Improving Water use efficiency in Rice

Management options	T	E	SP	SRO	RCL
Developing improved varieties	x				
Improving agronomic management	x				
Changing schedules to reduce evaporation		x			
Reducing water for land preparation		x	x	x	
Changing rice planting practices		x	x	x	
Reducing crop growth water		x	x	x	
Making more effective use of rainfall			x	x	
Water distribution strategies		x	x	x	
Water recycling and conjunctive use					x

require standing water and it has been tested and proved beyond doubt that intermittent irrigation or irrigating the rice crop one to two days after disappearance of ponded water from the soil surface will not affect the yield significantly. This practice alone can save 20 to 30 per cent of irrigation water. Table 1 summarizes the various options available for enhancing water use efficiency in rice. In the Table 1, "T" is the transpiration and "E" is the evaporation component of crop evapotranspiration, "SP" represents seepage and percolation losses, and "SRO" is the surface run off. It is possible to re-use some fraction of the seepage and percolation losses as well as surface runoff, i.e. they can be recycled within the system and are symbolized by "RCL" (Guerra *et al.* 1998).

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